Expanding Integrated Assessment Modelling: Comprehensive and Comprehensible Science for Sustainable, Co-Created Climate Action

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D6.6 – Report on drivers, barriers, and policies

WP6 – Explaining: Analysing policy from a political sciences perspective, developing, and extending capacities

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EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

The deliverable provides concrete recommendations for strengthening climate policies in four case study countries, Ethiopia, Kenya, Sri Lanka, and Ukraine and can be used to inform modelling work in Task 6.5. The report gathers the latest available scientific knowledge on mitigation drivers, barriers, and suitable policy options and identifies enablers and barriers to mitigation within each sector and country. As such, it can be used to inform policymakers perspective ways to combine policy instruments to effectively tackle barriers, and overarching governance approaches and their stringency in terms of ambition and implementation. It also provides a comprehensive analysis of drivers and barriers for sectoral transformations and innovations which can be utilised by the private sector, while researchers can integrate insights across countries and sectors into modelling.

3. Short summary of results (<250 words)

The goal of this report is to create concrete understanding of mitigation barriers, enablers, and trends toward NDC implementation within inter-related political, social, economic, structural, technological, and individual changes, by performing a deep dive into critical sectors. To this end, the report synthesises the latest available scientific knowledge on mitigation enablers, barriers, and suitable policy options from a universal perspective. The report is based on a document analysis relying on past and upcoming IPCC reports as well as other authoritative sources. It focuses on five key sectors: Industry, Energy, Transport, Buildings, and AFOLU. The global synthesis is intended to inform the analysis of four country case studies, namely Ethiopia, Kenya, Sri Lanka, and Ukraine. It also elaborates policy options available to leverage potentials and overcome challenges, paying due attention to country-specific conditions, thereby allowing the discussion of strategies that can help effectively overcome obstacles and enhance NDCs and their implementation.

4. Evidence of accomplishment

This report.

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Preface

IAM COMPACT supports the assessment of global climate goals, progress, and feasibility space, and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030 for major emitters and non-high-income countries. It uses a diverse ensemble of models, tools, and insights from social and political sciences and operations research, integrating bodies of knowledge to co-create the research process and enhance transparency, robustness, and policy relevance. It explores the role of structural changes in major emitting sectors and of political, behaviour, and social aspects in mitigation, quantifies factors promoting or hindering climate neutrality, and accounts for extreme scenarios, to deliver a range of global and national pathways that are environmentally effective, viable, feasible, and desirable. In doing so, it fully accounts for COVID-19 impacts and recovery strategies and aligns climate action with broader sustainability goals, while developing technical capacity and promoting ownership in non-high-income countries.

NTUA – National Technical University of Athens	EL	
Aalto – Aalto Korkeakoulusaatio SR	FI	
AAU – Aalborg Universitet	DK	
BC3 – Asociacion BC3 Basque Centre for Climate Change – Klima Aldaketa Ikergai	ES	
Bruegel – Bruegel AISBL	BE	
CARTIF – Fundacion CARTIF	ES	
CICERO – Cicero Senter for Klimaforskning Stiftelse	NO	
E3M – E3-Modelling AE	EL	
KTH – Kungliga Tekniska Hoegskolan	SE	
POLIMI – Politecnico di Milano	IT	
UPRC – University of Piraeus Research Center	EL	
UVa – Universidad De Valladolid	ES	
WI – Wuppertal Institut fur Klima, Umwelt, Energie GGMBH	DE	
IIMA – Indian Institute of Management	IN	
THU – Tsinghua University	CN	
USMF – University System of Maryland	US	
AAiT – Addis Ababa University	ET	
KEI – International Civic Organisation Kyiv Economics Institute	UA	
RUSL – Raja Rata University of SriLanka	LK	
TUM – Technical University of Mombasa	KE	
UNIGE – Université de Geneve	CH	
Imperial – Imperial College of Science, Technology and Medicine	UK	

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Executive Summary

This report aims to enhance the understanding of barriers, enablers, and policy options influencing the implementation of Nationally Determined Contributions (NDCs), considering political, social, economic, structural, technological, and individual factors across various sectors.
In a first step, the existing scientific knowledge on mitigation enablers, barriers, and suitable policy options globally is synthesized (chapter 2). The report relies on document analysis of past and forthcoming IPCC reports and other credible sources. It focuses on five key sectors: industry, energy, transport, buildings, agriculture, forestry, and other land use (AFOLU). This global analysis sets the stage for detailed examinations of four country case studies and their respective sectors: Ethiopia, Kenya, Sri Lanka, and Ukraine (chapter 3-7).

Ethiopia
Ethiopia, with a population of approximately 126.5 million in 2023, is Africa's second most populous country and has shown rapid economic growth, with an estimated 7.2% growth in FY2022/23. Despite being one of Africa's poorest nations, it aims to achieve lower-middle-income status by 2025. The country's impressive average annual GDP growth rate of nearly 10% over the past 15 years has slowed due to various shocks, including the COVID-19 pandemic. Agriculture remains resilient, employing over 70% of the population, but other sectors have lagged. Ethiopia's 10-Year Development Plan focuses on sustaining growth, promoting private sector involvement, and addressing macroeconomic challenges. However, since late 2020, a civil war has led to a humanitarian crisis and hindered climate policy advancements. Despite this, Ethiopia updated its Nationally Determined Contribution (NDC) in 2021, integrated into its Ten-Year Development Plan. The Climate Action Tracker rates Ethiopia's efforts as "Almost Sufficient," but projections indicate it will exceed its NDC targets by 2030, not accounting for the conflict's impact on emissions.
Ethiopia's climate change mitigation efforts face several barriers, including inadequate stakeholder collaboration, outdated technologies, limited infrastructure, high implementation costs, and lack of integrated planning. Key enablers to overcome these challenges include robust regulatory frameworks, effective policies, financial incentives, international collaboration, and enhanced R&D. Policy options to support mitigation involve setting clear renewable energy targets, providing professional training, establishing comprehensive land use plans, promoting sustainable agricultural practices, and improving institutional capacities. Financial support mechanisms like tax incentives and grants, along with public awareness campaigns and infrastructure investment, are critical for fostering a transition to sustainable practices across various sectors. Furthermore, financial means have to be provided for the conditionalities in the NDCs in order to achieve carbon neutrality. Finally, the links between political goals and implementation means have to be strengthened.

Kenya
Kenya has significantly improved its electrification rate and invested heavily in renewable energy sources like solar, geothermal, hydropower, and wind. Despite contributing only 0.1% of global emissions, climate change heavily impacts Kenya's economy, costing 3-5% of GDP annually. The country has implemented an Energy Transition and Investment Plan focused on decarbonisation, requiring substantial investment and supported by strong governance and policies. Facing rising greenhouse gas (GHG) emissions due to population growth and economic activities, Kenya aims to reduce GHG emissions by 32% by 2030, aligning with its National Determined Contribution (NDC) under the Paris Agreement. The country aspires to achieve 100% renewable energy by 2030 and is exploring green hydrogen by 2040, though plans to introduce coal power by 2040 could hinder these green energy goals.
Kenya's climate risk management strategies include the Climate Change Act, National Adaptation Plan (NAP), 2010 Constitution, and the National Climate Change Response Strategy. Enablers for mitigation include significant renewable energy potential, reforestation programs, and increased collaboration with organisations. Barriers include land and environmental degradation, lack of climate-proof infrastructure, and rising fossil fuel demand in the transport sector. Relevant policies and initiatives encompass the Least Cost Power Development Plan (2021-2030), Kenya Climate Smart Agriculture Strategy, various conservation and management acts, Vision 2030, and

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others focusing on water, energy, transport, waste management, and spatial planning. To enhance climate policy, a multifaceted approach is recommended, emphasizing financing, energy, agriculture, capacity building, and institutional frameworks. Initiatives include establishing a National Climate Change Fund, improving access to energy efficiency funds, fiscal incentives for renewable energy, revising the Feed-in Tariff (FiT) policy, supporting climate-friendly agricultural technologies, increasing climate change awareness, and fostering better coordination among agencies. Strengthening the monitoring, evaluation, and legislative processes for climate action, and promoting integrated climate considerations in policy, planning, and investments are also crucial.

Sri Lanka

A densely populated lower middle-income island nation, Sri Lanka is grappling with severe economic and climate-related challenges. The prolonged impact of the COVID-19 pandemic and a deepening economic crisis have led to a sharp decline in per capita GDP and an unprecedented inflation rate, compounded by a devalued currency and depleted foreign exchange reserves. These economic difficulties have exacerbated the country's vulnerability to climate change, evident in frequent extreme weather events and severe droughts impacting agriculture and water resources. Despite these hurdles, Sri Lanka is committed to climate change mitigation and economic recovery, focusing on investments in renewable energy, sustainable agriculture, and disaster risk reduction. The country's GHG emissions are primarily driven by the energy and agriculture sectors, with significant contributions from industrial and non-combustion sources. As a Paris Agreement signatory, Sri Lanka has set ambitious targets to reduce emissions by 20% in the energy sector and 10% across other sectors by 2030, compared to a Business-as-Usual scenario.

To mitigate climate change effectively, the country must leverage key enablers, such as programs like "Battle for Solar Energy", and the Energy Efficiency Improvement & Conservation initiatives. These are particularly necessary to reduce the reliance on imported fossil fuels and promote domestic energy sources in the context of Sri Lanka's aggressive goal to secure carbon neutrality by 2050. Additionally, aging and inefficient transmission and distribution system hinders the integration of renewable energy sources and overall stability of the power grid. The over reliance on hydropower exposes the country to risks from droughts and changing rainfall patterns.

The transport sector faces significant challenges including a decline in public transport usage. To tackle this, the government has already taken steps such as Bus Rapid Transit (BRT) and Light Rail Transit systems. Furthermore, promoting electric vehicles and hybrids to replace the aged private vehicle fleet is suppressed by import restrictions, high capital costs, and the need for charging infrastructure outside urban areas of Sri Lanka.

The AFOLU sector holds potential for climate mitigation with already set targets to increase forest cover in Sri Lanka and sustainable agriculture practices for major crops such as rice-paddy, tea, coconut and rubber. A significant portion are small-holder farmers in the agriculture sector who have limited adoption level of sustainable practices. Additionally, deforestation and land degradation are among leading barriers to reducing GHG emissions from the sector.

The industrial sector, heavily reliant on biomass and fossil fuels, faces vulnerably from price fluctuations and supply chain disruptions. Though a National Clear Production Center, lack of awareness and financial constraints impede and adoption of cleaner production technologies.

The building sector is expanding rapidly in urban areas but lacks the adoption of sustainable practices. The government is promoting energy efficiency improvements through guidelines from Sri Lanka Sustainable Energy Authority and green certifications through Sri Lanka Green Building Council, much of the construction sector operates informally which hinders the widespread adoption of these practices. To support a sustainable transition in the building sector, targeted incentives and capacity building programs are needed to increase the adoption of sustainable practices and materials.

Policy options to address the existing challenges encompass enforcing regulatory standards, providing financial incentives for green investments, and adopting market-based instruments like carbon pricing. Streamlining regulatory frameworks, enhancing institutional capacities, and fostering international collaboration are also critical. Furthermore, promoting public awareness, capacity building, and integrating social equity into policy design are essential to ensure that climate actions are inclusive and protect vulnerable communities. Setting clear and quantifiable goals, improving data collection, and establishing robust monitoring and reporting frameworks

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are vital for enhancing transparency and accountability in Sri Lanka's climate action efforts.

Ukraine

With a total land area of 603,549 km², Ukraine is the second largest country in Europe located in Eastern Europe at the Black Sea. Total population is 41.134 million. The country is highly vulnerable to the impacts of climate change. Classified as a lower middle-income country, the economy is dominated by agriculture and industry as Ukraine is a resource rich country. Ukraine became independent in 1991 when the Soviet Union dissolved and declared its neutrality. Since 2014 when Russia annexed Crimea, Ukraine is in a military conflict with Russia and in an ongoing war since the Russian invasion in February. With the evolving military conflict and change in government in 2014, political orientation shifted towards the European Union. In 2022, Ukraine applied for EU-Membership and has a candidate status. Requirement for an EU accession is the alignment with EU legislation and the EU acquis regarding six thematic clusters which has proven to be a key enabler to develop sectoral decarbonisation strategies and policies.

Ukraine submitted an updated first NDC to the UNFCCC with a commitment for an economy-wide net domestic reduction of 65 % of GHG emissions by 2030 compared to 1990 and announced a net zero target for 2060. This target setting was backed by scenario analysis and assessments of strategic measures. Ukraine, thus, demonstrated very good strategic planning and ambitious target setting to meet its pledges to the Paris Agreement and now plans to achieve the net-zero by 2050 ten years earlier than initially agreed. It approved an integrated National Energy and Climate Plan up to 2030 in June 2024 and presented its vision of net-zero by 2050 at COP28. As the energy intensity of the economy is generally very high, there is a huge potential for technology retrofitting, efficiency measures and systems optimisation in all sectors. Main barriers seem to be policy design, effective implementation and availability of financial means. Several regulations, market-based instruments and incentives have been introduced such as a carbon taxation but on a level that did not have a signalling and steering effect. Enablers such as low or non-carbon resource availability in the energy sector or systemic change in the transport sector have not yet been realised. The implementation of ambitious decarbonisation policies is difficult as Ukraine is confronted with very high destruction and damages from the military attacks. But not least, the age of existing infrastructure and industry facilities in combination with the build-back-better mentality of recovery discussions and efforts is an enabler and motivator for decarbonisation in all sectors.

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1 Introduction

The goal of this report is to create concrete understanding of mitigation barriers, enablers, and trends toward NDC implementation within inter-related political, social, economic, structural, technological, and individual changes, by performing a deep dive into critical sectors. To this end, the report synthesises the latest available scientific knowledge on mitigation enablers, barriers, and suitable policy options from a universal perspective. The report is based on a document analysis relying on past and upcoming IPCC reports as well as other authoritative sources. It focuses on five key sectors: Industry, Energy, Transport, Buildings, and AFOLU. The global synthesis is intended to inform the analysis of four country case studies, namely Ethiopia, Kenya, Sri Lanka, and Ukraine.
In the synthesis report, each sector chapter is divided into four parts, starting with an introduction and followed by an analysis of main mitigation strategies in the target sector. Afterwards, enablers and barriers are analysed, and each sector analysis concludes with a compilation of policies and measures which are needed to achieve net-zero by the middle of the century. The analysis of enablers and barriers follows a structure that is inspired by the IPCC, comprising 6 analytical dimensions of feasibility, namely: geophysical, environmental-ecological, technological, economic, sociocultural, and institutional. While each sector chapter is comparable in terms of broad structure and guidelines, they differ in their specificities, which is also reflected in the structure of the document.

To effectively analyse and strengthen climate change mitigation strategies in Ethiopia, Kenya, Sri Lanka, and Ukraine, a structured approach is essential across key sectors such as Industry, Energy, Transport, Buildings, and Land Use. The process begins with a comprehensive assessment of the current national-sectoral decarbonisation status and prospects. This involves a thorough review of existing literature to understand the historical, current, and projected future greenhouse gas (GHG) emissions in the target countries and sectors. Additionally, the review identifies trends that either facilitate or impede decarbonisation efforts. Building on this foundation, the next step is to identify the enablers and barriers to mitigation within each sector and country, using insights from literature and expert interviews to validate and expand findings. This step helps categorize and articulate the factors that support or hinder mitigation efforts, providing a nuanced understanding of each sector's unique challenges and opportunities.

The analysis then shifts to the current status of national-sectoral climate policies, where existing policies are reviewed and organized according to a typology of policy instruments. These policies are compared against global best practices to identify gaps and areas for improvement. Evaluating the effectiveness of these policies in overcoming barriers and mobilizing potential involves reviewing literature and expert feedback to assess their impact. This multi-step approach culminates in synthesizing recommendations to strengthen national-sectoral climate policy. By integrating insights from literature, policy comparisons, and expert opinions, the goal is to provide actionable strategies that enhance climate resilience and align national aspirations with global mitigation goals. This comprehensive framework not only facilitates a deeper understanding of each country's mitigation landscape but also paves the way for targeted interventions that promote sustainable development and effective climate action.

Apart from this general structure, the synthesis chapter and the country reports followed similar typologies. The typologies are explained in detail below. Although they inform the reports in general, the reports have internal differences to account for the specific conditions within each country.

1.1 Structure and Guidance for the synthesis

The analysis in each of the five sectors (Energy, Industry, Transport, Buildings, Land Use) follows the same structure:
Introduction: Set out from a general/universal perspective the decarbonisation status and prospects in the target sectors. Synthesise the latest IPCC reports and other authoritative summaries of the current science on the present status and past and future trends of reducing GHG emissions from a general perspective. E.g. where

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are emissions now, how have they developed in the past, what are the projections for the future. Highlight in particular the scale and speed of changes required to meet the PA objectives.

Main mitigation strategies in the target sector: What changes/transformations are needed in what timelines to achieve net-zero by mid-century? Synthesise existing knowledge from the latest IPCC reports and other authoritative sources on what mitigation strategies are available/needed to reduce sectoral emissions and who are the responsible political and economic actors who would need to implement these mitigation strategies. Highlight the scale and speed of changes required to meet the PA objectives.

Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction? Review existing knowledge from the latest IPCC reports and other authoritative sources on sectoral mitigation drivers and barriers. Categorise and describe sectoral mitigation enablers and barriers according to the guidelines and typology provided further below in section 2.

Policies and instruments: What policies are needed to achieve net-zero by mid-century? Synthesise the latest science on mitigation policy strategies and instruments. Synthesise existing knowledge from the latest IPCC reports and other authoritative sources on which policy strategies and instruments to promote decarbonisation are recommended by the latest literature. Organise and describe these policy options according to the typology of policy instruments provided further below in section 3.

Structure and Guidance for the country reports

Big picture: Current national-sectoral decarbonisation status and prospects

Briefly summarise existing literature on

what are current, past, and projected future GHG emissions in the target country and target sectors?

what are current trends that promote or hinder decarbonisation?

National-sectoral mitigation enablers and barriers

Step 1: Survey existing literature on mitigation enablers and barriers in the target country and sectors. Categorise and describe the enablers and barriers according to the guidelines provided further below in section 2.

Step 2: As necessary, either interview national experts or have interim results be reviewed by national experts to validate and further expand on the findings from step 1.

Step 3: Synthesise results from steps 1 and 2.

Current status of national-sectoral climate policy

Step 1: Review official documents and existing literature on which policies have already been implemented in the target country and target sectors. Organise and describe these policies according to the typology of policy instruments provided further below in section 5.

Step 2: Compare these existing national policies to the set of best-practice policies as identified in the global synthesis of existing knowledge on mitigation enablers, barriers and policy options. This will provide a first indication on where there are particular gaps in a country.

Step 3: Review existing literature to what extent the existing national policies have been successful in mobilizing potentials and overcoming barriers.

Step 4: As necessary, either interview national experts or have interim results be reviewed by national experts to validate and further expand on the findings from step 1. Detailed interview guidelines are provided further below.

Step 5: Synthesise results from steps 1-4

How to strengthen national-sectoral climate policy

Synthesis recommendations from existing literature, comparison of existing policies with the set of best-practice policies as developed in the global synthesis of existing knowledge on mitigation enablers, barriers and policy options, and results of the expert interviews.

Conclusion

Briefly summarize the main conclusions from the analysis in terms of climate change mitigation in each sector.

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Typology and Guidelines for analysis of enablers and barriers
The following table proposes a typology of mitigation enablers and barriers. It is initially based on the typology of the IPCC framework on the assessment of enablers and barriers (IPCC 2022). However, this typology is limited in some respects, so we added further useful indicators tailored to task 6.4 (Schaffrin et al. 2015) (Steg et al. 2022).
Mitigation drivers and barriers exist (at least) at two levels:
At the micro level, the actors on the ground who would need to implement the mitigation options may face barriers such as lack of capacity or higher costs of climate-friendly solutions, but also positive drivers/incentives such as economic or other non-climate benefits of mitigation actions.
There may also be drivers and barriers at the macro level, such as lack of suitable infrastructure for climate-friendly solutions or blocking power of fossil fuel interests impeding the adoption of ambitious mitigation policies.
The analysis will therefore proceed in a two-step approach.
First, at the micro level, identify which actors would be needed to implement the mitigation strategies listed in the preceding step of the analysis; and then identify which drivers and barriers these actors face.
Second, at the macro level, identify at the level of the entire sectoral system which drivers/barriers are promoting/impeding mitigation action.

For both levels, the following typology of drivers and barriers to structure the analysis has been used. The purpose of the typology is to serve as checklist to make sure that all issues that may potentially be relevant are taken into consideration, but not all issues may in fact be relevant in all country-sector combinations.

Table 1: Possible enhancements in various dimensions of feasibility

Dimension	Indicators (IPCC)	Possible enhancements
Geophysical feasibility (availability of required geophysical resources)	Availability of required geophysical resources: Physical potential Geophysical resource availability Land use	Resource profile (e.g. which climate-relevant resources are found in the country; what does the country rely on; what resources are im- and exported and for what purpose?) Including renewable energy potentials: solar radiation, wind availability, geothermal potential etc.
Environmental-ecological feasibility (impacts on the environment)	Impacts on environment: Air pollution Toxic waste, ecotoxicity and eutrophication Water quantity and quality Biodiversity	Vulnerability to climate risks and whether there is awareness of these risks Other environmental conditions (e.g. air pollution) that may prompt demand for stronger ambition/policy
Technological feasibility (extent to which the required technology can be implemented at scale quickly)	Extent to which the technology can be implemented at scale soon: Simplicity Technology scalability Maturity and technology readiness	The technological state and financial value embedded in material assets and infrastructure that influence the ability and willingness of actors to adopt alternative technologies or dispose of assets Comparative costs of climate-friendly solutions Upfront financing requirements Access to capital Intellectual capital such as accumulated knowledge and skills/competences in human resources, R&D programmes and business models
Economic feasibility (financial costs and benefits and	Financial costs and economic effects: Costs now, in 2030 and in the long term	Structure of the economy and economic trends, e.g. level of industrialisation and size of the service sector, energy consumption and energy/emission intensity of the economy, broader technological trends (e.g. automation and digitisation)

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economic effects)	Employment effects and economic growth	*Economic instruments* Macro: Emission or energy taxes, emission trading, removal of fossil fuel subsidies Micro/targeted fees/charges: e.g. congestion charging, sprawl taxes, vehicle taxation, versement transport (established law in France for the benefit of municipalities, and their citizens), tradable renewable energy or energy efficiency certificates, transportation generation Levy Targeted financial support schemes such as tax credits or subsidized loans/loan guarantees for green investments, renewables feed-in tariffs, grants for sustainable building renovations or contracts for difference to compensate for the higher costs of zero-emission technologies; R&D funds… Public procurement Industrialisation policies: Local content requirements, support for local companies
Sociocultural feasibility (public engagement and support, and health, well-being, and distributional effects)	Public engagement and support, and social impacts: Public acceptance Effects on health and well-being Distributional effects	Public investments and funding for policies and programmes, e.g. energy/transport/climate/environment funds, e.g. for public investments in public transport or in energy-efficient social housing. Inclusion of local citizens into transition (e.g. profit participation in adjacent renewable energy projects) Capacity building and acceptance measures e.g. for renewables Internalisation of the costs of care economical work in the society, quality of sanctioning continuing androcentrism: financial sanctioning of non-implementation of Gender mainstreaming imperatives Land use conflicts (e.g. civic participation in decision-making conflict resolution measures, land-use planning measures) Population growth and demographic trends, urbanisation, socio-economic situation
Institutional feasibility (institutional capacity, governance structures, and political support)	Institutional conditions that affect the implementation of the response option: Political acceptance Institutional capacity and governance, cross-sectoral coordination Legal and administrative capacity	**Polity** (This category captures the general setup of the political system and bureaucratic institutions in general) Political system and bureaucratic institutions in general Distribution of decision-making authority (e.g. executive vs. legislative branch) Degree of institutional coordination within governments Capacity of bureaucracies to develop and implement climate policies Possibilities for non-state actors to be heard and participate in decision-making **Politics** (This category captures the composition, relationships, power structures and vested interests of the actors involved in maintaining and changing the system) *Domestic/Internal* Role of political parties Role of elections Are there networks within, outside and between institutions exerting influence across different parts of the system? Role and preferences of social elites Organized interest groups, their relative strength and how they access political processes

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		Strength of civil society (e.g. court cases, NGO activity, activists, participation in relevant processes) Who is involved in changes that are already ongoing (e.g. incumbent industry actors vs. new low-carbon actors)? Focus events (e.g. floods) Public opinion on climate action *International/External* Normative pressure (e.g. treaties, international court decisions) Cosmopolitanism vs. nativism/populism International meetings (e.g. COP presidency, G20 meetings) Focus events (e.g. financial crisis, COVID-19) Policy diffusion Other international drivers (e.g. pressure/promises from financial institutions) **Policy** (This category captures formalised (i.e. codified and explicit) rules and principles that guide behaviour such as policies, standards, formal contracts, roadmaps, commitments and formalised governance mechanisms) Long-term strategies in place Governmental climate policies (and other governance mechanisms) in place Relevant non-climate policies (and other governance mechanisms)

1.2 Typology for the analysis of policy instruments

Various typologies of policy instruments exist in the literature (e.g. Lascoume and Le Gales 2007; Franco and Restrepo 2019; Salamon 2002; Vedung 1998). The following list represents a synthesis of these sources and may be subject to further refinement over the course of the analysis.

- Governance and Planning instruments
  - Policy targets (building renovation rate, x mn heat pumps by 2030, y mn BEV, z GW of PV, …), policy action plans, roadmaps and strategies (nZEB by 2021, introduce policy by 2025)
  - Establishment of governmental implementing agencies, such as climate / energy / gender equality and sustainability agencies

- Economic instruments:
  - Macro: Emission or energy taxes, emission trading, removal of fossil fuel subsidies
  - Micro/targeted fees/charges: e.g. congestion charging, sprawl taxes, vehicle taxation, versement transport (established law in France for the benefit of municipalities, and their citizens), tradable renewable energy or energy efficiency certificates, transportation generation Levy (Germany, cf. Spitzner 2021), internalisation of the costs of care economical work in the society, quality of sanctioning continuing androcentrism: financial sanctioning of non-implementation of Gender mainstreaming imperatives
  - Targeted financial support schemes such as tax credits or subsidised loans/loan guarantees for green investments, renewables feed-in tariffs, grants for sustainable building renovations or contracts for difference to compensate for the higher costs of zero-emission technologies; R&D funds
  - Public investments and funding for policies and programmes, e.g. energy/transport/climate/environment funds, e.g. for public investments in public transport or in

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energy-efficient social housing.
   - Public procurement

- Regulatory and "non-economic" instruments such as minimum performance standards for installations; building codes; speed limit or low-emission zones, energy sufficiency/efficiency/renewable energy obligation schemes/resource standards for energy utilities/suppliers, zoning and development regulations, transport worthiness verifications for transport allowance (cf. Austria initiative by minister von Einem)

- Voluntary agreements

- Educational/Informational/"Soft" instruments such as energy audits, labelling schemes, awareness raising and information campaigns, targeted advice, professional training, sectoral or innovation networks, supporting research, development and demonstration

1.3 Bibliography

- Franco, M., & Roldán Restrepo, D. (2019). The instruments of public policy. A transdisciplinary look. *Cuadernos de Administración*, *35*, 101–113. https://doi.org/10.25100/cdea.v35i63.6893
- IPCC (2022). Enablers and Barriers Concept of IPCC: Climate Change 2022 Mitigation of Climate Change IPCC Sixth Assessment Report Contribution of Working Group III [online] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf
- Lascoumes, P., & Le Gales, P. (2007). Introduction: Understanding Public Policy through Its Instruments—From the Nature of Instruments to the Sociology of Public Policy Instrumentation. *Governance*, *20*(1), 1–21. https://doi.org/10.1111/j.1468-0491.2007.00342.x
- Salamon, L. M. (Ed.) (2002). *The Tools of Government: A Guide to New Governance*. Oxford University Press.
- Schaffrin, André, Sebastian Sewerin, and Sibylle Seubert (2015). Toward a Comparative Measure of Climate Policy Output. *Policy Studies Journal* 43, no. 2: 257–82. https://doi.org/10.1111/psj.12095.
- Steg, L., Veldstra, J., de Kleijne, K., Kılkış, Ş., Lucena, A. F. P., Nilsson, L. J., Sugiyama, M., Smith, P., Tavoni, M., de Coninck, H., van Diemen, R., Renforth, P., Mirasgedis, S., Nemet, G., Görsch, R., Muri, H., Bertoldi, P., Cabeza, L. F., Mata, É., … Vérez, D. (2022). A method to identify barriers to and enablers of implementing climate change mitigation options. *One Earth*, *5*(11), 1216–1227. https://doi.org/10.1016/j.oneear.2022.10.007
- Vedung, E. (1998). *Policy instruments: Typologies and theories.* In M.-L. Bemelmans-Videc, R. C. Rist, & E. Vedung (Eds.), Carrots, sticks and sermons: Policy instruments and their evaluation (pp. 21–58). New Brunswick, NJ: Transaction.

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2 Synthesis Report - Global drivers, barriers, and policies (MS5)

2.1 Energy

2.1.1 Introduction

While the rise of global energy supply emissions has slowed in recent years due to lower energy intensities in almost all regions, the global consumption of oil and gas has continued to increase. The energy supply was responsible for 34% (20 $GtCO_2$-eq) of the 59 $GtCO_2$-eq global net anthropogenic GHG emissions in 2019 (Dhakal et al., 2022). Between 2015 and 2019, coal contributed more than any other source to CO_2 emissions, accounting for nearly 44% of those in 2019. Also, oil accounted for roughly 34%, and natural gas for around 22%. CO_2 emissions from coal, oil, and natural gas increased annually by 0.31%, 0.5%, and 3%, respectively, from 2015 to 2019 (Clarke et al., 2022).

The largest individual subsector contributing to emissions in 2019 was power and heat generation at 14 $GtCO_2$-eq, accounting for almost 69% of the total emissions from the energy supply (Dhakal et al., 2022). Additionally, the fugitive emissions from the production of oil and gas, coal mining, and petroleum refining all contributed to the GHG emissions from the energy supply. About 18% of energy supply emissions in 2019 came from fugitive emissions, mainly methane, from the extraction and production of fossil fuels, with 2.6 Gt CO_2-eq per year associated with oil and gas production and 1.3 $GtCO_2$-eq per year associated with coal mining. Besides, 2.9 $GtCO_2$-eq was emitted from oil and gas operations, nearly equally split between the two (Clarke et al., 2022).

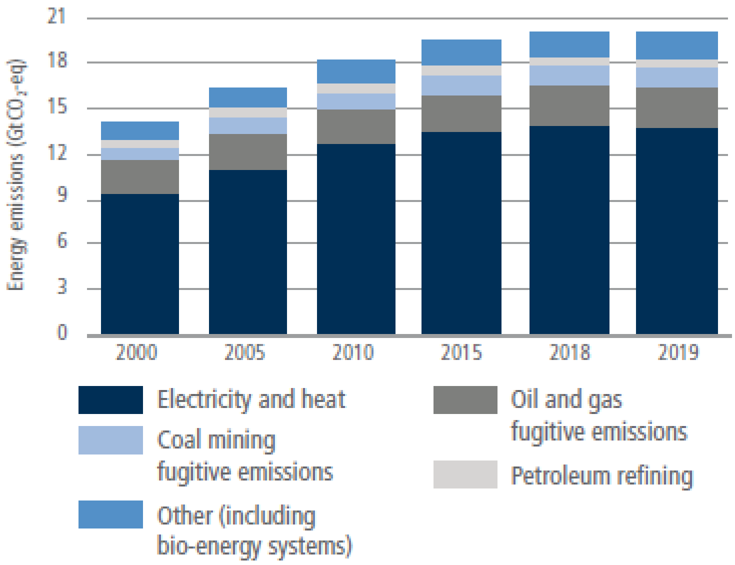

Figure 1: Global energy supply GHG emission (Clarke et al., 2022)

Despite contributing the most to the energy supply GHG emissions, power and heat generation have been becoming less carbon-intensive globally in recent years. In North America, a partial switch from coal to gas for power generation as well as an overall decline in the share of fossil fuels has decreased carbon intensity. The improvements in Europe's carbon intensity have been driven by the steady growth of renewable power generation since 2007. In China, the world's largest electricity producer (IEA, 2021b), the rise of emissions from coal power slowed after 2011 and even decreased between 2013 and 2016, partly because of a slowdown of economic growth and fewer coal capacity additions. However, discussions of a global peak coal, both in China and the global level, may be premature (Dhakal et al., 2022; IEA, 2021a).

According to the global reviews (IEA, 2021a), the world's PV and wind power capacity increased by up to 170%

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and 70%, respectively, between 2015 and 2019. Total solar and wind capacities in 2019 were 609 GW and 623 GW, and annual generation was 680 TWh and 1420 TWh (**Figure 2**). In 2019, the combined contribution of solar and wind to the world's total power output was about 8%, up from about 5% in 2015. The levelized cost of solar PV has decreased by more than 60% since 2015. Costs for onshore wind have decreased by 23%, while offshore wind costs have decreased by 32%. Low-carbon energy sources beyond wind and solar such as nuclear, hydropower, bioenergy, geothermal, marine, and fossil or bioenergy with carbon capture, use, and storage (CCUS) have kept growing since 2015. Annual nuclear power increased from 2570 TWh to 2790 TWh, or 8.6%, while annual hydropower increased from 3890 TWh in 2015 to 4290 TWh in 2019, or 10.3%. The proportions of nuclear and hydroelectric power in the total electricity production remained at roughly 10% and 16%, respectively. From 2015 to 2019, the production of biofuels increased globally, rising from 3.2 EJ to 4.0 EJ annually. In 2019, 2.4% of electricity was produced using bioenergy. Geothermal energy sources produced 92 TWh of electricity in 2019, up from 80 TWh in 2015. Currently, there are 28 commercially operating CCUS facilities of which only two are associated with electricity production. The share of marine energy in global electricity generation has remained at approximately 1 TWh annually since 2015.

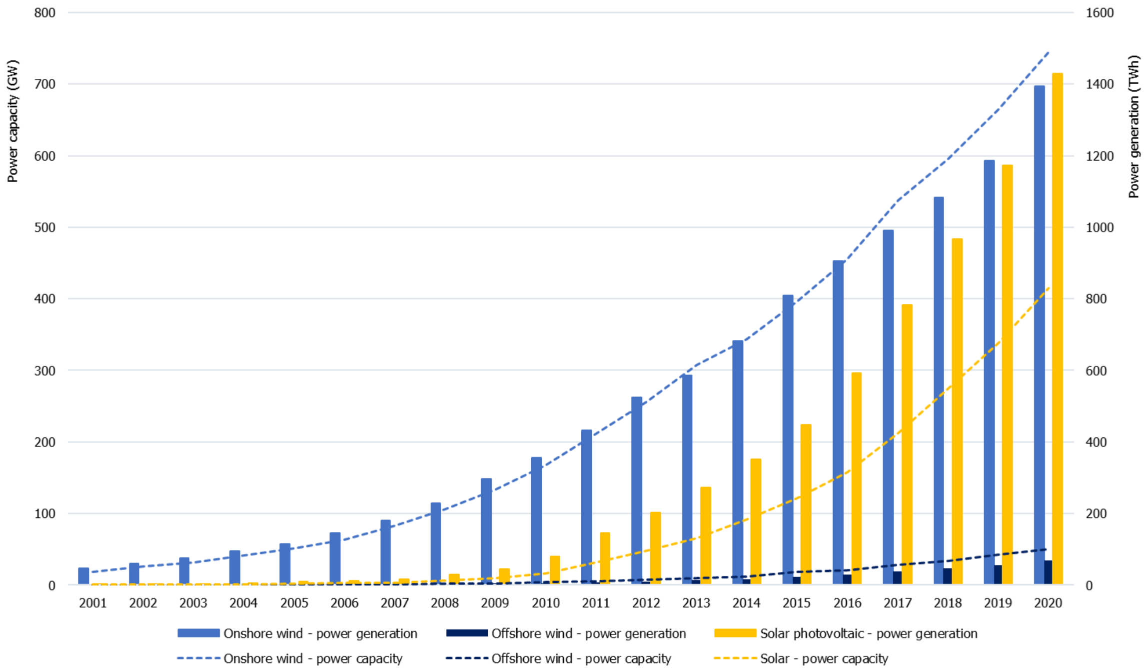

Figure 2: Global power capacity and generation by sources (IEA, 2021b)

The energy sector must cut CO_2 emissions to almost zero or even below zero if global warming is to be kept well below 2°C (Riahi et al., 2022). CO_2 emissions from energy supply reach net zero around 2041 (2033–2057) in pathways limiting warming to 1.5°C (with no or limited overshoot), and around 2053 (2040–2066) in pathways that limit warming to 2°C. Net-zero energy system configurations will probably have a few things in common. These characteristics include using significantly less fossil fuel than we do today, increasing use of electricity from decarbonised power system, relying on alternative fuels, particularly hydrogen or biofuels, in several sectors that are not amenable to electricity, utilisation of carbon dioxide removal (CDR) measures, massive deployment of all available clean energy technologies such as electric vehicles and energy efficient building retrofits, as well as innovation efforts in order to bring new technologies to the market in time, behavioural changes, and relying more on integrated energy systems. In scenarios that limit warming to 2°C (>67%), the share of renewable energy is between 30 and 70%, while for scenarios that limit warming to 1.5°C (>50%), it is above 40% (IEA, 2021c; Riahi et al., 2022). Even worldwide, scenarios have been published using 100% renewable energy sources, partly due to the rapid development of these technologies over the past ten years (Bogdanov et al., 2021; Creutzig et al., 2017; Pietzcker et al., 2017).

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2.1.2 Main mitigation strategies in the energy supply sector: What changes/ transformations are needed in what timelines to achieve net-zero by mid-century?

It is very unlikely that CO_2 emissions from the energy supply will fall below the 2°C threshold without additional efforts to cut emissions. A benchmark for comparison against energy-related CO_2 emissions is provided by scenarios assuming technological advancements but no new climate policies beyond those already in place (**Figure 3**). Emissions in these reference scenarios increase through 2050 but span a broad range. The lowest is modestly below today's emissions, while the highest emission levels are about four times current emissions.

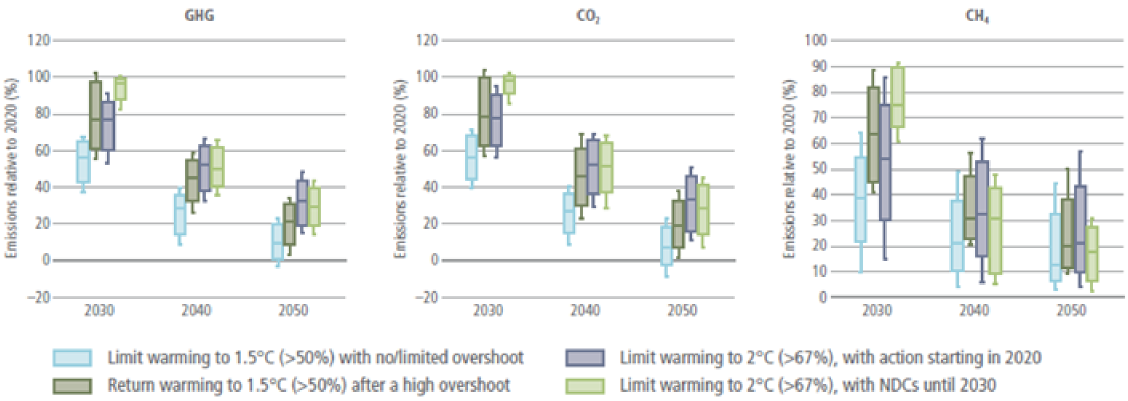

Figure 3: Projected energy sector GHG emissions for the 1.5°C scenarios (without and with overshoot), and likely below 2°C scenarios (without and with delayed policy action) during 2020–2050 - Boxes indicate 25th and 75th percentiles, while whiskers indicate 5th and 95th percentiles (Clarke et al., 2022)

Without swift, rapid, and significant reductions in the GHG emissions from the energy supply, warming cannot be kept to well below 2°C. The mitigation scenarios reinforce the idea that clear and implementable policy measures in both near-term and long-term are required to cut emissions (Clarke et al., 2022; van de Ven et al., 2023). In scenarios limiting warming to 1.5°C (>50%) with no or limited overshoot, energy supply sector CO_2 emissions decline by 87-97% by 2050 and by 60-79% in scenarios limiting warming to 2°C (>67%) with action beginning in 2020. Also, in scenarios limiting warming to 1.5°C (>50%) with no or limited overshoot, net CO_2 emissions from the energy supply in 2030 fall by 35–51% (Clarke et al., 2022). To decarbonize the energy supply most cost-effectively, global net CO_2 emissions from electricity generation will likely reach zero before the rest of the sectors, as zero-carbon electricity can then be used to replace the use of fossil fuels in transport, industries, and buildings. In scenarios limiting warming to 1.5°C (>50%) with no or limited overshoot (2°C (>67%)), net electricity sector CO_2 emissions reach zero globally between 2044 and 2055 (2052 and 2078) (Figure 4).

Because there are comparatively more low-emission options (that are already cost-competitive) in the energy supply sector than in other sectors, it is anticipated to be less expensive to reduce net CO_2 emissions close to or below zero in this sector. In addition, there are potential options to remove CO_2 from the atmosphere in the electricity sector, notably through using biomass energy with carbon capture and storage (BECCS), which would allow electricity sector emissions to drop below zero. Without CDR options, electricity sector emissions may not fall to zero. Even in net-zero economies, some fossil fuel facilities may still result in positive net power sector CO_2 emissions if CDR is applied in other sectors but not in electricity (Clarke et al., 2022).

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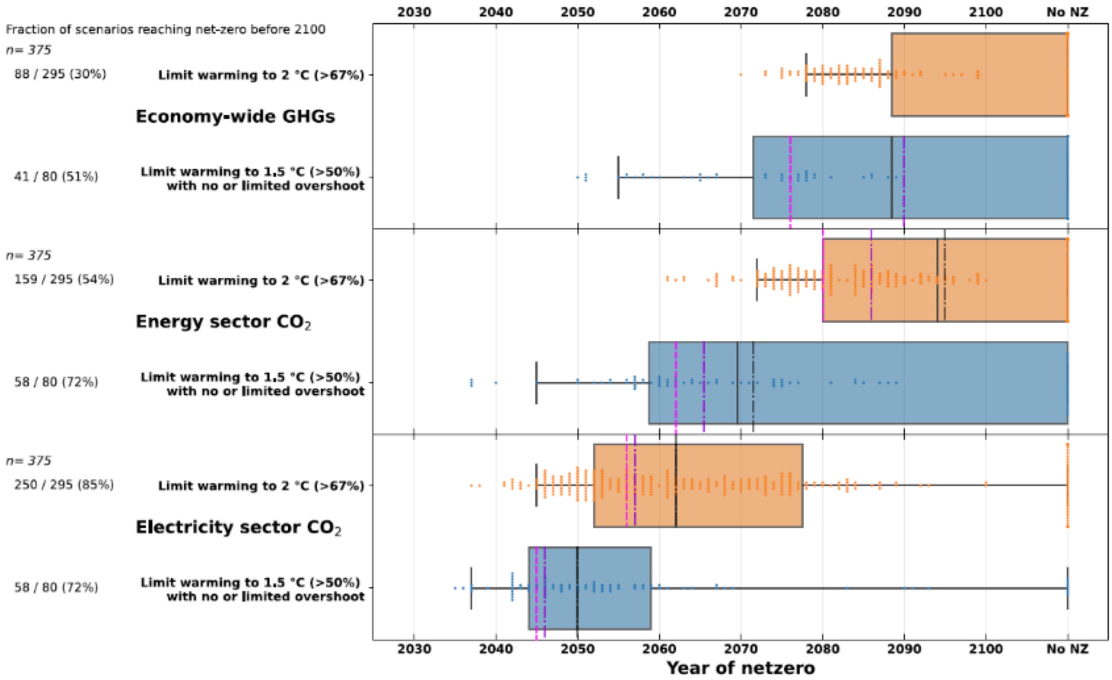

Figure 4: The timing of net-zero emissions for full economy greenhouse gases (GHGs), energy sector CO2, and electricity sector CO2 (Clarke et al., 2022). Boxes indicate 25th and 75th percentiles, centre black line is the median, while whiskers indicate 1.5x the inter-quartile range. The vertical dashed lines represent the median point at which emissions in the scenarios have dropped by 95% (pink) and 97.5% (purple), respectively. Dots represent individual scenarios. The fraction indicates the number of scenarios reaching net-zero by 2100 out of the total sample.

There are multiple pathways to reduce energy system emissions. The most promising technological pathways include:

Decarbonising primary energy and electricity generation

Low- and zero-carbon technologies provide 74–82% of primary energy in 2050 in scenarios limiting warming to 1.5°C (>50%) with no or limited overshoot and 55–68% in scenarios limiting warming to 2°C (>67%). The share of low-carbon technologies in the global primary energy supply today is below 20%. Low- and zero-carbon sources produce 97–99% of global electricity in 2050 in scenarios limiting warming to 1.5°C (>50%) with no or limited overshoot and 93–97% in scenarios limiting warming to 2°C (>67%) (Clarke et al., 2022). Many low-carbon electrical systems are projected to use a significant amount of renewable energy, particularly solar and wind. Wind and solar electricity contributions will depend on their levelised costs relative to other options, integration costs, system value, and the ability to integrate variable resources into the grid. The technology mixes for the electric sector will vary by location, and they often incorporate extra resources, including geothermal energy, hydropower, nuclear power, and fossil generation with CCS. However, wind and solar are anticipated to dominate low-carbon generation and capacity development over the next few decades, given favorable policies in many nations, their large involvement in the early decarbonisation of the electric sector, and the decline in coal power (Bistline & Blanford, 2021). A crucial near-term option for limiting warming is decarbonizing energy generation while expanding electricity usage.

Switching to low-carbon energy carriers

A crucial short-term mitigation strategy is to accelerate the electrification of end uses, including light-duty transportation, space heating, and cooking and industrial processes (IEA, 2019). Even while electrifying end uses is a critical decarbonisation method, some end uses, such as long-distance transportation and energy-intensive industries, will be more difficult to electrify. Alternative fuels or energy carriers, including biofuels, hydrogen,

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ammonia, or synthetic methane, may be required in this regard. According to a broad range of scenarios, the use of hydrogen will steadily increase and become more profitable once the energy system is mostly low-carbon (Clarke et al., 2022).

Offset Residual Emissions through CDR

CDR technology can reduce emissions from hard-to-decarbonize sectors, changing the pace and nature of transitions in the energy supply sector. Numerous studies indicate that to keep global warming to 1.5°C, CDR is no longer an option but a necessity (Luderer et al., 2018; Rogelj et al., 2015). The requirement for CDR to limit CO_2 emissions varies across scenarios and is closely related to future energy demand and the pace of emission reductions over the next two decades. Deeper near-term emissions reductions will lessen this need.

Net-zero energy systems require shifts in technology, institutions, businesses, and society throughout. As a result, it entails reforms to institutions and modifications to the supply, technology, or markets. The nature of net-zero systems is influenced by institutional relationships between governments and energy sector actors, as these parties may cooperate or disagree on net-zero goals and strategies for achieving them. In addition, mitigation is increasingly being led by cities, states, provinces, businesses, and other sub-national or non-national actors, demonstrating the importance of actors' involvement across different levels (Clarke et al., 2022). Different actors contributing to the mitigation of emissions could be grouped as citizens, businesses, investors, private and development banks, subnational governments, national governments, and international entities. There are transformation requirements (United Nations Environment Programme, 2022) to be followed by those actors presented in the following figure.

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Citizens

- Create demand for renewable energy by purchasing 100 per cent renewable power from high quality a

Businesses

- purchase 100 per cent renewable power with high quality power purchase agreements or try own production (not through renewable energy credits)
- Electrify energy end-use
- provide demand flexibility, on-site storage, training and skills

Investors, private and development banks

- Engage with fossil fuel electricity utilities to incentivize change
- Divest from fossil fuel related assets

National and subnational governments

- Remove fossil fuel subsidies in a socially acceptable manner
- Stop expansion of fossil fuel infrastructure
- Plan for fossil fuel phase-out well ahead and in a socially just manner
- Set renewable targets
- Allow renewable production for own use
- Accelerate provision of sites, remove bureaucratic hurdles, and regulate grid access and connection for expansion of renewables
- Educate workers
- Adapt market rules of electricity system for high shares of renewables

International entities

- Cooperate on and support a just fossil fuel phase-out
- Support international initiatives on emissions-free electricity and power system flexibility and interconnection solutions
- Agree to higher energy performance standards

Figure 5: Recommended actions to transform energy supply by actor groups

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Citizens	Businesses	Investors, private and development banks	National and subnational governments	International entities
• Create demand for renewable energy by purchasing 100 per cent renewable power from high quality providers	• purchase 100% renewable power with high quality power purchase agreements or try own production (not through renewable credits) • Electrify energy end-use • Provide demand flexibility, on-site storage, training and skills	• Engage with fossil fuel electricity utilities to incentivize change • Divest from fossil fuel related assets	• Remove fossil fuel subsidies in a socially acceptable manner • Stop expansion of fossil fuel infrastructure • Plan for fossil fuel phase-out well ahead and in a socially just manner • Set renewable targets • Allow renewable production for own use • Accelerate provision of sites, remove bureaucratic hurdles, and regulate grid access and connection for expansion of renewables • Educate workers • Adapt market rules of electricity system for high shares of renewables	• Cooperate on and support a just fossil fuel phase-out • Support international initiatives on emissions-free electricity and power system flexibility and interconnection solutions • Agree to higher energy performance standards

Figure 6: Recommended actions to transform energy supply by actor groups

2.1.3 Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction

Based on the previously presented typology, an attempt is made to discuss the drivers and barriers to implementing energy supply mitigation options within the pathways considered in the previous section. Based on the literature review, enablers and barriers are discussed by different technologies. Nevertheless, a concise summary will be provided to conclude this section.

2.1.3.1 Solar energy

Geophysically, direct solar energy has a much greater potential than any other renewable energy source worldwide, and it can produce far more energy than is required to enable ambitious mitigation over the coming century. The highest solar irradiation areas are western South America, northern, eastern, and southwestern Africa, and the Middle East and Australia (Prăvălie et al., 2019)us mitigation over the coming century. The highest solar irradiation areas are western South America, northern, eastern, and southwestern Africa, and the Middle East and Australia (Prăvălie et al., 2019).

Solar photovoltaic (PV) is the least expensive alternative in many applications and is becoming increasingly competitive with other methods of producing electricity. The cost of electricity produced from solar energy is often lower than that produced from fossil fuels; in certain cases, it is even lower than the operational costs of power produced from fossil fuels (IRENA, 2022). Increasingly, the costs of PV electricity are attributed to the installation and related soft costs of marketing and permitting associated with the technology rather than to the modules themselves (IRENA, 2022). Costs for Concentrated Solar Power (CSP) have also decreased, albeit half as quickly as for PV. Even though it will be challenging for CSP to compete with PV and even hybrid PV-battery systems, maintaining the pace of improvement seen in recent years will make CSP competitive with fossil fuels in sunny places (Clarke et al., 2022).

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Even though silicon wafer-based semiconductors still have the major share of the solar PV market, new designs and materials have the potential to further cut costs, boost efficiency, consume less resources, and open up new applications. The broad adoption of the passivated emitter and rear cell design, which now makes up the majority of manufacturing, has been the most significant technological development over the previous ten years. Bifacial modules further improve efficiency by utilizing the backside of the modules to reflect light from the ground or roof. With the wide range of alternatives to producing PV from crystalline silicon, future costs, material utilisation, and efficiency improvements are all feasible (Clarke et al., 2022; Victoria et al., 2021).

To keep global warming well below 2°C, the material need for PV will probably rise significantly. However, PV materials, already available widely, have potential alternatives and can be recycled (Clarke et al., 2022). Making sound decisions on land usage and recycling materials at the end of PVs' lifetime are the two most crucial approaches to reducing environmental impacts. Despite the wide range of GHG LCA estimates for PVs, recent research considering improved efficiency and manufacturing advancements finds lower lifespan emissions (Louwen et al., 2016). The lifespan impacts may be lessened by increasing efficiencies, extending lifetimes, locating in sunny areas, using less carbon-intensive manufacturing inputs, and switching to thin films.

Land conversion for the purpose of using PVs can have local consequences, particularly in areas close to cities and where solar development competes with other uses. Large installations may also potentially have a negative effect on biodiversity. Animal migration also is hampered by landscape fragmentation. There are now several ways to reduce land use problems, though. By employing crops that can grow in the shade, for instance, solar energy can be combined with other purposes through agrivoltaics, the utilisation of land for both agricultural and solar energy generation (Dinesh & Pearce, 2016). Land-use conflicts could also be avoided by floating PV installations as well as by dual-use infrastructure like landfills and reservoirs, where evaporation can also be decreased (Jäger-Waldau, 2020).

Solar energy is generally accepted as a clean and environmentally friendly resource in most nations. Expected financial rewards, environmental benefits, the desire to become more self-sufficient, and peer expectations are major drivers for households to install PV systems. On the other hand, high upfront costs, aesthetics, landlord-tenant incentives, and worries about performance and reliability are the main utilisation obstacles for households regarding solar energy (Faiers & Neame, 2006; Vasseur & Kemp, 2015).

Future global solar energy potential is not constrained by solar radiation but rather by the need for grid integration to address its fluctuation and the availability of financing, particularly in developing nations. Additionally, due to their extremely low operating costs, solar PV panels can potentially drive down prices in wholesale power markets at high penetration rates. This might make it more difficult to recover investment and lessen incentives for new installations, which could be partially resolved by continuing cost reductions. Although, comprehensive solutions necessitate the addition of transmission and storage as well as, more importantly, modifications to the structure of the electricity market (Bistline & Young, 2019; Das et al., 2020).

2.1.3.2 Wind energy

Recent global estimates of potentially exploitable wind energy are 20–30 times the global electricity demand in 2017. The technological wind potential is even greater than required to keep warming below 2°C. Also, every continent has potential hotspots of wind resources despite the uneven distribution worldwide and by the season. Power plant control, flexible grid integration, and storage can reduce the effects of local short-term variability caused by wind power (Barra et al., 2021). Offshore wind has greater potential because of being stronger and less variable than onshore wind. However, offshore wind is more expensive due to increased building, maintenance, and transmission costs (Bosch et al., 2017). Since 2015, wind energy costs have decreased by 18% and 40%, respectively, on land and offshore. Further declines are anticipated by 2030. Larger capacity turbines, larger rotor diameters, and taller hub heights primarily contribute to decreased costs (Beiter et al., 2021; Clarke et al., 2022).

Technological breakthroughs and economies of scale are crucial to support ongoing improvements. However, the future potential is primarily constrained by the availability of land in wind-rich regions, a lack of supporting

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infrastructure, grid connectivity, and financial accessibility, particularly in developing countries. The co-location of wind and solar PV power farms, and batteries, commonly called hybrid power plants, is a cutting-edge technology under development (Lindberg et al., 2021).

Wind turbine operation generates no waste or contaminants. Still, there could be CO_2 emissions primarily during production, transport, and construction, as well as disposal once wind turbines reach the end of their useful lives. Wind farms can also cause local ecological impacts, including the impacts on animal habitat and movements, biological concerns, bird and bat fatalities from collisions with rotating blades, and health concerns. The impacts on animal habitats and collisions can be resolved or reduced by selectively stopping some wind turbines in high-risk locations, often without affecting the productivity of the wind farm (de Lucas et al., 2012). Recent research reveals weak links between noise from wind farms and indicators of human health (Poulsen et al., 2018a, 2018b, 2019b, 2019a).

Generally, there is strong public support for wind energy, even though some wind farm projects may face opposition. Most people think wind energy is quite inexpensive and has advantages for the environment. However, some people hold the opinion that wind turbines can pollute the environment with noise and aesthetics, threaten locations with symbolic value, and harm wildlife, which raises questions about the public acceptance (Devine-Wright & Wiersma, 2020; Rand & Hoen, 2017). Also, fossil fuel stakeholders may resist the advancement of wind energy (Clarke et al., 2022).

High initial capital costs, long payback periods, and insufficient access to funding are typical economic impediments to wind growth. Governmental commitment to financial support mechanisms, technological efforts to assist local supply chains, and grid improvements all increase the likelihood that wind energy will expand most efficiently (Clarke et al., 2022; Diógenes et al., 2020).

2.1.3.3 Hydroelectric power

Hydropower is technically mature, proved worldwide as a primary source of renewable electricity, and may be used to balance the electricity supply by providing flexibility and storage. Global gross theoretical available hydropower potential estimates exceed total electricity production in 2018. Hydropower facilities with storage can generate 10 GW, although they often need much areas (Clarke et al., 2022). Hydropower plants' storage capacity offers flexibility to account for sudden electricity supply and demand changes. Hydropower plants without storage or with small storage are useful for supplying energy at a scale ranging from households to small communities. Conversely, its potential is limited in water-scarce regions and may be vulnerable to climate change, particularly droughts (Premalatha et al., 2014).

Hydropower is a cost-effective electricity source. It offers high efficiency and low operating and generation costs, though its upfront investment cost is relatively high. However, hydropower cost is even lower than the least expensive fossil fuel-fired option. Still, maximizing environmental and social benefits during the planning stages, lowering the likelihood of dam collapses, and modernizing the aging hydropower fleet are all necessary to maximize hydropower's potential for future cost reduction. However, the time it takes to fill the reservoir may add to the building time of hydroelectric power facilities, which is already greater than that of many other renewable technologies. This extended timeline can create uncertainty in the completion of the plants. Also, there is uncertainty due to the annual variations in precipitation and the water intake to fill reservoirs. This is particularly important for transnational hydroelectric power facilities since overfilling the reservoirs could significantly affect downstream users in other countries (Clarke et al., 2022).

Hydroelectric generating facilities could have negative impacts on society and the environment. Although it is considered a clean energy option, but there are still some emissions from concrete to construct dams, and emissions from the water bodies. Dams may cause natural habitats to become fragmented because they obstruct the movement of sediments, water flow, and aquatic and terrestrial wildlife. There may be significant changes to vegetation, normal river flows, free movement of fish, sediment and nutrient retention, water quality, and temperature below dams. Instead, hydropower offers ancillary services like municipal water supply, irrigation and drought management, navigation and recreation, flood control, and local economic benefits (Clarke et al., 2022;

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IRENA, 2022). Given the competing stakeholder interests, there could undoubtedly be disputes over transboundary hydropower projects (Llamosas & Sovacool, 2021; Zarfl et al., 2015).

Generally, there is strong public support for hydroelectric power, which is higher than coal, gas, and nuclear power (Steg, 2018). Particularly in areas where hydropower has historically been used, public support is often high for small- and medium-scale hydropower. However, popular support for new hydropower projects appears to be declining, and the development of brand-new, massive hydropower plants has encountered fierce opposition in several regions (Gormally et al., 2014).

2.1.3.4 Nuclear energy

There are sufficient resources for substantially increasing nuclear deployment. Over time, estimates for known uranium resources have been gradually rising. At present use rates, conventional uranium deposits are considered adequate for more than 130 years of supply; in 2009, 100 years were predicted (NEA/IAEA, 2021).

Notably, nuclear energy can also generate freshwater (through desalination) and low-carbon hydrogen. However, cost overruns, significant up-front investment requirements, problems with the final long-term disposal of radioactive waste and contaminated water used for processing of nuclear fuel and cooling purposes within the power generation cycle, different levels of public acceptance, and political opposition still hamper nuclear power. There are pronounced employment effects epically during the construction phase. But in countries experiencing rapid nuclear expansion, a shortage of qualified and skilled labor may become a significant issue (Clarke et al., 2022).

Costs of nuclear energy vary significantly across countries. First-of-a-kind projects being built in North America and Europe have experienced delays and cost overruns. On the other hand, most recent projects in Eastern Asia were finished in five to six years (IEA, 2020). Future nuclear prices will depend on the capacity to take advantage of the accumulated knowledge in controlling the primary cost drivers in addition to region-specific considerations (NEA/IAEA, 2021).

Nuclear technology alternatives between 2030 and 2050 include enhanced large reactors, fleet life extensions, and Small Modular Reactors (SMRs). Cost-cutting opportunities, such as design standardisation and innovations in construction approaches, are expected to make SMRs competitive against large reactors (Clarke et al., 2022).

Regarding consequences on the environment and land occupation, nuclear energy is shown to be advantageous. Similarly, only small amounts of bulk materials (such as aluminum, copper, iron, and rare earth metals) are needed for each unit of energy produced. However, inland nuclear power stations that require a lot of water contribute to localised water stress and competition for water resources. The selection of a cooling system (closed-loop as opposed to once-through) can significantly reduce the pace at which freshwater is withdrawn, and water scarcity problems have little impact on reactors located near the ocean.

According to lifecycle analysis studies, the overall effects of nuclear power plant operations on human health are significantly less severe than those brought on by fossil fuels and are comparable to those of renewable energy sources (Gibon et al., 2017; Luderer et al., 2019). However, the potential for major nuclear accidents exists despite low probabilities, and the radiation exposure impacts could be significant and long-lasting. Although modern reactor designs greatly reduce the likelihood of such accidents with passive and improved safety mechanisms, nuclear power still faces limited public and political support in some nations. Public support for nuclear energy is consistently lower than that for natural gas and renewable energy resources. In many nations, it is even lower than that for energy derived from coal and oil (Bird et al., 2014). Public anxieties about radioactive waste do not even appear to be alleviated by efforts to reposition nuclear power as a low carbon energy option, and polls at best indicate ambivalence regarding nuclear energy (Pampel, 2011). However, when individuals are worried about energy security, particularly about energy availability and high energy prices, and when they anticipate local benefits, public support for nuclear energy is higher (Gupta et al., 2019).

Nearly 90% of nuclear power stations now under construction are operated by state-owned or controlled corporations, with governments bearing a significant portion of the risks and expenses due to the enormous

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amount of investment required. For nations that decide to include nuclear power in their energy mix, stable political environments, robust regulatory frameworks, and sufficient financial resources are essential for a successful and effective deployment. Concerns about nuclear power's role in proliferation also stem from the fuel cycle, specifically from processing spent fuel and uranium enrichment. These procedures are carried out in relatively few nations while adhering to strict international and national standards and regulations (Clarke et al., 2022).

2.1.3.5 Bioenergy

Bioenergy has the potential to be a high-value and widespread mitigation option. Bioenergy may be very beneficial in industries with few alternatives to fossil fuels, such as aviation and heavy industry, the manufacturing of chemicals and goods, and carbon dioxide removal (CDR). Additionally, bioenergy is versatile, and biomass resources can be used to create a variety of energy carriers and other value-added products through a variety of technological methods. However, due to its intricate connections to problems outside the energy system, such as competition with land for food production and forestry, water consumption, effects on ecosystems, and land-use change, evaluating the possibility of a significant scale-up of purpose-grown bioenergy is difficult. The potential for bioenergy is mostly defined by these variables rather than by geophysical qualities, which also explains why different estimations of the potential differ. Overall, the environmental effects of large-scale production are yet unknown and depend on the geography and application (Clarke et al., 2022).

Although first-generation bioenergy costs more on average than other final energy sources, it is currently competitive in particular markets. Currently, there is a competitive market for bioenergy made from waste and agricultural and forestry residues, but the supply is constrained. These prices vary depending on the situation, and areas with abundant waste resources are already producing bioenergy at a low cost (Clarke et al., 2022).

By capturing CO_2 during various stages of the conversion process and then permanently storing the CO_2, bioenergy can be utilised to remove carbon from the atmosphere (using BECCS). The implementation of BECCS on a large scale is hindered by several technological and institutional issues, such as the high energy requirements for CCS, the cost and availability restrictions on biomass, the lack of widespread geologic CO_2 sinks, and the high cost of CO_2 capture equipment (Clarke et al., 2022). While different scenarios propose BECCS as one of the most promising technologies to reach climate targets, its widespread deployment in climate stabilisation scenarios might become a dangerous distraction (Fuss et al., 2014).

Although first-generation biofuels and traditional biomass are still commonly utilised today, growing specific crops for bioenergy raises a wide range of sustainability issues, and the technology for large-scale production from sophisticated technologies is not competitive. Advanced methods like gasification, Fischer-Tropsch processing, hydrothermal liquefaction (HTL), and pyrolysis will be needed to scale up bioenergy usage. In parallel, the price of feedstocks may increase as bioenergy demand rises, particularly in scenarios with significant bioenergy implementation (Muratori & Mai, 2021).

Impacts on lifecycle emissions from bioenergy are highly unclear and, in certain cases, might not be compatible with net-zero emissions. Depending on operational conditions and regional contexts, bioenergy systems may fail to achieve near-zero emissions due to the possibly high energy conversion requirements and accompanying GHG emissions. As a result, the question of whether bioenergy is carbon neutral is debatable. It depends on several variables, including the biomass source, the energy and conversion pathways used to produce and transport the biomass, land use changes, the assumed analysis boundary, and the time scale (Fan et al., 2021; Lade et al., 2019). Also, direct use of bioenergy without carbon capture and storage (CCS) leads to air pollutant emissions. The influence of bioenergy on biodiversity is contingent upon several factors, including the initial land use status, the specific bioenergy production method employed, and the overall landscape arrangement. Second-generation bioenergy crops typically exhibit fewer adverse effects compared to first-generation varieties and, in certain instances, may even have a positive impact (Clarke et al., 2022).

The public acceptance of bioenergy is relatively low compared to natural gas and other renewable energy sources like solar and wind. In addition, compared to other energy sources, people know very little about bioenergy and

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tend to be more ambivalent about it than other mitigation measures (Whitmarsh et al., 2011). People are more favourable toward biomass made from waste than they are toward energy crops that are developed specifically for that reason (Demski et al., 2015). Furthermore, biomass is not widely seen as a renewable energy source, maybe because it requires burning materials (Clarke et al., 2022).

Increasing agricultural yields, enhancing conversion efficiencies, and creating sophisticated biotechnologies for raising the fuel yield per tonne of feedstock are all necessary to address these problems (Henry et al., 2018). To maintain biodiversity, control water consumption, reduce emissions due to deforestation and land use change, and ultimately integrate bioenergy with shifting ecosystems as best as possible, policy mechanisms would be required. Additional institutional and financial impediments must be addressed (Clarke et al., 2022).

2.1.3.6 Geothermal energy

Geothermal resources are renewable heat sources geophysically capable of producing up to 13 times the world's electricity needs in 2019. High upfront costs, decentralised heat production, lack of uniformity among projects, geological uncertainty, and geotechnical risks are the main contributors to the mismatch between potential and produced geothermal resources (Limberger et al., 2018).

New technologies are being developed, including enhanced geothermal systems, deep geothermal technology, or shallow geothermal energy. As a viable energy source for heating and cooling buildings, shallow geothermal will likely be well deployed on a broad scale if appropriate regulatory frameworks are created in addition to site-specific economic performance (Narsilio & Aye, 2018).

Water usage, water shortages, and seismic dangers associated with drilling are the key issues with geothermal energy, particularly for large-scale, high-temperature geothermal power-producing plants (Dowd et al., 2011). Furthermore, protests against particular projects have been motivated by noise, stench, and landscape degradation concerns. However, geothermal energy now has less of a negative environmental impact due to modern technology developments.

Geothermal energy is considered to be less acceptable than other renewable energy sources like solar and wind, but favoured over fossil and nuclear energy. However, the general public has little information or awareness about geothermal energy(Clarke et al., 2022).

2.1.3.7 Marine energy

The ocean is a vast energy source that can be extracted from tides, waves, ocean thermal energy conversion, currents, and salinity gradients. Except for wave energy, the main benefit of most marine energy is that it can be produced both during the day and at night, and its sources are very regular and predictable. Creating more affordable district cooling systems close to the ocean is another use for seawater (Bindoff et al., 2022).

Most marine technological advancements are hampered by relatively high upfront costs, ambiguity surrounding environmental regulations and their effects, and inadequate infrastructure. There are also issues with technological performance and maturity. Thus, not all have the potential to be profitable (Kempener & Neumann, 2014a, 2014b).

2.1.3.8 Energy from waste

Using thermal (incineration, gasification, and pyrolysis) or biological (anaerobic digestion and landfill gas to energy) methods, waste-to-energy is a strategy to recover energy from waste. When the necessary facilities support related technologies, they can help provide clean electricity and lower GHG emissions (Ahmad, 2021).

Incineration facilities can reduce waste volume by 80–90%, reducing soil and water contamination. Besides, anaerobic digestion technology has a favourable effect on the environment and the capacity to lower GHG emissions. The by-product of anaerobic digestion could be used as a fertilizer with high nitrogen content to improve soil quality for agricultural usage (Haraguchi et al., 2019).

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Compared to alternative energy sources like fossil fuels and natural gas, waste to energy is expensive. However, the economic and environmental benefits justify its high financial expenses. Depending on where the waste comes from, the combination of waste to energy and CCS may possibly make it possible for waste to have net-zero or even net negative emissions (Wienchol et al., 2020).

Due to the potential negative impacts on the domestic environment and residents' health, waste to energy projects face strong opposition from the local communities in which they are located (Baxter et al., 2016). Therefore, policies would need to be developed with particular recommendations aimed at emissions reduction for waste to energy to be employed more broadly.

2.1.3.9 Carbon dioxide capture, utilisation, and storage (CCUS)

Recently, increased attempts have been associated with CO_2 capture, CO_2 utilisation, and storage. There could be a considerable contribution to the transition to low-carbon energy systems while raising the power price. The theoretical global geologic storage potential of carbon is about 10,000 Gt CO_2, with more than 80% of this capacity existing in saline aquifers. Due to geological and engineering constraints, not all of the storage capacity is usable, but the plausible storage still exceeds the storage needed through 2100 to keep global warming to 1.5°C (Martin-Roberts et al., 2021).

Geological storage resources are frequently not close to CO_2 sources, raising prices and decreasing viability. The capacity of oil and gas reservoirs and coalbed methane fields is also limited. More than half of the world's potential for enhanced oil recovery is in the Middle East (Selosse & Ricci, 2017).

Utilisation of CCUS reduces air pollution from fossil sector as an indirect advantage based on technological specifications. However, water use could be increased and could lead to plant retirements in several water-stressed regions (Clarke et al., 2022).

An alternative to geologic storage for carbon dioxide is carbon dioxide utilisation. However, the possibility of using CO_2 as a feedstock is currently constrained. Some CO_2 utilisation paths are still in the experimental, prototype, and pilot phases of technical development, while others (like urea production) have reached full commercialisation. Purity restrictions for CO_2 as a feedstock impede technology progress in some end users. The availability of energy might cap many CO_2 usage options. The combustion of carbon-rich fuel end-products also releases CO_2 back into the atmosphere (Hepburn et al., 2019; Wei et al., 2020).

The key challenge is CO_2 capture costs, which are still greater than USD50 per tCO_2 for most technologies and geographical areas. Innovative technology, though, could be able to cut some costs. A coal or gas electricity-producing facility with CCS has roughly twice the capital expense of one without CCS. For better oil or gas recovery, injecting CO_2 into hydrocarbon deposits can increase profits and cut costs. However, the potential for enhanced oil recovery is severely limited. CCS requires significant use of several chemicals and resources, most notably water. Water scarcity may force CCS-equipped power facilities to occasionally shut down (Clarke et al., 2022; Edwards & Celia, 2018).

Most individuals are unaware of carbon capture, utilisation, and storage technologies, and many may not have developed consistent opinions or risk perceptions about them (Kang et al., 2020). Related technologies have generally received little public support, and when given impartial information, people tend to prefer other mitigation strategies like renewable energy and energy efficiency. Policy instruments (e.g., carbon prices) are needed for CCS to be broadly used as the application of CCS technologies raises costs compared to unabated fossil fuel use or the uptake of renewable energy. Financial tools like emission certification and trade, legally mandated emission limitations, and carbon pricing are examples of pertinent policy instruments (Tcvetkov et al., 2019). Public may also consider CCU to be lower-risk and more favourable than CCS (Arning et al., 2019). Eventually, there is a need for robust monitoring and verification (Clarke et al., 2022).

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2.1.3.10 Integration of energy system

All human activities emit greenhouse gases, and a cost-effective decarbonisation strategy must consider how various energy systems and industries interact (Jacobson et al., 2019). Future low-carbon energy systems may require far less energy infrastructure thanks to flexible technology and sophisticated integrated energy system control.

Electricity system management faces financial and technological difficulties when integrating significant volumes of variable renewable generation, especially wind and solar energy. Additionally, extended electrification can cause a peak demand imbalance between supply and demand. System integration and a digitalised control paradigm integrating cutting-edge information and communication technology can overcome these difficulties in managing the energy system. In this context, technologies like power storage, flexible demand, and grid forming converters would be increasingly valuable for the real-time preservation of supply-demand balance and adequate flexibility (López Prol & Schill, 2021).

2.1.3.11 Energy Storage

Energy storage technologies make low-carbon systems more cost-effective (Clarke et al., 2022). Energy storage, which uses short-, medium-, and long-term storage of excess energy for delivery later or at a different place, enables power from fluctuating renewable sources to be matched against growing demands across time and space, whereas decarbonisation primarily depends on increasing electrification. Energy storage encompasses devices that may store energy as heat, cold, and both liquid and gaseous fuels in addition to electricity storage.

Large amounts of storage will be needed to accomplish very low-carbon systems, and the best solution can be found by combining various complementary storage technologies. Many less advanced energy storage technologies have few developed worldwide supply channels. Then, there are considerable chances for future cost reductions, brought about by both technological innovation and increased manufacturing volume (Clarke et al., 2022).

The pumped hydroelectric storage (PHS) plants have been in operation for many decades. Regarding the PHS plants, extended building times delay the return on its expensive investment, and the construction itself might damage the neighbourhood and environment. Furthermore, there aren't many suitable locations for large-scale PHS plants. Small-scale PHS installations are being given new considerations, and siting options are being increased (Hayes et al., 2019; Kougias et al., 2019).Besides, Seasonal pumped hydropower storage (SPHS) can also provide long-term energy storage at a relatively low-cost. Its estimated global energy storage capacity at a comparable cost is estimated to be approximately 79% of the global electricity consumption in 2017 (Hunt et al., 2020).

Rechargeable battery cells have been widely used for storage purposes for decades, especially in automotive and grid applications. Except for seasonal storage, batteries can deliver practically all electricity services. As this industry expands, EV batteries are anticipated to become a dispersed storage resource that will influence and support the grid. Batteries have certain drawbacks, such as relatively limited lifespans and the use of expensive or toxic elements in some varieties. Economies of scale are a significant component in developing batteries to lower costs. Even if the costs of battery storage systems are falling, issues still need to be resolved, including the threat of thermal runaway, which could cause a fire, worries about long-term resource availability, and concerns about global cradle-to-grave effects. Extending the battery's life can bring down overall costs and mitigate environmental impacts. Also, cost-effective recycling of batteries will address many sustainability issues and prevent hazardous and wasteful disposal of used batteries (Clarke et al., 2022; Harper et al., 2019).

Since the 1970s, compressed air energy storage, or CAES, has been used. But there are currently few deployments. Although CAES has a lot of potential, it requires a substantial upfront expenditure. Utilising the hydrostatic pressure of deep water to compress air within submersible reservoirs can lead to higher efficiency and energy densities. CAES has much more siting choices than PHS and less environmental impact (Clarke et al., 2022; Pimm et al., 2014).

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Various technologies are referred to as thermal energy storage (TES), which takes advantage of a material's capacity to absorb and store heat or cold. The efficiency of many industrial, building, and home operations can be dramatically increased thanks to TES, which can be far less expensive than batteries. Latent TES is less developed and has fewer uses, whereas sensible TES is well-established and widely used (Clark et al., 2020; Clarke et al., 2022).

Another form of storage that is powered by rotor/flywheel acceleration is the flywheel. Flywheels provide high power for short durations and are ideally suited for stationary grid storage, even though they are more expensive to install than batteries. Despite having many advantages over other storage systems, flywheels are a relatively mature storage technology that is not frequently deployed (Amiryar & Pullen, 2017; Clarke et al., 2022).

Hydrogen may also be used to store energy for long periods of time for transportation, industry, and other uses. It may be seasonally stored in large amounts at moderate pressure in geological formations. An electrolyser uses water to separate it into hydrogen and oxygen, using extra electricity. Recombining hydrogen and oxygen into water in reverse, a fuel cell transforms chemical energy into electricity. Costs for fuel cells must be brought down, and hydrogen's synergies with complementary technologies, such as batteries, must be further investigated (Clarke et al., 2022; Gabrielli et al., 2020).

Other storage technologies include liquid air energy storage (LAES), supercapacitors, and redox flow batteries (RFB). There is a lack of public knowledge and awareness of storage technologies, their current state, and their potential contribution to future energy systems (Jones et al., 2018). For instance, people tend to underestimate the need for flexibility and storage in the energy system or believe that storage is already happening.

Though considered a cutting-edge and environmentally friendly technology, safety is a concern for some storage technologies. Improper disposal of device materials can pose environmental constraints. Certain devices utilize critical resources and materials that are ecotoxic or pollutant, especially during their extraction and manufacturing processes. The extraction of materials and manufacturing processes for certain devices consumes a significant quantity of freshwater. Wastewater generated during various stages, such as manufacturing, treatment, and recycling, can be hazardous. When wastewater infiltrates the ground and enters surface waters, it can pose numerous health risks. Therefore, the capture and treatment of contaminated wastewater are of utmost importance and vital (Clarke et al., 2022).

In some areas, using batteries in homes and communities was seen as marginally advantageous. It is believed that one of the biggest obstacles is cost. The present number of EV owners and worries that one's car battery would not be fully charged when needed are limiting EV batteries' ability to serve as flexible storage (Clarke et al., 2022).

2.1.3.12 Hydrogen as a low-carbon fuel

Hydrogen is a possible energy carrier for a decarbonised society that can be used for power and heat generation, transportation, and industrial purposes in addition to being a storage option for energy. Hydrogen is anticipated to be used in low-carbon energy systems for purposes less suited to electrification, such as heavy-duty shipping and road transportation (Griffiths et al., 2021).

Low- or zero-carbon produced hydrogen is not currently competitive for large-scale applications. Still, it is likely to have a significant role in future energy systems due to its wide range of applications. Critical challenges for hydrogen development are (i) cost-effective low/zero carbon production; (ii) delivery infrastructure cost; (iii) land area requirements of hydrogen pipelines, compressor stations, and other infrastructure; (iv) challenges in using existing pipeline infrastructure; (v) maintaining hydrogen purity; (vi) minimizing hydrogen leakage; and (vii) the cost and performance of end uses. Furthermore, the infrastructural needs associated with hydrogen technologies must be taken into account, as well as how the general public accepts them (Clarke et al., 2022).

2.1.3.13 Electricity transmission

Electricity transmission could help with the cost-effective deployment of renewable generation, improved

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resilience and supply security, and boosted operational effectiveness due to the considerable regional differences in the efficiency of renewable resources. For nations that may benefit from the diversity of their energy mixes and usage, and are physically close to one another, connectivity is often more cost-optimal (Schlachtberger et al., 2017). However, such advancements are not without cost, and among other challenges, they pose questions about the use of land, public acceptance, and the procurement of resources for required materials (Vakulchuk et al., 2020).

Considering the increasing interest in interconnection among various regions or continents, a wide range of geopolitical and socio-techno-economic obstacles would need to be addressed in order to sustain global collaboration and extensive network expansion (Palle, 2021). However, the lack of suitable market structures and legal and policy frameworks poses the biggest obstacle to interregional transmission. Commercial obstacles also exist to enhance cross-border transmission further. New business models that offer incentives for investment and efficient operation, handle risks and uncertainties, and promote coordinated planning and governance may also be necessary (Poudineh & Rubino, 2017). The public's support, which studies show is typically low, will also be essential for extending transmission systems (Perlaviciute et al., 2018).

2.1.3.14 Table on Enablers and Barriers

Table 2: Summary of enablers and barriers across technologies

Technology	Dimension	Enablers	Barriers
Solar Energy	Geophysical	• Abundant Potential: Solar energy keeps vast global potential, surpassing many other renewables.	• Unequal Distribution: Regions with abundant solar irradiation, such as parts of South America, Africa, the Middle East, and Australia, offer ideal conditions for solar energy generation. On the other hand, its potential is limited in higher latitudes and urban areas.
	Environmental-Ecological	• Low Environmental Impact: Solar energy has minimal environmental impacts compared to fossil fuels. Even, there are minimal effects during manufacturing. • Less Pollution: Solar energy production contributes to lower air pollution, reduced toxic waste, and fewer water quantity and quality concerns. The toxic waste is low if recycling is done properly. • Biodiversity Conservation: Solar technology offers methods to mitigate its impact on biodiversity.	
	Technological	• Cost Reduction: Advances in technology, including innovative designs and materials, lead to cost reductions. • Efficiency Enhancement: New technologies like bifacial modules	

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		enhance efficiency and resource use.	
	Economic	• Cost Competitiveness: Solar energy often offers a lower cost of electricity production compared to fossil fuels, bolstering its economic viability. • Cost Evolution: Current costs favour solar energy, with decreasing reliance on government incentives.	
	Sociocultural	• Public Acceptance: Solar energy enjoys widespread public acceptance, driven by financial rewards, environmental benefits, and self-sufficiency desires. • Social Benefits: Solar energy adoption aligns with peer expectations and contributes to health, well-being, and economic growth.	• Utilisation Challenges: Overcoming obstacles like landlord-tenant dynamics and upfront costs enables greater utilisation.
	Institutional	• Political Support: Solar energy benefits from political acceptance, creating a favorable institutional environment. However, it needs support for rapid scale-up in developing countries. • Legal Framework: A well-defined legal and administrative framework supports efficient deployment. Reforms on electricity market is required for expanded development.	• Lack of political support or a legal framework
Wind Energy	Geophysical	• Vast Potential: Global estimates indicate that potentially exploitable wind energy is 20–30 times the global electricity demand in 2017. • Widened Resources: Every continent has potential hotspots of wind resources,	• The distribution of wind resources varies seasonally.
	Environmental-Ecological	• Low Environmental Consequences: Operation of wind turbines generates no waste or contaminants.	• Ecological Considerations: Wind farms can impact animal habitats, movements, and fatalities, but mitigation measures are possible. The impacts can be minimised by careful site selection. • Noise issue: Recent studies suggest weak links between wind farm noise and human health markers.

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	Technological	• Hybrid Power Plants: Co-location of wind and solar PV power farms, along with batteries, is an emerging technology, offering new possibilities. • Technological Advancements: Larger capacity turbines, rotor diameters, and taller hub heights contribute to cost reductions.	
	Economic	• Cost Reduction: Wind energy costs have decreased by 18% and 40%, respectively, on land and offshore since 2015.	• Economic Impediments: High initial capital costs, long payback periods, and limited access to funding are common barriers.
	Sociocultural	• Public Support: There is generally strong public support for wind energy, driven by its perceived environmental advantages.	• Opposition Factors: Some projects face opposition due to concerns about noise, aesthetics, symbolic locations, and wildlife impacts.
	Institutional	• Infrastructure and Connectivity: Availability of land in wind-rich regions, supporting infrastructure, grid connectivity, and financial accessibility are key factors influencing future potential of wind energy. • Government Support: Commitment to financial support mechanisms, local supply chain development, and grid improvements can facilitate wind energy expansion.	• Opposed Interests: Development of wind may be opposed by stakeholders with interests on fossil fuel.
Hydropower	Geophysical	• Vast Global Potential: Theoretical available hydropower potential exceeds total electricity production in 2018.	• But it is limited in water-scarce regions and where good suitable locations are taken, its potential could be impacted by climate change.
	Environmental-Ecological		• Ecosystem Impact: Dams can fragment natural habitats, affect water flow, and impact aquatic and terrestrial wildlife. Although it is considered a clean energy option, but there are still some emissions from concrete to construct

			dams, and from the water bodies.
	Technological	• Flexibility and Storage: Hydropower facilities with storage capacity offer flexibility in balancing electricity supply and demand. • Efficient Source: Hydropower is cost-effective with high efficiency and low operating costs.	
	Economic	• Cost Reduction Potential: Maximizing environmental and social benefits, reducing dam-related risks, and modernisation contribute to future cost reduction.	• Investment Challenge: High upfront investment costs are a challenge, but long-term cost-effectiveness surpasses fossil fuels. • Construction Time: The extended timeline for filling reservoirs and annual variations in precipitation can create construction uncertainty.
	Sociocultural	• Public Support: Hydropower enjoys strong public support, especially in areas with historical use b	• New massive projects face growing opposition, especially where indigenous land is affected
	Institutional		• Transboundary Disputes: Transboundary hydropower projects can lead to disputes among competing stakeholders and downstream impacts on other countries.
Nuclear Energy	Geophysical	• Abundant Uranium Resources: Known uranium resources can support more than 130 years of supply at current use rates.	
	Environmental-Ecological		• Water Usage Considerations: Inland nuclear power stations contribute to local water stress, but cooling system choices can reduce freshwater withdrawal.

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			• Environmental Impacts: Nuclear energy has less severe environmental effects compared to fossil fuels. Generally, there are low impacts on biodiversity but devastating impacts in case of an accident.
	Technological	• Future Technology: Future nuclear technology includes Small Modular Reactors (SMRs) expected to become competitive through design innovations.	• Skilled Labor requirement: In countries experiencing rapid nuclear expansion, a shortage of qualified and skilled labor may become a significant issue.
	Economic	• Employment Effects: There are pronounced employment effects during the construction phase.	• Cost Variations: Costs of nuclear energy vary across countries, with differences in project timelines and outcomes. • Upfront Investment: High upfront investment requirements and cost overruns challenge nuclear power projects.
	Sociocultural		• Public Support: Nuclear power faces public and political opposition, with lower support compared to other energy sources. Public backing may increase when energy security, local benefits, and economic factors are considered.
	Institutional	• Stable Setting: Stable political environments, robust regulations, and adequate financial resources are crucial for successful deployment. Concerns about proliferation are linked to fuel cycle activities, including spent fuel processing and uranium enrichment.	• Government Involvement: Many nuclear power projects are state-operated, with governments shouldering risks and costs

		• Strict Standards: Related processes are carried out under strict international and national standards and regulations to address proliferation concerns.	
Bioenergy	Geophysical		• Availability Challenges: Bioenergy's potential is influenced by complex factors such as competition with land for food production, water consumption, ecosystem effects, and land-use change rather than geophysical qualities.
	Environmental-Ecological	• Biodiversity Impacts: The influence of bioenergy on biodiversity is contingent upon several factors, including the initial land use status, the specific bioenergy production method employed, and the overall landscape arrangement. Second-generation bioenergy crops typically exhibit fewer adverse effects compared to first-generation varieties.	• Varying Effects: Large-scale production of bioenergy raises environmental concerns, with impacts varying based on geography and application. • Emissions: The carbon neutrality of bioenergy is debatable, with emissions affected by biomass source, energy pathways, land use changes, and other factors.
	Technological	• Bioenergy with Carbon Capture and Storage: Bioenergy can contribute to carbon removal through BECCS • Need for Advanced Technology: Advanced methods like gasification, hydrothermal liquefaction, and pyrolysis are needed for scalability.	• BECCS implementation faces several challenges, including high CCS energy requirements.
	Economic	• Competitive Prices: Although first-generation bioenergy costs more on average than other final energy sources, it is currently competitive in particular markets with abundant supply.	
	Sociocultural	• Biomass made from waste is more favourably viewed than crops.	Public Support: Acceptance of bioenergy by public is relatively low compared to other renewables.
	Institutional	• Addressing concerns requires policy mechanisms, enhanced agricultural practices,	

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		biotechnological advancements, and financial support are required to address the concerns.	
Geothermal Energy	Geophysical	• Significant Potential: Geothermal resources have the potential to produce a significant amount of renewable heat	• Factors such as high upfront costs, geological uncertainty, and geotechnical risks contribute to underutilisation.
	Environmental-Ecological	• There are little impacts on overground land use.	• Environmental Concerns: Water usage, water shortages, and seismic risks associated with drilling, especially for large-scale geothermal power plants are among the concerns.
	Technological	• Advancements: The technology is mature but likely to be improved, particularly for high depth potential. Ongoing technological developments, including enhanced geothermal systems and shallow geothermal energy, can enhance the feasibility of geothermal energy.	
	Economic		• Investments Issue: The mismatch between potential and developed geothermal resources is caused by several factors, including high upfront costs.
	Sociocultural	• Public Support: Geothermal energy is generally favoured over fossil and nuclear energy but is less well-known and accepted compared to solar and wind energy.	
	Institutional	• Needs for Extension: Addressing water and seismic concerns, creating regulatory frameworks, and increasing public awareness are essential for the effective deployment of geothermal energy.	
Carbon Dioxide Capture, Utilisation,	Geophysical	• Availability Challenges: Global geologic storage potential for carbon dioxide storage is	• Not all capacity is usable due to geological constraints.

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And Storage (CCUS)		substantial, primarily in saline aquifers	• Geological storage resources are often distant from CO_2 sources, which can increase costs and decrease viability.
	Environmental-Ecological	• Considerable Impacts: Its utilisation reduces emissions from fossil sector as an indirect advantage based on technological specifications.	• Water use could be high.
	Technological	• New Technologies: Innovative technologies may help reduce costs.	• Its utilisation is logistically challenging requiring widespread infrastructural coordination.
	Economic		• High Costs: Facilities equipped with CCS generally have higher capital expenses. The main challenge lies in reducing CO_2 capture costs, which remain high for most technologies and regions. CO_2 injection into hydrocarbon deposits can improve profits but has limitations.
	Sociocultural		• Low Support: Public awareness and support for CCUS technologies are generally low. Public perception often favors other mitigation strategies like renewable energy and energy efficiency.
	Institutional	• Policy Requirements: Carbon pricing and legally mandated emission limitations are needed to incentivize the widespread use of CCUS technologies. • Carbon capture and utilisation may be seen as lower-risk and more favorable than carbon storage by the public. There is also a need for robust monitoring and verification.	
Energy Storage	Geophysical	• Vast Potentials within New Systems: Energy storage	

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		technologies facilitate the integration of fluctuating renewable sources. Combining complementary storage technologies may be necessary for achieving low-carbon systems. • Pumped hydroelectric storage (PHS) has been in use but face challenges in terms of suitable locations. • Compressed air energy storage (CAES) has potential with more siting choices.	
	Environmental-Ecological		• Critical Concerns: Certain devices utilize critical materials that are ecotoxic or pollutant, especially during their extraction and manufacturing. Improper disposal of materials can pose environmental constraints. Improving recycling practices and extending battery lifespan are key challenges. • Water Related Issues: Extraction and manufacturing of specific devices require substantial freshwater, and the resulting wastewater can be harmful if it contaminates surface waters. Capturing and treating this wastewater are critical for preventing health and environmental hazards.
	Technological	• Different technologies in different sizes are available but at various stages of development, with potential for cost reductions through technological innovation and increased manufacturing volume. • Integration with other technologies like batteries and the exploration of safety measures are areas of consideration. • Hydrogen and other storage technologies like liquid air energy	

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		storage, supercapacitors, and redox flow batteries are under development.	
	Economic	• Economies of scale play a significant role in lowering costs. • Financing mechanisms and recycling practices can impact overall economic feasibility. • Also, skilled employment is required in manufacturing, maintenance, and installation companies.	• High Costs: Cost-effectiveness remains a key consideration for energy storage technologies.
	Sociocultural		• Low Public Support: Public awareness and support for storage technologies are generally low. Concerns include safety, cost, and the perceived need for flexibility.
	Institutional	• Critical Needs: Regulatory frameworks and policy support are needed to promote the adoption of energy storage technologies and address associated challenges.	

2.1.4 Policies and measures: What policies are needed to achieve net-zero by mid-century

To achieve decarbonisation, it is essential to implement policy measures or instruments. These policy interventions are necessary to fully realize the policy goals. (D'Arcangelo et al., 2022) Many nations have adopted policy mixes that include a wide range of complementary measures or instruments to meet their energy and climate policy goals. One such instance is the German Energiewende, a scheme combining carbon pricing with significant support for renewable energy utilisation, an action plan for energy efficiency, and phase-out procedures for nuclear and coal-based power generation (Löschel et al., 2019). When pursuing multiple policy goals, well-designed policy mixes can lower mitigation costs and address associated concerns like distributional issues. In the EU's clean low-carbon strategy for 2050, for instance, combining carbon pricing and the support for clean energy technology could lower mitigation costs and enable the early adoption of more rigorous climate targets (Vandyck et al., 2016). However, policy initiatives to encourage the adoption of low-carbon technology are more effective if they include behavioural interventions that target pertinent cognitive and motivational elements in addition to economic incentives (Khanna et al., 2021).

According to the literature reviews (Rogelj et al., 2022), mitigation pathways in line with the 1.5°C goal would necessitate policy interventions in the form of strict economy-wide emission targets (and resulting peak-and-decline of emissions), greater coverage of NDCs to more gases and sectors, much lower energy and carbon intensity targets, carbon prices much higher than the ones observed in real markets, along with additional initiatives. Among these, regulatory instruments are common tools for enhancing renewable energy and improving energy efficiency (de Coninck et al., 2022). These instruments may set a wide range of requirements (such as emission quotas, technology mandates, and others). They can be especially effective in certain areas, such as restricting and phasing out high-emitting activities or technologies and accelerating the deployment of low-emitting technologies. However, poorly thought-out laws could make decarbonisation more expensive by making

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it harder to track performance, obscuring price signals, and reducing the incentives for the entire sector. Economic incentives such as feed-in tariffs, subsidies, or tax exemptions can boost the effectiveness of regulatory tools. The literature reveals the higher implementation costs of the climate and energy policies grounded only in regulation, standards, and public funding of R&D, due to the risk of being influenced by political and administrative arbitrariness. Accordingly, making these costs explicit through carbon taxes and carbon trading may be more effective, while their implementation can be considerably challenging.

Accounting for the different development stages of new technologies will also enhance low-emissions transitions (Graaf & Sovacool, 2020). Research subsidies and demonstration programs are crucial for prototype technologies and those in the demonstration stage. Besides, infrastructure development and market expansion are becoming more crucial for early-adopting technologies while retiring or reusing existing assets is crucial for mature technologies (Clarke et al., 2022; Terwilliger, 2021). In fact, policy mixes focused on low-carbon transitions are more effective when they include components that boost the phase-out of carbon-intensive technology and practices. Policy mixes should likewise account for political opposition from incumbents who benefit from high-carbon systems (Edmondson et al., 2019). Coalitions for rigorous climate policy can be built by establishing or tightening carbon prices once supportive coalitions have been formed, starting with green policies (such as promoting renewable energies through feed-in tariffs). Complementary promising approach is designing short-term policies that could give subsequent entry points for more aggressive climate policy and supporting institutions (Kriegler et al., 2018). Also, well-designed policy mixes will need to address the entire lifecycle or value chains, for example, through policies on limiting fossil fuel use or including measures to restrict carbon leakage (Clarke et al., 2022). All policy instruments can benefit from information campaigns (e.g., TV ads), although some authors report that the effects obtained by such campaigns are short-lived and decrease over time (Somanathan, 2015).

Accordingly, a well-designed policy mix should encompass measures or instruments related to governance and planning, economic incentives, regulatory frameworks, as well as educational and informational initiatives. Drawing from the enablers and barriers identified in the previous section of the study, a range of policy measures and instruments have been categorized into four distinct groups to address the enablers and barriers. The table below outlines the proposed policy measures and instruments based on the IEA's Policies Database (IEA, 2023).

Table 3: Proposed policies and policy measures/instruments addressing the identified enablers and barriers

Type of enablers and barriers	Policy or Policy Measure/ Instrument Category	Proposed Policies and Instruments
Geophysical	Governance and Planning	Renewable Energy Targets; National Energy Security Frameworks; Strategies to Secure the Supply Chain for a Robust Transition; Strategic Plans; Environmentally Friendly Solutions on Small Islands; Transition Deals: • Address the geophysical enabler of abundant potential by reducing national dependency on imported fossil fuels and setting specific renewable targets aligned with geophysical resources. • Increase the availability of critical materials and expand domestic manufacturing capabilities. • Address the uneven distribution issue by planning for efficient utilisation of available resources.
	Economic	Feed-in Tariffs for Renewables; Financing Development of Transmission Lines by National Banks; Providing Grants for Small-

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		Scale Renewable Generation: • Address the geophysical enabler of abundant potentials by incentivizing their development.
	Regulatory	Zoning for Renewable Energy; Provision of Procedures for Land Acquisition: • Addresses the enabler of geophysical potentials by designating specific zones or leasing municipal and state land for renewable projects. These measures designate specific areas as targets of promotion projects. • Mitigates the barrier of land use conflicts by streamlining renewable development in suitable areas.
	Soft	Public Awareness Campaigns on Geophysical Potentials: • Address the enabler of geophysical potential by educating the public about the benefits of renewables. • Reduce the barrier of resistance to renewable energy adoption by fostering a greater understanding of geophysical advantages.
Environmental-Ecological	Governance and Planning	Nationally Determined Contributions; Climate and Nature Protection Action Plans; Emission Reduction Targets; Biodiversity-Friendly Renewable Project Planning: • Address the environmental enabler of low impact resources by incorporating natural resource conservation measures into energy projects. • Mitigate the barrier of potential ecological harm by ensuring responsible energy use.
	Economic	Funding and Granting; Emission Tax for High-Impact Energy Sources; Minimum Price for GHG Emissions: • Address the environmental impacts by investing to reduce emission intensities or imposing taxes or charges on using high-impact energy sources. • Address the challenges in limiting the amount of waste produced and protecting the land and air. • Encourage the enabler of low environmental impact by making renewables more attractive. Hydropower Remediation: • Compensate the expenses of remediation actions that hydropower plant operators need to undertake to prevent or mitigate environmental impacts.
	Regulatory	Limits on Emissions of New Plants; Quota on Using Renewables; Bills on Shut Down of Fossil-Fuelled Power Plants; Environmental Codes; Allocation of Project Areas by Government for Development of Renewables; Methodologies to Value Externalities; Wildlife Impact Assessment Requirements; Changes in Licensing with Better Impact Assessment; Provisional Management Measures for Distributed Renewable Project Development and Construction; Establishment of Energy Parks: • Recognize the impacts of emissions from fossil-fuelled power plants as a risk to human health and to the environment. Some measures forbid combustion of fossil fuels, and some set a percentage quota of electricity use that needs to come from renewables and keep the carbon targets reachable. • Address the barrier of potential environmental or ecological harms by mandating thorough assessments for projects. • Ensure the environmental enablers of biodiversity conservation by reducing harm to ecosystems.

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		• Ensure projects to be built on land under the appropriate right of use (e.g., industrial park land), and don't occupy permanent prime farmland. The measures may offer sites for environmentally sound development of renewable energy on public lands. Those measures also Identify related priority areas for countries in technological development. Management of Biomass Power Stations: • Forbid usage of forest and agriculture biomass residue mix for co-firing with fossil fuels. Decree on Disposal of Photovoltaic Modules: • Reduce the impact of disposal on human health and the environment through setting out the procedure for the reception, treatment, and removal of different kind of photovoltaic modules.
	Soft	Renewable Energy and Biodiversity Education Programs: • Address the enabler of minimal environmental impact by educating the public on how renewables support biodiversity. • Reduce the barrier of opposition due to environmental concerns by enhancing awareness of the positive ecological aspects.
Technological	Governance and Planning	National Green Energy Missions; Strategy for Developing New Technologies: • Address the technological enabler of innovation by encouraging research and development, and deployment of renewable energy technologies. • Support the barrier of technology costs by promoting advancements that reduce expenses. Renewable Portfolio Standard (RPS): • Encourage the adoption and diffusion of renewables by setting specific requirements on renewable energy in a region, typically for electricity providers.
	Economic	R&D Funding for Innovation in Renewable Technologies; Funding Research Opportunities for Small Businesses; Funding feasibility studies of New Technologies to Replace, Upgrade, or Complement Existing Energy Supply Arrangements; Energy Incubator Programs: • Address the technological enabler of innovation by allocating funds for research, development, and deployment of new technologies. It also facilitates technology transfer between research institutions and small businesses. Subsidizing Production of Battery Cells for Electric Vehicles; Launching Tenders for Power-To-X; Tax Credits for Advanced Renewable Tech Adoption; Developing Markets for Emerging Technologies; Replacement of Old Renewable Technologies: • Address the enabler of technological advancement by offering incentives like grants and tax credits for the adoption of advanced renewable energy technologies. • Help overcome the barrier of high initial costs for cutting-edge technologies. Market Premium for Large-Scale Hydropower; Market-based Mechanisms for Demand Responses: • Address the issue of renewable energy intermittency. • Support dispatchable power generation if the sold electricity prices on the market are lower than their production costs. • Reward energy users for scaling down their demand during periods of demand peak or low renewable availability.

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	Regulatory	Performance or Technical Standards of Renewables; Introducing Control Mechanisms: • Addresses the technological enabler of efficiency by implementing performance standards. • Improve the security of electricity supply in a market with high share of renewables. • Enhance transparency and provide clear procedures in equipment procurement and commissioning. • Mitigate the barrier of energy waste by promoting optimal technological performance.
	Soft	Professional Training for Renewable Technology Experts; Publishing Reference Books on Best Available Techniques for Instance: • Address the enabler of technological innovation by providing training programs for professionals in the renewable energy sector. • Reduce the barrier of skills shortages by building a skilled workforce.
Economic	Governance and Planning	Recovery and Resilience Plans; Development Plans; Energy Conservation Act/Targets: • Alleviate the economic burden of significant energy waste and harness the economic opportunities. • Defines renewables as a key portion of the whole development plans. Establishing New Initiatives: • Support efficient use of allocated fundings for proceeding mitigation measures.
	Economic	Tax related Incentives (including Tax Credits); Income Tax Exemption; Auction Scheme; Auction with Strike Price Guarantee (to Provide Subsidies in Case the Electricity Market Price Will Be Below the Strike Price); Governmental Budget Allocation; State Finance Aid Scheme; State-Based Finance Through Competitive Bidding; Loans for Power Grid Upgrades; Renewable Energy Funds; Applying Levies on Consumption of Fossil Fuels or GHG Emissions; Developing Levy-Funded Supports for Renewables; Waiver of Transmission Charges Allowed for Trading of Renewables; Co-Financing Investment Projects; Feed-in Tariffs; Setting Sliding Premium for Renewable Electricity Generation on Top of the Market Price; Contract for Difference (CfD); Renewable Capacity Markets; Deletion of Customs on Equipment and Material of Renewables; No Additional Premium for Trading Renewable Electricity in the Market; Perform, Achieve, Trade (PAT) Scheme; Accelerated Depreciation Benefits; Renewable Concession Programs: • Addresses the economic enabler of financial support by offering incentives for investments in renewable, nuclear energy, etc. • Also, support renewables installations in developing countries or least-developed regions to address the issue of high capital cost. • Mitigate the barrier of high upfront costs by reducing the financial burden on individuals and businesses. Energy Price Compensation Plans: • Reduce the risk of relocation of GHG emissions to countries with more lenient climate protection regulations. Rural Electrification; Water Pumping by Renewables; Funding

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		Research Opportunities for Underrepresented Communities; Energy Social Tariff: • Support a variety of communities or alleviates energy poverty by electrification of rural areas through on-grid or off-grid renewables. The followed investment will create good-paying jobs and reinvigorate local economies. The measures may contribute to poverty alleviation through installation of renewable units for the poor households to increase their income. • Support consumers to have a discount on renewable electricity use. Renewable Energy Certificates (RECs); Green Certificates; Carbon Pricing Mechanisms: • Address the economic enabler of competitiveness by making renewable energy more attractive compared to fossil fuels. The mechanisms assure selling of generated renewable power in the market. • Provide a solution to the barrier of economic viability by incentivizing emissions reduction.
	Regulatory	Renewable Energy Obligations for Utilities; Targeting a Minimum Share of Energy Provided by Wholesalers to Come from Renewables; Electricity Infrastructure Regulatory Bills; Agreements to Grant Loans; Power Purchase Agreements; Laws on Renewable Energy Auctions: • Address the economic enabler of renewable energy integration by requiring or encouraging utilities to source renewables and consumers to use renewables. • Mitigate the barrier of limited financing availability. • Reduce the dependence on fossil fuels by diversifying energy sources. • Define the timing and quotas of auctions, and elaborate the conditions for Feed-in Tariffs (FiT) and Purchase Power Agreements (PPAs).
	Soft	Financial Literacy and Renewable Investment Education: • Address the economic enabler of financial literacy by educating the public about the benefits of renewable energy investments. • Reduce the barrier of financial uncertainty by promoting informed financial decisions in the renewable energy sector.
Sociocultural	Governance and Planning	Developing Community-Based Battery and Renewable Energy Projects: • Addresses the sociocultural enabler of public acceptance by involving local communities in the planning and decision-making processes for renewable energy projects. • Mitigates the sociocultural barrier of opposition by fostering community engagement and ownership.
	Economic	Financial Incentives for Community Energy Cooperatives; Just Energy Transition Programs; Subsidies for Renewable Installation in Specific Industries; Providing Grants to Not-for-Profit Community Organisations: • Address the sociocultural enabler of diverse community engagement and participation in technological innovation as well as their preparedness for fossil phase-out. • Reduce the sociocultural barrier of distrust in centralized energy providers by promoting community-led renewable initiatives.

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		Developing Community Banks of Renewables: • Address the social barriers of installing on-site renewables.
	Regulatory	Changes in Licensing with Improved Regional and Local Engagement; Public Consultation Requirements for Large-Scale Projects: • Address the sociocultural enabler of public involvement by mandating public consultations for large-scale renewable projects. • Mitigate the sociocultural barrier of lack of engagement by ensuring that local communities have a say in project development.
	Soft	Public Awareness Campaigns on Sociocultural Benefits; Pilot (Renewable) Cities/Regions; Renewable Decathlon Programs: • Address the sociocultural enabler of social benefits by conducting awareness campaigns highlighting the positive societal impacts of renewable energy adoption. • Reduce the sociocultural barrier of misinformation by providing accurate information on the social advantages of renewables.
Institutional	Governance and Planning	Strengthening Institutional Capacity; Renewable Energy Offices: • Address the institutional enabler of effective governance by investing in the capacity and expertise of governmental agencies responsible for energy, climate, and sustainability. • Mitigate the institutional barrier of inefficiency by enhancing the ability to implement and oversee renewable energy policies. • Conduct RD&D on renewable energy technologies and systems. They address the removal of technical and non-technical market barriers for diffusion of renewables. Action Plans for the Development of Renewable Industry: • Facilitate the development of manufacturing industry to implement and benefit from the newest technologies available. The plans also seek to support the whole supply chain.
	Economic	Governmental Loan and Guarantee Scheme; Funding the Establishment of Modern Technology Manufacturing Plants; Specific Incentives: • Address the challenge of access to liquid funds for companies. Also, incentivize industries and different parties for investments in renewables. Government Support for Renewable Technology Research: • Address the institutional enabler of technological advancement by allocating funds to research and development. • Help overcome the institutional barrier of limited innovation in the energy sector.
	Regulatory	Streamlining Permitting Processes for Renewable Projects; Guidelines for Simplification of Permitting Procedures Common Rules for Electricity Markets; Regulations for Connecting to the Unified Power System; Framework for Grid Connection Agreements; Regulation of Guarantees of Origin (GOs); Market Liberalisation; Reorganisation of Energy Sector Regulation; Renewable Energy Purchasing Conditions; Sustainable Finance Taxonomy Including Bond Standards: • Address the institutional enabler of efficient deployment by simplifying and expediting permitting processes for renewable energy projects. The measures develop a framework to

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		enhance transparency and credibility. • Tackle the obstacles related to renewable integration as well as facilitating dynamic pricing, competition, trading, and customer engagement. More digitalisation, including smart metering, may be needed. • Mitigate the institutional barrier of bureaucratic delays by promoting smoother project development. Mandatory Reporting of GHGs Emission: • Enable the collection of precise emissions data, identifying emission sources, guiding effective policies, as well as aiding businesses in emissions tracking and comparisons.
	Soft	Resource Assessment and Mapping (Atlas); Listing the Appropriate Sites for Utilisation of Renewables: • Facilitate the utilisation of renewables and use of wasted heat for the benefit of government agencies, project developers, researchers, and the public. Bi-lateral or International Cooperation on Co-Financing: • Address weaknesses of financing institutes in developing countries. Cross-Sector Collaboration and Knowledge Sharing; Establishing Research Collaboration Programme; Joint Cooperations on Knowledge Sharing; Creation of Public-Private Coalitions; Memorandum of Understanding (MOU) between public bodies and private companies; Priorities Plan; Creation of Information Hubs or on-Line Portals: • Address the institutional enabler of effective governance by fostering collaboration between government, industry, and civil society. • Reduce the institutional barrier of fragmented efforts by promoting information exchange and coordination among stakeholders. The measures assist developers in obtaining all applicable fiscal and non-fiscal incentives, including registration licenses and securing of access to lands.

2.1.5 Conclusion

Several energy supply characteristics are evident in decarbonisation pathways, including (i) growth in the share of energy derived from low- or zero-carbon emitting sources, (ii) rapid decline in the carbon intensity of electricity generation along with further electrification, and (iii) the growth in the use of CCS applied to fossil and biomass carbon in most 1.5°C pathways. By the mid-century, the majority of primary energy comes from non-fossil fuels (i.e., renewables and nuclear energy) in most decarbonisation pathways. The magnitude and split between bioenergy, wind, solar, and hydro differ across pathways. Nuclear power increases its share not in all pathways but most of them. There are large differences in nuclear power across pathways as the future deployment of nuclear can be constrained by societal preferences assumed in narratives underlying the pathways.

To attain decarbonisation objectives, it's imperative to account for a multitude of enablers and barriers. These encompass geophysical, environmental-ecological, technological, economic, sociocultural, and institutional elements. Geophysically, the main mitigation enablers are the abundant potential for renewable energy sources like solar and wind, which do not require extensive land use and have the capacity to exceed current electricity demands. However, disparities in distribution across regions can be a barrier, with some areas having limited access to these abundant resources. Environmental-ecologically, low environmental impact is a significant enabler for mitigation measures, particularly for technologies like solar and wind. These energy sources have minimal detrimental effects compared to fossil fuels. They contribute to reduced air pollution, fewer toxic waste concerns, and biodiversity conservation as well. Nevertheless, they aren't entirely without consequences, as wind farms and hydropower dams can affect ecosystems and wildlife if not managed well. Additionally, water usage can be a

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concern, especially in arid regions where water resources are limited. Technologically, advancements in energy technologies offer enablers such as efficiency enhancement and cost reduction. Innovations like more efficient photovoltaic modules and wind turbines with larger capacity contribute to their viability. Furthermore, the emergence of hybrid technologies, combining wind and solar power farms with batteries, provides new possibilities for energy generation and storage. Economically, cost competitiveness is a significant enabler for renewable energy sources like solar and wind, making them economically attractive alternatives to fossil fuels. However, barriers include high upfront capital costs, long payback periods, extended construction time, and variations in costs across regions and countries. Socioculturally, public acceptance plays a critical role in enabling the adoption of mitigation technologies. The support is driven by factors such as financial rewards, environmental benefits, and alignment with peer expectations. Nevertheless, opposition factors like concerns about noise, aesthetics, and wildlife impacts can present barriers to the widespread acceptance and deployment. Institutionally, political support and effective governance are key enablers. Policies that favor mitigation technologies and provide a supportive institutional environment facilitate rapid scale-up. Conversely, opposition from vested interests in fossil fuels and the need for regulatory and market related reforms can act as barriers. Well-designed policy mixes that include a wide range of complementary measures or instruments, should be adopted to address the enablers and barriers. Policies and measures targeting geophysical enablers and barriers focus on harnessing the abundant potential of renewable resources. In governance and planning, policy measures and instruments include setting renewable energy targets, national energy security frameworks, and the development of supply chain strategies. These measures reduce national dependency on imported fossil fuels and establish specific renewable energy objectives aligned with geophysical resources. Economically, Feed-in Tariffs provide incentives for the development of abundant potentials. Regulatory actions, such as zoning for renewable energy and procedures for land acquisition, designate specific zones or land for renewable projects. These measures aim to efficiently utilize geophysical resources and reduce land use conflicts. Public awareness campaigns on geophysical potentials address the enabler of geophysical potential by educating the public about the benefits of renewables.

Regarding the environmental-ecological enablers and barriers, governance and planning policies encompass Nationally Determined Contributions, climate and nature protection action plans, and emission reduction targets. These measures incorporate natural resource conservation into energy projects, mitigating potential ecological harm and promoting responsible energy use. Economic measures include funding and grants, emission taxes, minimum GHG emission prices, and invest in reducing emissions and environmental impact. Regulatory policies like limits on emissions and wildlife impact assessments recognize the environmental impacts of emissions from fossil-fueled power plants and mandate assessments for projects. Also, renewable energy and biodiversity education programs may address the enabler of minimal environmental impact by educating the public on how renewables support biodiversity.

To promote technological innovation, governance and planning measures include national green energy missions and renewable portfolio standards. These encourage research and development, deployment of renewable energy technologies, and set specific requirements for renewable energy. Economically, there is funding for innovation in renewable technologies, subsidies, and tax credits for advanced renewable tech adoption. Market mechanisms support advanced renewable technologies and assist in overcoming high initial costs. Regulatory actions, such as performance standards and control mechanisms, implement efficiency measures and enhance technological performance. Professional training for renewable technology experts could reduce the barrier of skill shortages by building a skilled workforce.

Policies addressing economic enablers and barriers are also multifaceted. Governance and Planning policies, such as recovery and resilience plans, focus on reducing the economic burden of energy waste and integrating renewables into broader development strategies. Concurrently, economic measures encompass tax incentives, auctions, loans, and levies that encourage investments, reduce upfront costs, and promote emissions reduction. Regulatory policies streamline permitting processes and mandate greenhouse gas emissions reporting to expedite

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renewable projects and enable precise emissions tracking. Also, educational policies encompass public awareness campaigns and educational programs that educate the public about the benefits of renewables, fostering understanding and acceptance.
Sociocultural enablers and barriers are addressed through governance and planning measures, including the development of community-based battery and renewable energy projects. These measures involve local communities in the planning and decision-making processes for renewable energy projects, fostering public acceptance and mitigating opposition. Economic policies promote diverse community engagement supporting just energy transition. Regulatory actions like public consultations for large-scale projects encourage public involvement. Public awareness campaigns on sociocultural benefits or pilot (renewable) cities/regions could reduce the sociocultural barrier of misinformation by providing accurate information on the social advantages of renewables.
To address institutional enablers and barriers, governance and planning measures could be applied, such as strengthening institutional capacity and the creation of renewable energy offices. These measures invest in governmental agency expertise, enhancing their capacity to implement renewable energy policies and mitigate institutional inefficiency. Economic measures like government support for renewable technology research allocate funds to research and development, overcoming the institutional barrier of limited innovation in the energy sector. Regulatory actions streamline permitting processes, guidelines, and mandatory reporting of GHGs emissions. These measures expedite project development, improve transparency, and promote efficient governance by simplifying renewable energy project permits and providing precise emissions data. Regarding the informational and educational policies, resource assessment and mapping, alongside listing suitable sites for renewables, will enhance the knowledge on resource utilisation.

2.1.6 Energy Bibliography

- Ahmad, A. (2021). Increase in frequency of nuclear power outages due to changing climate. *Nature Energy*, *6*(7), 755–762. https://doi.org/10.1038/s41560-021-00849-y
- Amiryar, M., & Pullen, K. (2017). A Review of Flywheel Energy Storage System Technologies and Their Applications. *Applied Sciences*, *7*(3), 286. https://doi.org/10.3390/app7030286
- Arning, K., Offermann-van Heek, J., Linzenich, A., Kaetelhoen, A., Sternberg, A., Bardow, A., & Ziefle, M. (2019). Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany. *Energy Policy*, *125*, 235–249. https://doi.org/10.1016/J.ENPOL.2018.10.039
- Barra, P. H. A., de Carvalho, W. C., Menezes, T. S., Fernandes, R. A. S., & Coury, D. V. (2021). A review on wind power smoothing using high-power energy storage systems. *Renewable and Sustainable Energy Reviews*, *137*, 110455. https://doi.org/10.1016/j.rser.2020.110455
- Baxter, J., Ho, Y., Rollins, Y., & Maclaren, V. (2016). Attitudes toward waste to energy facilities and impacts on diversion in Ontario, Canada. *Waste Management*, *50*, 75–85. https://doi.org/10.1016/j.wasman.2016.02.017
- Beiter, P., Cooperman, A., Lantz, E., Stehly, T., Shields, M., Wiser, R., Telsnig, T., Kitzing, L., Berkhout, V., & Kikuchi, Y. (2021). Wind power costs driven by innovation and experience with further reductions on the horizon. *WIREs Energy and Environment*, *10*(5). https://doi.org/10.1002/wene.398
- Bindoff, N. L., W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin, S. O'Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, & P. Williamson. (2022). Changing Ocean, Marine Ecosystems, and Dependent Communities. In *The Ocean and Cryosphere in a Changing Climate* (pp. 447–588). Cambridge University Press. https://doi.org/10.1017/9781009157964.007
- Bird, D. K., Haynes, K., van den Honert, R., McAneney, J., & Poortinga, W. (2014). Nuclear power in Australia: A comparative analysis of public opinion regarding climate change and the Fukushima disaster.

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Energy Policy, *65*, 644–653. https://doi.org/10.1016/j.enpol.2013.09.047

- Bistline, J. E. T., & Blanford, G. J. (2021). The role of the power sector in net-zero energy systems. *Energy and Climate Change*, *2*, 100045. https://doi.org/10.1016/j.egycc.2021.100045
- Bistline, J. E. T., & Young, D. T. (2019). Economic drivers of wind and solar penetration in the US. *Environmental Research Letters*, *14*(12), 124001. https://doi.org/10.1088/1748-9326/ab4e2d
- Bogdanov, D., Ram, M., Aghahosseini, A., Gulagi, A., Oyewo, A. S., Child, M., Caldera, U., Sadovskaia, K., Farfan, J., De Souza Noel Simas Barbosa, L., Fasihi, M., Khalili, S., Traber, T., & Breyer, C. (2021). Low-cost renewable electricity as the key driver of the global energy transition towards sustainability. *Energy*, *227*, 120467. https://doi.org/10.1016/j.energy.2021.120467
- Bosch, J., Staffell, I., & Hawkes, A. D. (2017). Temporally-explicit and spatially-resolved global onshore wind energy potentials. *Energy*, *131*, 207–217. https://doi.org/10.1016/j.energy.2017.05.052
- Clark, R.-J., Mehrabadi, A., & Farid, M. (2020). State of the art on salt hydrate thermochemical energy storage systems for use in building applications. *Journal of Energy Storage*, *27*, 101145. https://doi.org/10.1016/j.est.2019.101145
- Clarke, L., Wei, Y.-M., Navarro, A. D. L. V., Garg, A., Hahmann, A. N., Khennas, S., Azevedo, I. M. L., Löschel, A., Singh, A. K., Steg, L., Strbac, G., & Wada, K. (2022). Energy Systems. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.008
- Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy 2017 2:9*, *2*(9), 1–9. https://doi.org/10.1038/nenergy.2017.140
- D’Arcangelo, F. M., Levin, I., Pagani, A., Pisu, M., & Johansson, Å. (2022). *A framework to decarbonise the economy*. OECD Publishing. https://doi.org/https://doi.org/10.1787/4e4d973d-en
- Das, S., Hittinger, E., & Williams, E. (2020). Learning is not enough: Diminishing marginal revenues and increasing abatement costs of wind and solar. *Renewable Energy*, *156*, 634–644. https://doi.org/10.1016/j.renene.2020.03.082
- de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L., & Sugiyama, T. (2022). Strengthening and Implementing the Global Response. In *Global Warming of 1.5°C* (pp. 313–444). Cambridge University Press. https://doi.org/10.1017/9781009157940.006
- de Lucas, M., Ferrer, M., Bechard, M. J., & Muñoz, A. R. (2012). Griffon vulture mortality at wind farms in southern Spain: Distribution of fatalities and active mitigation measures. *Biological Conservation*, *147*(1), 184–189. https://doi.org/10.1016/j.biocon.2011.12.029
- Demski, C., Butler, C., Parkhill, K. A., Spence, A., & Pidgeon, N. F. (2015). Public values for energy system change. *Global Environmental Change*, *34*, 59–69. https://doi.org/10.1016/j.gloenvcha.2015.06.014
- Devine-Wright, P., & Wiersma, B. (2020). Understanding community acceptance of a potential offshore wind energy project in different locations: An island-based analysis of ‘place-technology fit.’ *Energy Policy*, *137*, 111086. https://doi.org/10.1016/j.enpol.2019.111086
- Dhakal, S., Minx, J. C., Toth, F. L., Abdel-Aziz, A., Figueroa Meza, M. J., Hubacek, K., Jonckheere, I. G. C., Kim, Y.-G., Nemet, G. F., Pachauri, S., Tan, X. C., & Wiedmann, T. (2022). Emissions Trends and Drivers. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change*

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2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157926.004

- Dinesh, H., & Pearce, J. M. (2016). The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *54*, 299–308. https://doi.org/10.1016/j.rser.2015.10.024
- Diógenes, J. R. F., Claro, J., Rodrigues, J. C., & Loureiro, M. V. (2020). Barriers to onshore wind energy implementation: A systematic review. *Energy Research & Social Science*, *60*, 101337. https://doi.org/10.1016/j.erss.2019.101337
- Dowd, A.-M., Boughen, N., Ashworth, P., & Carr-Cornish, S. (2011). Geothermal technology in Australia: Investigating social acceptance. *Energy Policy*, *39*(10), 6301–6307. https://doi.org/10.1016/j.enpol.2011.07.029
- Edmondson, D. L., Kern, F., & Rogge, K. S. (2019). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy*, *48*(10), 103555. https://doi.org/10.1016/j.respol.2018.03.010
- Edwards, R. W. J., & Celia, M. A. (2018). Infrastructure to enable deployment of carbon capture, utilization, and storage in the United States. *Proceedings of the National Academy of Sciences*, *115*(38). https://doi.org/10.1073/pnas.1806504115
- Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy Policy*, *34*(14), 1797–1806. https://doi.org/10.1016/j.enpol.2005.01.001
- Fan, Y. Van, Klemeš, J. J., & Ko, C. H. (2021). Bioenergy carbon emissions footprint considering the biogenic carbon and secondary effects. *International Journal of Energy Research*, *45*(1), 283–296. https://doi.org/10.1002/er.5409
- Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M. R., Sharifi, A., Smith, P., & Yamagata, Y. (2014). Betting on negative emissions. *Nature Climate Change*, *4*(10), 850–853. https://doi.org/10.1038/nclimate2392
- Gabrielli, P., Poluzzi, A., Kramer, G. J., Spiers, C., Mazzotti, M., & Gazzani, M. (2020). Seasonal energy storage for zero-emissions multi-energy systems via underground hydrogen storage. *Renewable and Sustainable Energy Reviews*, *121*, 109629. https://doi.org/10.1016/j.rser.2019.109629
- Gibon, T., Hertwich, E. G., Arvesen, A., Singh, B., & Verones, F. (2017). Health benefits, ecological threats of low-carbon electricity. *Environmental Research Letters*, *12*(3), 034023. https://doi.org/10.1088/1748-9326/aa6047
- Gormally, A. M., Pooley, C. G., Whyatt, J. D., & Timmis, R. J. (2014). "They made gunpowder … yes down by the river there, that's your energy source": attitudes towards community renewable energy in Cumbria. *Local Environment*, *19*(8), 915–932. https://doi.org/10.1080/13549839.2013.810206
- Graaf, T. Van de, & Sovacool, B. K. (2020). *Global Energy Politics*. Polity. https://www.wiley.com/en-gb/Global+Energy+Politics-p-9781509530519
- Griffiths, S., Sovacool, B. K., Kim, J., Bazilian, M., & Uratani, J. M. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Research & Social Science*, *80*, 102208. https://doi.org/10.1016/j.erss.2021.102208
- Gupta, K., Nowlin, M. C., Ripberger, J. T., Jenkins-Smith, H. C., & Silva, C. L. (2019). Tracking the nuclear 'mood' in the United States: Introducing a long term measure of public opinion about nuclear energy using aggregate survey data. *Energy Policy*, *133*, 110888. https://doi.org/10.1016/j.enpol.2019.110888
- Haraguchi, M., Siddiqi, A., & Narayanamurti, V. (2019). Stochastic cost-benefit analysis of urban waste-

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to-energy systems. *Journal of Cleaner Production*, *224*, 751–765. https://doi.org/10.1016/j.jclepro.2019.03.099

- Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S., Abbott, A., Ryder, K., Gaines, L., & Anderson, P. (2019). Recycling lithium-ion batteries from electric vehicles. *Nature*, *575*(7781), 75–86. https://doi.org/10.1038/s41586-019-1682-5
- Hayes, D., Moreira, M., Boavida, I., Haslauer, M., Unfer, G., Zeiringer, B., Greimel, F., Auer, S., Ferreira, T., & Schmutz, S. (2019). Life Stage-Specific Hydropeaking Flow Rules. *Sustainability*, *11*(6), 1547. https://doi.org/10.3390/su11061547
- Henry, R. C., Engström, K., Olin, S., Alexander, P., Arneth, A., & Rounsevell, M. D. A. (2018). Food supply and bioenergy production within the global cropland planetary boundary. *PLOS ONE*, *13*(3), e0194695. https://doi.org/10.1371/journal.pone.0194695
- Hepburn, C., Adlen, E., Beddington, J., Carter, E. A., Fuss, S., Mac Dowell, N., Minx, J. C., Smith, P., & Williams, C. K. (2019). The technological and economic prospects for CO2 utilization and removal. *Nature*, *575*(7781), 87–97. https://doi.org/10.1038/s41586-019-1681-6
- Hunt, J. D., Byers, E., Wada, Y., Parkinson, S., Gernaat, D. E. H. J., Langan, S., van Vuuren, D. P., & Riahi, K. (2020). Global resource potential of seasonal pumped hydropower storage for energy and water storage. *Nature Communications*, *11*(1), 947. https://doi.org/10.1038/s41467-020-14555-y
- IEA. (2019). *Renewables 2019*.
- IEA. (2020). *Projected Costs of Generating Electricity 2020*. https://www.iea.org/reports/projected-costs-of-generating-electricity-2020
- IEA. (2021a). *Global Energy Review 2021*.
- IEA. (2021b). *Key World Energy Statistics 2021*. IEA. https://www.iea.org/reports/key-world-energy-statistics-2021
- IEA. (2021c). *Net Zero by 2050*. IEA. https://www.iea.org/reports/net-zero-by-2050
- IRENA. (2022). *Renewable Power Generation Costs in 2021*.
- Jacobson, M. Z., Delucchi, M. A., Cameron, M. A., Coughlin, S. J., Hay, C. A., Manogaran, I. P., Shu, Y., & von Krauland, A.-K. (2019). Impacts of Green New Deal Energy Plans on Grid Stability, Costs, Jobs, Health, and Climate in 143 Countries. *One Earth*, *1*(4), 449–463. https://doi.org/10.1016/j.oneear.2019.12.003
- Jäger-Waldau, A. (2020). The Untapped Area Potential for Photovoltaic Power in the European Union. *Clean Technologies*, *2*(4), 440–446. https://doi.org/10.3390/cleantechnol2040027
- Jones, C. R., Gaede, J., Ganowski, S., & Rowlands, I. H. (2018). Understanding lay-public perceptions of energy storage technologies: Results of a questionnaire conducted in the UK. *Energy Procedia*, *151*, 135–143. https://doi.org/10.1016/j.egypro.2018.09.038
- Kang, J.-N., Wei, Y.-M., Liu, L., Han, R., Chen, H., Li, J., Wang, J.-W., & Yu, B.-Y. (2020). The Prospects of Carbon Capture and Storage in China's Power Sector under the 2 °C Target: A Component-based Learning Curve Approach. *International Journal of Greenhouse Gas Control*, *101*, 103149. https://doi.org/10.1016/j.ijggc.2020.103149
- Kempener, R., & Neumann, F. (2014a). *Tidal Energy Technology Brief*.
- Kempener, R., & Neumann, F. (2014b). *Wave Energy Technology Brief*.
- Khanna, T. M., Baiocchi, G., Callaghan, M., Creutzig, F., Guias, H., Haddaway, N. R., Hirth, L., Javaid, A., Koch, N., Laukemper, S., Löschel, A., Zamora Dominguez, M. del M., & Minx, J. C. (2021). A multi-country

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meta-analysis on the role of behavioural change in reducing energy consumption and CO2 emissions in residential buildings. *Nature Energy*, *6*(9), 925–932. https://doi.org/10.1038/s41560-021-00866-x

- Kougias, I., Aggidis, G., Avellan, F., Deniz, S., Lundin, U., Moro, A., Muntean, S., Novara, D., Pérez-Díaz, J. I., Quaranta, E., Schild, P., & Theodossiou, N. (2019). Analysis of emerging technologies in the hydropower sector. *Renewable and Sustainable Energy Reviews*, *113*, 109257. https://doi.org/10.1016/j.rser.2019.109257
- Kriegler, E., Bertram, C., Kuramochi, T., Jakob, M., Pehl, M., Stevanović, M., Höhne, N., Luderer, G., Minx, J. C., Fekete, H., Hilaire, J., Luna, L., Popp, A., Steckel, J. C., Sterl, S., Yalew, A. W., Dietrich, J. P., & Edenhofer, O. (2018). Short term policies to keep the door open for Paris climate goals. *Environmental Research Letters*, *13*(7), 074022. https://doi.org/10.1088/1748-9326/aac4f1
- Lade, S. J., Steffen, W., de Vries, W., Carpenter, S. R., Donges, J. F., Gerten, D., Hoff, H., Newbold, T., Richardson, K., & Rockström, J. (2019). Human impacts on planetary boundaries amplified by Earth system interactions. *Nature Sustainability*, *3*(2), 119–128. https://doi.org/10.1038/s41893-019-0454-4
- Limberger, J., Boxem, T., Pluymaekers, M., Bruhn, D., Manzella, A., Calcagno, P., Beekman, F., Cloetingh, S., & van Wees, J.-D. (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renewable and Sustainable Energy Reviews*, *82*, 961–975. https://doi.org/10.1016/j.rser.2017.09.084
- Lindberg, O., Arnqvist, J., Munkhammar, J., & Lingfors, D. (2021). Review on power-production modeling of hybrid wind and PV power parks. *Journal of Renewable and Sustainable Energy*, *13*(4), 042702. https://doi.org/10.1063/5.0056201
- Llamosas, C., & Sovacool, B. K. (2021). The future of hydropower? A systematic review of the drivers, benefits and governance dynamics of transboundary dams. *Renewable and Sustainable Energy Reviews*, *137*, 110495. https://doi.org/10.1016/j.rser.2020.110495
- López Prol, J., & Schill, W.-P. (2021). The Economics of Variable Renewable Energy and Electricity Storage. *Annual Review of Resource Economics*, *13*(1), 443–467. https://doi.org/10.1146/annurev-resource-101620-081246
- Löschel, A., Lutz, B. J., & Managi, S. (2019). The impacts of the EU ETS on efficiency and economic performance – An empirical analyses for German manufacturing firms. *Resource and Energy Economics*, *56*, 71–95. https://doi.org/10.1016/j.reseneeco.2018.03.001
- Louwen, A., van Sark, W. G. J. H. M., Faaij, A. P. C., & Schropp, R. E. I. (2016). Re-assessment of net energy production and greenhouse gas emissions avoidance after 40 years of photovoltaics development. *Nature Communications*, *7*(1), 13728. https://doi.org/10.1038/ncomms13728
- Luderer, G., Pehl, M., Arvesen, A., Gibon, T., Bodirsky, B. L., de Boer, H. S., Fricko, O., Hejazi, M., Humpenöder, F., Iyer, G., Mima, S., Mouratiadou, I., Pietzcker, R. C., Popp, A., van den Berg, M., van Vuuren, D., & Hertwich, E. G. (2019). Environmental co-benefits and adverse side-effects of alternative power sector decarbonization strategies. *Nature Communications*, *10*(1), 5229. https://doi.org/10.1038/s41467-019-13067-8
- Luderer, G., Vrontisi, Z., Bertram, C., Edelenbosch, O. Y., Pietzcker, R. C., Rogelj, J., De Boer, H. S., Drouet, L., Emmerling, J., Fricko, O., Fujimori, S., Havlík, P., Iyer, G., Keramidas, K., Kitous, A., Pehl, M., Krey, V., Riahi, K., Saveyn, B., … Kriegler, E. (2018). Residual fossil CO2 emissions in 1.5–2 °C pathways. *Nature Climate Change*, *8*(7), 626–633. https://doi.org/10.1038/s41558-018-0198-6
- Martin-Roberts, E., Scott, V., Flude, S., Johnson, G., Haszeldine, R. S., & Gilfillan, S. (2021). Carbon capture and storage at the end of a lost decade. *One Earth*, *4*(11), 1569–1584. https://doi.org/10.1016/j.oneear.2021.10.002
- Muratori, M., & Mai, T. (2021). The shape of electrified transportation. *Environmental Research Letters*,

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16(1), 011003. https://doi.org/10.1088/1748-9326/abcb38

- Narsilio, G. A., & Aye, L. (2018). *Shallow Geothermal Energy: An Emerging Technology* (pp. 387–411). https://doi.org/10.1007/978-981-10-7326-7_18
- NEA/IAEA. (2021). *Uranium 2020: Resources, Production and Demand*.
- Palle, A. (2021). Bringing geopolitics to energy transition research. *Energy Research & Social Science*, *81*, 102233. https://doi.org/10.1016/j.erss.2021.102233
- Pampel, F. C. (2011). Support for Nuclear Energy in the Context of Climate Change. *Organization & Environment*, *24*(3), 249–268. https://doi.org/10.1177/1086026611422261
- Perlaviciute, G., Steg, L., Contzen, N., Roeser, S., & Huijts, N. (2018). Emotional Responses to Energy Projects: Insights for Responsible Decision Making in a Sustainable Energy Transition. *Sustainability*, *10*(7), 2526. https://doi.org/10.3390/su10072526
- Pietzcker, R. C., Ueckerdt, F., Carrara, S., de Boer, H. S., Després, J., Fujimori, S., Johnson, N., Kitous, A., Scholz, Y., Sullivan, P., & Luderer, G. (2017). System integration of wind and solar power in integrated assessment models: A cross-model evaluation of new approaches. *Energy Economics*, *64*, 583–599. https://doi.org/10.1016/J.ENECO.2016.11.018
- Pimm, A. J., Garvey, S. D., & de Jong, M. (2014). Design and testing of Energy Bags for underwater compressed air energy storage. *Energy*, *66*, 496–508. https://doi.org/10.1016/j.energy.2013.12.010
- IEA. (2023). *Policy database*. Data & Statistics - IEA. https://www.iea.org/policies/about
- Poudineh, R., & Rubino, A. (2017). Business model for cross-border interconnections in the Mediterranean basin. *Energy Policy*, *107*, 96–108. https://doi.org/10.1016/j.enpol.2017.04.027
- Poulsen, A. H., Raaschou-Nielsen, O., Peña, A., Hahmann, A. N., Nordsborg, R. B., Ketzel, M., Brandt, J., & Sørensen, M. (2018a). Long-term exposure to wind turbine noise and redemption of antihypertensive medication: A nationwide cohort study. *Environment International*, *121*, 207–215. https://doi.org/10.1016/j.envint.2018.08.054
- Poulsen, A. H., Raaschou-Nielsen, O., Peña, A., Hahmann, A. N., Nordsborg, R. B., Ketzel, M., Brandt, J., & Sørensen, M. (2018b). Short-term nighttime wind turbine noise and cardiovascular events: A nationwide case-crossover study from Denmark. *Environment International*, *114*, 160–166. https://doi.org/10.1016/j.envint.2018.02.030
- Poulsen, A. H., Raaschou-Nielsen, O., Peña, A., Hahmann, A. N., Nordsborg, R. B., Ketzel, M., Brandt, J., & Sørensen, M. (2019a). Impact of Long-Term Exposure to Wind Turbine Noise on Redemption of Sleep Medication and Antidepressants: A Nationwide Cohort Study. *Environmental Health Perspectives*, *127*(3). https://doi.org/10.1289/EHP3909
- Poulsen, A. H., Raaschou-Nielsen, O., Peña, A., Hahmann, A. N., Nordsborg, R. B., Ketzel, M., Brandt, J., & Sørensen, M. (2019b). Long-Term Exposure to Wind Turbine Noise and Risk for Myocardial Infarction and Stroke: A Nationwide Cohort Study. *Environmental Health Perspectives*, *127*(3). https://doi.org/10.1289/EHP3340
- Prăvălie, R., Patriche, C., & Bandoc, G. (2019). Spatial assessment of solar energy potential at global scale. A geographical approach. *Journal of Cleaner Production*, *209*, 692–721. https://doi.org/10.1016/j.jclepro.2018.10.239
- Premalatha, M., Tabassum-Abbasi, Abbasi, T., & Abbasi, S. A. (2014). A critical view on the eco-friendliness of small hydroelectric installations. *Science of The Total Environment*, *481*, 638–643. https://doi.org/10.1016/j.scitotenv.2013.11.047
- Rand, J., & Hoen, B. (2017). Thirty years of North American wind energy acceptance research: What

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have we learned? *Energy Research & Social Science*, *29*, 135–148. https://doi.org/10.1016/j.erss.2017.05.019

- Riahi, K., Schaeffer, R., Arango, J., Calvin, K., Guivarch, C., Hasegawa, T., Jiang, K., Kriegler, E., Matthews, R., Peters, G. P., Rao, A., Robertson, S., Sebbit, A. M., Steinberger, J., Tavoni, M., & Van Vuuren, D. P. (2022). Mitigation pathways compatible with long-term goals. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.005
- Rogelj, J., Luderer, G., Pietzcker, R. C., Kriegler, E., Schaeffer, M., Krey, V., & Riahi, K. (2015). Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nature Climate Change*, *5*(6), 519–527. https://doi.org/10.1038/nclimate2572
- Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., L. Mundaca, R. Séférian, & M.V.Vilariño. (2022). Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In *Global Warming of 1.5°C* (pp. 93–174). Cambridge University Press. https://doi.org/doi.org/10.1017/9781009157940.004
- Safarzyńska, K., & van den Bergh, J. C. J. M. (2017). Financial stability at risk due to investing rapidly in renewable energy. *Energy Policy*, *108*, 12–20. https://doi.org/10.1016/j.enpol.2017.05.042
- Schlachtberger, D. P., Brown, T., Schramm, S., & Greiner, M. (2017). The benefits of cooperation in a highly renewable European electricity network. *Energy*, *134*, 469–481. https://doi.org/10.1016/j.energy.2017.06.004
- Selosse, S., & Ricci, O. (2017). Carbon capture and storage: Lessons from a storage potential and localization analysis. *Applied Energy*, *188*, 32–44. https://doi.org/10.1016/j.apenergy.2016.11.117
- Somanathan, E. et al. (2015). National and Sub-national Policies and Institutions. In *Climate Change 2014: Mitigation of Climate Change* (pp. 1141–1206). Cambridge University Press. https://doi.org/10.1017/CBO9781107415416.021
- Steg, L. (2018). Limiting climate change requires research on climate action. *Nature Climate Change*, *8*(9), 759–761. https://doi.org/10.1038/s41558-018-0269-8
- Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). Public perception of carbon capture and storage: A state-of-the-art overview. *Heliyon*, *5*(12), e02845. https://doi.org/10.1016/j.heliyon.2019.e02845
- Terwilliger, J. (2021). Global energy politics. *Environmental Politics*, *30*(3), 488–490. https://doi.org/10.1080/09644016.2020.1865727
- United Nations Environment Programme. (2022). *Emissions Gap Report 2022: The Closing Window*.
- Vakulchuk, R., Overland, I., & Scholten, D. (2020). Renewable energy and geopolitics: A review. *Renewable and Sustainable Energy Reviews*, *122*, 109547. https://doi.org/10.1016/j.rser.2019.109547
- van de Ven, D.-J., Mittal, S., Gambhir, A., Lamboll, R. D., Doukas, H., Giarola, S., Hawkes, A., Koasidis, K., Köberle, A. C., McJeon, H., Perdana, S., Peters, G. P., Rogelj, J., Sognnaes, I., Vielle, M., & Nikas, A. (2023). A multimodel analysis of post-Glasgow climate targets and feasibility challenges. *Nature Climate Change*, *13*(6), 570–578. https://doi.org/10.1038/s41558-023-01661-0
- Vandyck, T., Keramidas, K., Saveyn, B., Kitous, A., & Vrontisi, Z. (2016). A global stocktake of the Paris pledges: Implications for energy systems and economy. *Global Environmental Change*, *41*, 46–63. https://doi.org/10.1016/j.gloenvcha.2016.08.006
- Vasseur, V., & Kemp, R. (2015). The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renewable and Sustainable Energy Reviews*, *41*, 483–494.

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https://doi.org/10.1016/j.rser.2014.08.020

- Victoria, M., Haegel, N., Peters, I. M., Sinton, R., Jäger-Waldau, A., del Cañizo, C., Breyer, C., Stocks, M., Blakers, A., Kaizuka, I., Komoto, K., & Smets, A. (2021). Solar photovoltaics is ready to power a sustainable future. *Joule*, *5*(5), 1041–1056. https://doi.org/10.1016/j.joule.2021.03.005
- Wei, Y.-M., Han, R., Wang, C., Yu, B., Liang, Q.-M., Yuan, X.-C., Chang, J., Zhao, Q., Liao, H., Tang, B., Yan, J., Cheng, L., & Yang, Z. (2020). Self-preservation strategy for approaching global warming targets in the post-Paris Agreement era. *Nature Communications*, *11*(1), 1624. https://doi.org/10.1038/s41467-020-15453-z
- Whitmarsh, L., Seyfang, G., & O'Neill, S. (2011). Public engagement with carbon and climate change: To what extent is the public 'carbon capable'? *Global Environmental Change*, *21*(1), 56–65. https://doi.org/10.1016/j.gloenvcha.2010.07.011
- Wienchol, P., Szlęk, A., & Ditaranto, M. (2020). Waste-to-energy technology integrated with carbon capture – Challenges and opportunities. *Energy*, *198*, 117352. https://doi.org/10.1016/j.energy.2020.117352
- Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2015). A global boom in hydropower dam construction. *Aquatic Sciences*, *77*(1), 161–170. https://doi.org/10.1007/s00027-014-0377-0

2.2 Industry

2.2.1 Introduction

The industrial sector is a primary contributor to global GHG and CO_2 emissions; it encompasses activities such as mining ores and minerals, manufacturing, construction, and waste management. Emissions originate from various sources within the sector, including direct and indirect emissions from fuel combustion, emissions from industrial processes, emissions resulting from the use of industrial products, and emissions from waste management (IPCC, 2022a). Industrial GHG emissions are attributable to a small number of high-emitting industries; in particular steel (8.3%), cement (6.4%), and basic chemicals (4%) contribute disproportionately to global CO_2 emissions (Bataille et al., 2021, figures for 2016). For this reason, this paper focuses on energy-intensive industries due to their high emissions in order to emphasise the importance of these sectors in the context of climate change. However, although this paper only focuses on primary industries, other sectors are also relevant in the context of climate change.

Since the year 2000, industrial emissions have been increasing at a faster rate compared to emissions from other sectors. This growth is primarily driven by the extraction and production of basic materials resulting from economic growth, rising affluence, and consumption, as well as a rapid rise in urban populations and associated infrastructure development. In 2019, the industrial sector accounted for 14.1 gigatons of CO_2-equivalent emissions or 24% of all direct human-caused GHG emissions. This places the industrial sector as the second-largest emitter globally, behind the energy transformation sector. However, when considering indirect emissions from power and heat generation, the industrial sector becomes a leading emitter, contributing 20 Gt of CO_2-equivalent or 34% of global GHG emissions in 2019. In terms of direct industrial emissions, fuel combustion accounted for 7 Gt of CO_2-equivalent emissions in 2019, representing 50% of the total direct industrial emissions (IPCC, 2022a).

Meeting the climate mitigation targets of the Paris Agreement and the Sustainable Development Goals requires a fundamental transformation of existing industrial systems. Scenario analyses used by the IPCC indicate that substantial reductions in global GHG emissions, including reaching near-net-zero emissions, are possible in GHG-intensive industries such as steel, plastics, ammonia, and cement by 2050. Achieving these emission cuts requires the implementation of a range of available and emerging options. To significantly reduce emissions in the industry sector, there needs to be a shift in focus from incremental improvements, such as energy efficiency, to

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transformative changes in energy and feedstock sourcing, materials efficiency, and promoting circular material flows (IPCC, 2022a).

2.2.2 Main mitigation strategies in the industry: What changes/ transformations are needed in what timelines to achieve net-zero by mid-century?

Energy efficiency has long been recognized as the first mitigation option in industry, with a critical role in previous decades. It is a key strategy for limiting global warming to 1.5°C, especially regarding the potential for heat use efficiency improvement and development of smart systems. Other important conventional approaches such as fuel switching to low-emission fuels, electrification, green hydrogen uptake, and power sector decarbonisation are also of high importance. But to achieve zero emissions in energy intensive industries, which is the focus of this paper, additional measures, including managing and improving material end-use demand, promoting efficiency in circular economy practices, utilising fossil-free feedstocks, implementing carbon capture and utilisation (CCU), and adopting carbon capture and storage (CCS), are crucial (IPCC, 2022a).

By reducing materials demand, improving material efficiency, and adopting circular economy solutions, industry can decrease the reliance on primary production. Besides, new processes utilizing low to zero GHG energy carriers and feedstocks such as electricity, hydrogen, biofuels, and CCU for carbon feedstock, as well as CCS for remaining CO_2, need to be implemented. However, the successful implementation of these options requires extensive scaling up of infrastructure for electricity, hydrogen, recycling, CO_2, and others, as well as the phase-out or conversion of existing industrial plants. Although the improvement in GHG intensities of major basic materials has slowed down in the past three decades, historical technology shifts and newly available technologies suggest that these intensities can be reduced to net zero emissions by the middle of the century (IPCC, 2022a).

In this regard, electrification is gaining prominence as a crucial method for mitigating emissions in the industry sector. Electricity, as a flexible energy carrier, can be generated from renewable sources, though its availability, costs, potentials, and preferences vary by region. Utilizing electricity directly or indirectly through hydrogen produced via electrolysis presents numerous opportunities for emissions reduction. This approach can address high-temperature needs (e.g., for DRI in steel making) and serve as a chemical feedstock while offering grid balancing benefits, such as utilising electrolysis and long-duration energy storage for chemical processes or demand response purposes (IPCC, 2022a). Industrial use of hydrogen is currently focused on oil refining, ammonia, methanol, and steel production (IEA, 2019), with H_2 produced mainly from natural gas and coal. Decarbonising hydrogen production is thus one of the primary ways to reduce the carbon intensity of H_2-dependent industrial processes (Griffiths et al, 2021).

Carbon also plays a crucial role as a fundamental component in organic chemicals, fuels, and materials, and its significance will persist. To achieve net zero CO_2 emissions, considering carbon requirements in various sectors such as plastics, wood, aviation fuels, solvents, and more, it is essential to establish closed-loop systems for carbon and carbon dioxide utilisation. This can be achieved through increased circularity, employing mechanical and chemical recycling methods. Additionally, optimising the utilisation of biomass feedstock, coupled with low GHG hydrogen, can enhance product yields, for instance, in the production of biomethane and methanol. Another currently discussed potential approach involves capturing CO_2 directly from the air to serve as a novel carbon source (IPCC, 2022a).

The following chapters provide (1) a general overview of the main climate change mitigation options, technical measures and relevant actors (chapter 2.1) and (2) explore the enormous potential of the different industrial sectors and examine their various options and unique opportunities to make a significant contribution to climate change mitigation (chapter 2.2 – 2.7). This approach was chosen because the technical options vary greatly depending on the industry sector.

2.2.2.1 Overview of mitigation strategies and actors

The following table provides a general overview of the necessary technical measures and the actors that would

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need to take action. The table is based on the IPCC mitigation options as mentioned in the next figure.

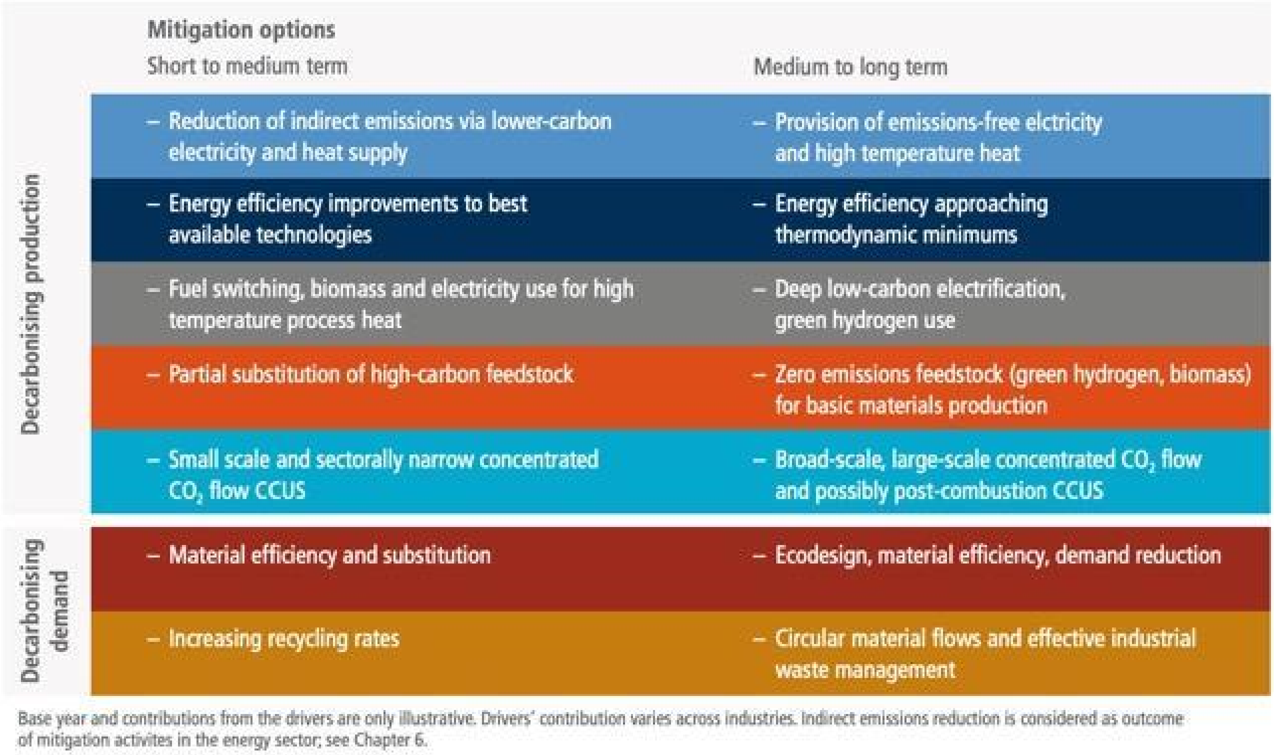

Figure 7: Stylised composition and contribution from different drivers to the transition of industry to net zero emissions (IPCC, 2022a).

Table 4: Mitigation strategies and related technical measures and actors in the industry-sector

Mitigation strategies	Technical measures	Actors
S1: Reduction of emissions via low-carbon electricity and heat supply	• Install renewable energy systems and use climate friendly energy sources • Energy efficiency improvements • Combined Heat and Power (CHP) Systems • Carbon Capture and Storage	• Industry owners and operators • Regulatory bodies • Energy Utilities • Research and development actors • Technology providers
S2: Energy efficiency improvements to best available technologies	• Energy audit • Waste Heat Recovery • Process optimisation • Employee training	• Industry owners and operators • Regulatory bodies • Energy Service Companies • Technology Providers • Financial institutions

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		• Research and development actors
S3: Fuel switching, biomass, hydrogen and electrification	• Fuel switching to low-carbon and renewable energy sources • Biomass utilisation • Electrification options, especially when renewable energy is available • Combined Heat and Power Systems	• Industry owners and operators • Regulatory bodies • Renewable Energy Supplier • Technology Providers • Consultants
S4: Zero emission feedstock (green hydrogen, biomass) for basic material production	• Green hydrogen production • Biomass as feedstock • Carbon Capture and Utilisation (CCU) • Supply Chain optimisation • Technology integration	• Industry owners and operators • Green hydrogen producers • Biomass suppliers and producers • Carbon Capture Technology Providers • Regulatory Bodies • Environmental NGOs • Certification bodies
S5: Carbon Management	• Utilisation of waste CO2 • Direct Air Capture • CO2 transportation • Storage and utilisation technologies • Monitoring and verification	• Industry owners and operators • CCUS technology providers • CO2 transport infrastructure developers • Regulatory bodies • Research and development actors • Environmental NGOs, Public awareness groups
S6: Eco-design, material efficiency, demand reduction	• Eco-design principles, minimum energy performance standards • Material efficiency technologies • Circular Economy Practices (recycling, reuse)	• Industry owner and operator • Designers • Engineers • Recycling and waste management actors

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	• Digital Product Passport • Product durability, repairability, longevity • Business models such as Product as a Service	• Regulatory bodies • Consumer • Research and development actors
S7: Circular material flows and waste management	• Closed-Loop Material Systems • Recycling Technologies • Waste Heat • Smart Waste Management Systems • Supply Chain practices	• Industry owner and operator • Waste management companies • Technology providers • Regulatory bodies • Research and development actors • NGOs

2.2.2.2 Iron and Steel Industry

The iron and steel industry is currently the largest coal consumer and the most carbon intensive industry (Kim et al. 2022). To achieve very low to zero emissions in the iron and steel industry, several technological options are available, but their adoption relies on the implementation of comprehensive policies that integrate material efficiency, recycling, and production decarbonisation. Material efficiency measures, such as process design for reduced steel usage, long product life cycles, reusability, and low-contamination recycling, have the potential to decrease steel demand by up to 40%. While steel production can be divided into primary production based on iron ore and secondary production based on steel scrap, secondary steel-making is more efficient than ore-based production. Then, it is crucial to maximise secondary production through high-quality recycling methods. Additionally, production decarbonisation is essential, starting with retrofitting existing facilities for partial fuel switching to biomass or hydrogen, CCU, and CCS. Subsequently, achieving very low and zero emissions in steel production can be accomplished through high-capture CCS or direct hydrogen utilisation, resource efficiency and material substitution, process integration and optimisation by e.g., utilising electrolytic iron ore reduction followed by an electric arc furnace (IPCC, 2022a), and can also contribute to reducing indirect emissions in other industries (automobile, shipbuilding, etc.).

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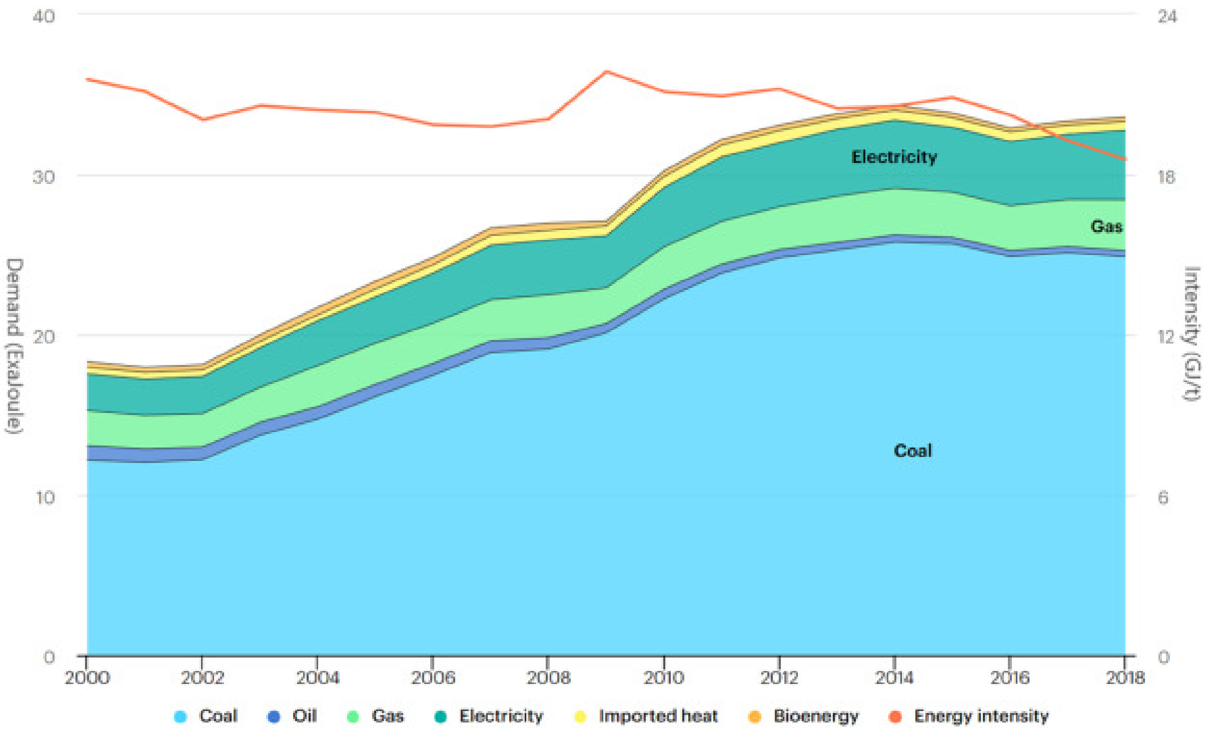

Figure 8: Energy demand and intensity of the global iron and steel industry (2000–2018) (Kim, J., et. al., 2022)

2.2.2.3 Cement and Concrete Industry

Concrete materials are the most consumed material in the world by mass – second only to water. In 2019, production, transport, use, and demolition of cement and concrete accounted for roughly 9–10% of global energy-related CO_2 emissions (Griffiths et al, 2023). The concrete and cement industry (CCI) is unique in that a significant fraction of total emissions occur from the chemical reactions during the making of cement rather than from fossil fuel energy sources. Considering the direct role of the CCI in economic growth, e.g. with regard to the infrastructure needs especially in emerging countries, reducing its emissions while meeting demand will be very challenging. There are however multiple existing and upcoming options that could significantly reduce emissions in CCI; implementing basic material efficiency measures, such as using well-made concrete thoughtfully and only where necessary (e.g., employing appropriately sized prefabricated components), can lead to emissions reductions of 24-50% by decreasing the demand for clinker (IPCC, 2022a). Another effective strategy is substituting cementitious materials with alternatives like ground limestone and calcined clays, which can lower process calcination emissions by up to 50% or more in certain cases. Coupling the cement and concrete value chain with other industries for waste stream utilisation is also important. However, until a viable, very low GHG emissions alternative binder to Portland cement is commercially viable, CCS will be essential for eliminating emissions from the limestone calcination process involved in clinker production and energy use. CCS technology is a potentially important element of an ambitious mitigation strategy in the cement sector, according to the IPCC WGIII report. Currently, these emissions account for approximately 60% of GHG emissions in the best available technology plants within the industry (IPCC, 2022a). Negative emission technologies (BECCS, CCUS, etc.) would require further development and demonstration, feasibility studies (Kusuma et al. 2022), as well as policy support in order to be widely adopted in the CCI.

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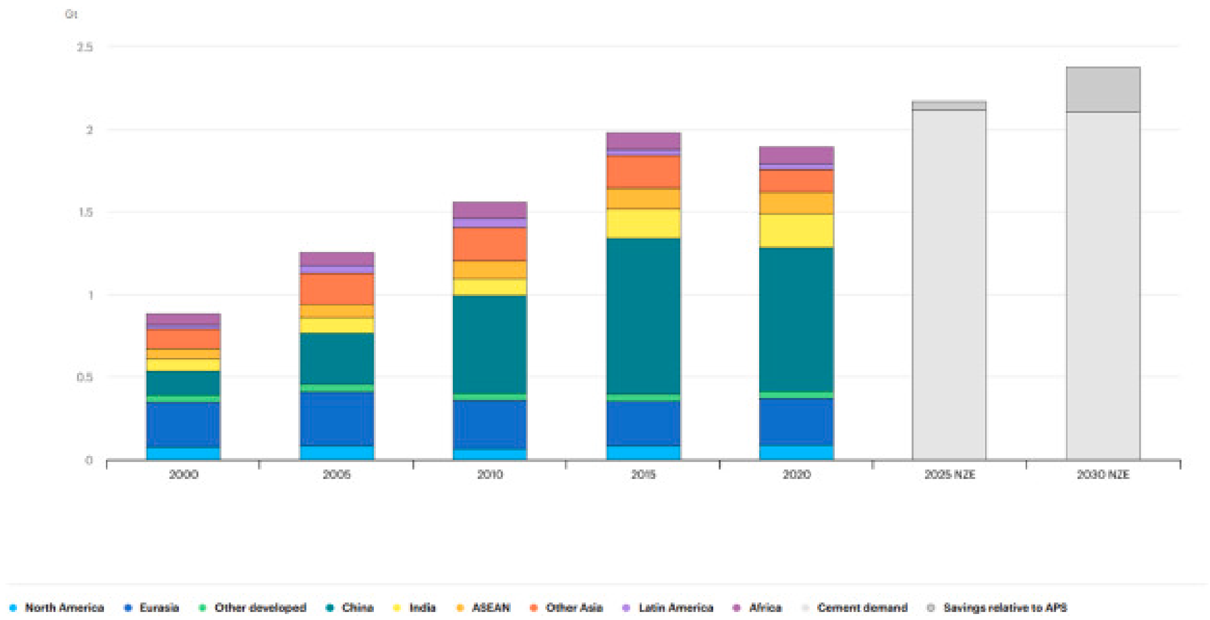

Figure 9: Global cement demand for building construction 2010–2020 (colored bars), and 2025–2030 forecast in the IEA Net Zero Emissions (NZE) scenario (light grey) and difference from business-as-usual values in the Announced Pledges Scenario (APS), in dark grey (Griffith et al, 2023).

2.2.2.4 Chemical Industry

Chemicals production entails considerable energy inputs and carbon-intensive materials. In the EU, the largest exporter of chemical products (Eurostat, 2023), the total energy consumption of the chemical industry in 2019 was 50.8 Mt. of oil equivalent (Chung et al, 2023). Multiple technological options exist for decarbonising industrial feedstock chemicals and their derivatives, chemical products making and usage. However, the costs of these options can vary significantly. In addition to the need for feedstock, the production of primary chemicals also requires heat and steam, both of which are currently almost exclusively provided by fossil fuels but could be replaced by bioenergy, hydrogen, or low- or zero-carbon electricity, for instance, by using electric boilers or high-temperature heat pumps. The chemical industry has one of the most considerable potentials for electrifying industrial energy demands with existing technologies, raising the prospect of a rapid decrease in emissions related to energy use (Madeddu et al. 2020). Further options are energy efficiency, renewable energies in the chemical industry, heat management technologies, process optimisation, circular economy etc. (Chung et al. 2023). Currently, fossil fuel-based feedstocks are economically advantageous due to low carbon prices, while biomass and electricity-based substitutes are expected to be more expensive. The chemical industry plays a major role in consuming various fossil-based chemicals like hydrogen, ammonia, toluene, and mixed xylenes and aromatics from fossil feedstock, which are utilised to manufacture a wide range of derivative end-use chemicals. To effectively reduce emissions, alternative feedstocks such as hydrogen, biogenic or air-captured carbon, collected plastic waste/ other recycling options and demand-reduction strategies can be employed. However, the availability of biogenic carbon feedstock may be limited due to competing land uses (IPCC, 2022a).

2.2.2.5 Light Industry and Manufacturing

Light industry and manufacturing entail a wide range of industrial sub-sectors like food processing, textile, consumer goods, vehicles and machinery. These industries have a lower energy demand compared to the heavy industries and have the potential for significant decarbonisation by transitioning to low GHG fuels, such as biofuels and hydrogen, as well as utilising electricity for electrothermal heating and heat pumps. Many of these technologies are already well-developed, especially for low-temperature heat applications and a lot of progress has been made over the past decade, for example with low-emission heating technologies as well as energy efficiency measures (IEA 2023). However, a major hurdle lies in the current affordability of fossil methane and coal compared to low or zero GHG alternatives like electricity, hydrogen, and biofuels. This cost disparity poses a

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significant challenge to the widespread adoption of these cleaner technologies in the industry (IPCC, 2022a).

2.2.2.6 Pulp and Paper Industry

The pulp and paper industry is among the top five most energy-intensive industries globally, the fourth largest industrial energy user (Furszyfer Del Rio et al. 2022), and the largest user of original or virgin wood. The pulp and paper industry predominantly generates biogenic carbon emissions and has relatively minor direct fossil carbon emissions – it is therefore not considered a hard-to-abate industry sector (Svensson et al. 2021). Pulp mills have the advantage of utilising biomass residues and by-products, while paper mills can leverage low to medium temperature process heat for electrification. However, if wood is increasingly used as a substitute for building materials and feedstock in the petrochemical industry, competition for feedstock resources may intensify. It is still discussed how the forestry industry can contribute to the decarbonisation of these sectors and how this is related to the mitigation potential in the pulp and paper industry. Moreover, the pulp and paper industry can contribute to the production of biogenic carbon dioxide and serve as a potential source of carbon for organic chemicals feedstock. Additionally, carbon dioxide removal (CDR) through CCS can be employed within the industry to mitigate emissions (IPCC, 2022a); the industry even has the potential to contribute to negative emissions through CCS applied to existing processes (Svensson et al. 2021).

2.2.2.7 Aluminum and other non-ferrous metals

Aluminum, copper and other non-ferrous metals are important inputs to several technologies critical for the energy transition; the demand for aluminum alone is expected to grow by more than 50% by 2050 (WEF 2020); the International Aluminium Institute (IAI) even predicts a growth of more than 80% by 2050 (IAI 2021). Currently the aluminum sector alone accounts for about 2% of global human-caused CO2 emissions per year (WEF 2020). At the same time aluminium is well known for its nearly infinite recyclability; this attribute not only makes it ideal to reduce waste generally, a building block of the circular economy approach, but is also an opportunity to reduce emissions in its own sector (WEF 2021). The potential here is huge: over 90% of current aluminium emissions are associated with primary production whereas secondary, or recycled, aluminium uses just 5% of the energy required for primary production (WEF 2021).

2.2.3 Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction

The deep decarbonisation of energy-intensive industries, which is the focus of this paper, faces economic, political, and structural barriers and challenges (IPCC, 2022a; IEA, 2022a; Löfgren & Rootzén, 2021). These challenges particular to energy-intensive industries encompass factors such as dependence on fossil fuels for energy and feedstock, limited accessibility to deep decarbonisation technologies in the market, as well as prolonged asset lifetimes and substantial capital investments (IEA, 2022b). Furthermore, another challenge is fear of declines in competitiveness and industrial relocation to unregulated countries (carbon leakage), especially for trade-exposed products and industries. These fears relate not only to competition among industries but there is also an increasing pressure on natural resources and growing competing claims on those – also with regard to the energy transition (e.g. rare earth materials). In addition to challenges, however, there are also numerous enablers that demonstrate the possibilities and opportunities for climate protection measures in the industrial sector. These include financial opportunities, technology transfer and locational advantages.

Table 5: Overview of factors affecting the transformation in the industry sector and industry-related emissions

Dimension	Enablers	Barriers
Geophysical feasibility	The distribution of renewable energy resources across different regions and the corresponding infrastructure has a significant impact on the industrial sector. The availability of zero-emission electricity and affordable hydrogen generated by solar and wind-powered electrolysis, as well as	

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<table>
<tr><td rowspan="2"></td><td colspan="2">low-emission hydrogen from other sources, has the potential to reshape the location of energy- and emissions-intensive basic materials production. This transformation can have an impact on the organisation of value chains, trade structures and the international shipping of goods.</td></tr>
<tr><td>Enablers
Macro
• Regions with abundant solar and wind resources, or those with low fugitive methane in proximity to CCS sites, may emerge as exporters of hydrogen or hydrogen-based carriers like methanol and ammonia
• Those regions may also become hubs for the production of iron, steel, organic platform chemicals, and other energy-intensive basic materials (IPCC, 2022a)
• With the availability and distribution of energy, infrastructure requirements such as hydrogen pipelines, CCS, and power grid are also relevant and can serve as both barriers and enablers for future development</td><td>Barriers
Macro
• Potential barriers are material bottlenecks, limited access to raw materials, geopolitical dynamics and dependencies (Eike, 2022)
• With the availability and distribution of energy, infrastructure requirements such as hydrogen pipelines, CCS, and power grid can also serve as barriers for future development</td></tr>
<tr><td rowspan="2">Environmental-ecological feasibility</td><td colspan="2">The impact on the environment depends heavily on the technological potential in the various sectors and the specific climate protection efforts (see IPCC, 2022a).</td></tr>
<tr><td>Enablers
Macro
• By switching fuels or implementing carbon capture technologies, energy-intensive industries can effectively reduce their emissions, resulting in significant benefits such as improved air and water quality and contributing to the fight against climate change
• Prioritising energy efficiency and reducing energy consumption not only supports local energy security but also enhances overall energy accessibility
Micro
• Emphasising material efficiency improvements and adopting circular economy principles not only reduces material waste but also promotes the development of innovative business models while minimizing environmental pressures and negative impacts on the natural environment (Otto et al., 2023)</td><td>Barriers
Macro
• Large-scale adoption of carbon capture technologies might raise concerns about the long-term environmental impact. Questions about the storage and potential leakage of captured carbon dioxide could pose a barrier
Micro
• Emphasising material efficiency improvements may face challenges related to the scarcity of certain resources. In a circular economy, where materials are reused and recycled, the availability of specific resources becomes crucial. If key resources are scarce, it can pose a barrier to the feasibility of material efficiency improvements</td></tr>
<tr><td rowspan="2">Technological feasibility</td><td colspan="2">The spread of climate-friendly technologies in energy-intensive industries is an essential prerequisite for combating climate change and achieving the sustainability goals.</td></tr>
<tr><td>Enablers
Macro</td><td>Barriers
Macro</td></tr>
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With respect to technologies with long investment cycles and long lifespans, it is essential to quickly invest in climate-friendly solutions
Continued investment in research and development can drive technological advancements and improve the scalability of climate-friendly solutions
Collaborative efforts between industry, academia, and governments can foster innovation and facilitate knowledge transfer
Intensifying digitalisation of industrial processes (Industry 4.0 etc) could also help material tracing, waste management, and better maintenance (European Commission et al. 2022)
Due to expected rising industrial emissions in emerging countries, technology transfer to these countries is crucial (Sovacool et al 2023)

Micro

The maturity and readiness of climate-friendly technologies play a crucial role in their widespread adoption
Industries need access to proven, reliable, and commercially viable solutions that can seamlessly integrate into their existing processes

</td>
<td>

Uncertainties and existing structures that have developed over the years can lead to carbon lock-in effects, significantly slowing down the decarbonisation of industry.

Micro

The complexity of implementing new technologies can pose a significant barrier for the industry sector.

</td>
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<tr>
<td rowspan="2">Economic feasibility</td>
<td colspan="2">The production costs associated with manufacturing basic materials with very low to zero emissions may be high, but the costs for end consumers and the overall economy are likely to be relatively limited. The potential for cost reductions and emissions mitigation in the industry, especially in heavy industry, depends heavily on innovation, commercialisation, and policies that promote market acceptance (Lead markets for climate-friendly products/ Green Lead Markets).</td>
</tr>
<tr>
<td>
Enablers
Macro

An infrastructure boom in developing nations may lead to an increase in emissions, particularly in steel and cement production. Financing is a key issue, while the boom could also enable the development and use of new technologies

Micro

Implementation of targeted industrial decarbonisation policies that provide economic incentives, subsidies, or support mechanisms for businesses to invest in and adopt climate-

</td>
<td>
Barriers
Macro

Technologies capable of achieving very low or zero emissions across all industry sectors exist, but their widespread implementation requires five to 15 years of focused innovation, commercialisation, and policy support to ensure uptake
Industry is a capital-intensive sector with prolonged investment cycles and limited profit margins, which provide significant transition challenges
The adoption of the technological solution relies on the presence of ample

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<td>friendly technologies. These policies can address the economic feasibility challenges associated with capital-intensive industries and prolonged investment cycles, encouraging businesses to transition toward sustainable practices
While production cost increases can be significant, the impact on the final product's cost is generally minimal, typically amounting to a few percent or less, depending on the specific product, assumptions, and system boundaries (IPCC, 2022a). Important to consider is also the fair allocation of mitigation costs (Pachauri et a. 2022)</td>
<td>and affordable supplies of zero-emission electricity, green hydrogen, alternative feedstocks, or infrastructure for CO_2 transportation and storage. However, these resources are currently limited and come at a high cost (Otto et al., 2023)
The estimated mitigation costs fall within a range of approximately USD 50-150 per ton of CO_2-equivalent, although there is considerable variation within and outside this range. Such costs affect competitiveness and necessitate supportive policies
Micro
In the absence of supportive policies, businesses may face challenges in justifying the economic feasibility of transitioning to climate-friendly technologies, hindering their ability to make sustainable investments</td>
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<tr>
<td rowspan="2">Sociocultural feasibility</td>
<td colspan="2">Recognising the importance of sociocultural feasibility in shaping industry policy, there are several drivers and barriers. Just Transition policies play a critical role in ensuring a fair distribution of benefits during the transition to low carbon economies. The profound transformation of industry not only entails changes in the skills required, but also risks the disappearance of certain job profiles due to the restructuring or reduced activity of industries.</td>
</tr>
<tr>
<td>Enablers

Macro
In several industrialised countries, private sector support and action for industrial decarbonisation are emerging as key enablers (Otto et al., 2023)
Just Transition policies play an important role, to ensure equity is better accounted for in low carbon transitions (IPCC, 2022b)
As industry is a major job-creating sector, the industry transition will inevitably have an impact on employment. There will be skill changes and demand for higher skilled jobs (Vandeplas et al., 2022). In the meantime, certain jobs could disappear due to the industry's reduced or restructured activity
Micro
Implementing targeted worker training and engagement programmes can support industry decarbonisation measures</td>
<td>Barriers

Macro
Public opinion and societal resistance to policy changes aimed at decarbonisation could hinder the development and implementation of effective policies. Political and public resistance may arise if there is a perceived threat to existing industries, employment, or local economies, impacting the sociocultural feasibility of large-scale policy initiatives
Micro
Employees within industries undergoing decarbonisation may experience challenges in adapting to new technologies, work processes, and skill requirements. Sociocultural resistance to change or lack of awareness and acceptance could hinder the successful implementation of policies
Local communities surrounding industrial facilities may have concerns about changes in the industry's activities, potential job losses, or disruptions to their way of life. A lack of community engagement, communication, or acceptance of the</td>
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<td>• Ensuring active community participation and transparent communication strategies</td>
<td>decarbonisation efforts could pose a barrier to the successful implementation of policies</td>
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<tr>
<td rowspan="2">Institutional feasibility</td>
<td colspan="2">A regulatory framework can also be an opportunity for energy-intensive industries. Political measures such as the promotion of research and development, regulation, financial incentives, or public procurement can act as enablers to strongly support the decarbonisation of the industry. In general, the economic and regulatory framework condititions should be designed in such a way that investment and location decisions are encouraged in favor of low-emission, innovative technologies and process solutions. In this respect, public support and acceptance of climate action plays a crucial role in driving policy change, including the decarbonisation of energy-intensive industries (e.g. in relation to CCS/CCU, pipelines, grid extension). However, in some countries, climate change concerns are often not taken into account in policy debates, which hinders progress.</td>
</tr>
<tr>
<td>Enablers
Macro
• International collaboration, standardisation, shared best practices and coordinated efforts on a global scale can enhance the effectiveness and feasibility of institutional measures for industrial decarbonisation. Collaborating on research and development

Micro
• Implementing a circular economy and measures addressing material demand and efficiency can be implemented if awareness raising campaigns, encouraging engagement of stakeholders, and extensive training and education
• Implementing streamlined permitting processes and clear rules can facilitate the swift deployment of new technologies in energy-intensive industries</td>
<td>Barriers
Macro
• An insufficient capacity of the public sector can hinder the progress of decarbonisation efforts.
• Political instability and widespread corruption further undermine the public sector's ability to address climate change and create an unfavorable investment climate
• Discrepancy between the globalised nature and the international climate policy framework: While the Paris Agreement emphasises national responsibility for climate action, most energy-intensive industries are dominated by large multinational conglomerates operating in several countries. This situation limits the effectiveness of national policy measures and increases the risk of carbon leakage to countries with less stringent climate regulations
• Institutional and regulatory barriers, including permitting procedures and complex rules, impede the swift deployment of new technologies in energy-intensive industries, particularly in industrialised countries like the EU. These barriers hinder the progress of decarbonisation and pose additional challenges to achieving sustainability goals (Otto et al., 2023)

Micro
• Vested interests and industrial lobbying against stringent decarbonisation policies pose significant barriers to domestic efforts. These concerns extend beyond industrial lobbying to broader</td>
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		discussions on the potential negative impacts of industrial decarbonisation, such as the relocation of industries and subsequent socio-economic consequences

2.2.4 Policies and measures: What policies are needed to achieve net-zero by mid-century?

The level of policy maturity and technological readiness varies greatly among different mitigation options. Energy efficiency has been extensively addressed through various policies such as voluntary and negotiated agreements, regulations, energy auditing, and demand side-management (DSM) programmes, accumulating decades of experience. On the other hand, policies regarding materials demand management and efficiency are not well-developed and lack sufficient understanding. Barriers to recycling, which could be addressed through policy interventions, are often specific to different material loops, such as copper contamination for steel or the lack of technologies and unfavorable economics for plastics. Regarding electrification and fuel switching, the emphasis has predominantly been on innovation and the development of technical supply-side solutions, rather than stimulating market demand.

The following table presents the main policy instruments that are suitable for promoting the transformation of the industry and also describes how these instruments can address existing barriers. In this regard it is crucial to consider the policy instruments as a policy package, meaning that the individual measures should be combined, and synergistic effects should be leveraged.

Table 6: Policy instruments and how they can address existing barriers

Typology of policy instruments	Potential Policy Options and Instruments and how they can address each barrier
Governance and Planning Instruments	• Long-term planning and target setting: Developing comprehensive decarbonisation plans and setting ambitious emission reduction targets can provide planning security • Policy roadmaps: (Sector-specific) roadmaps outlining clear visions, steps and strategies for decarbonising industries and for reducing risks for investors can also provide planning security and promote transparency in implementation and investment planning • Initiatives and partnerships: Encouraging collaboration between governments, industry stakeholders, research institutions, and civil society organisations can increase stakeholder participation and promote benefits for local communities • Public infrastructure planning (hydrogen, CO_2, etc) are preconditions for low carbon technologies, markets and exports • Project aggregation platforms bundle knowledge and strengthens R&D

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	• Strengthened international outreach
Economic instruments	• Carbon pricing and border tariffs: Carbon taxes or cap-and-trade systems to provide economic incentives for reducing emissions and tackle carbon leakage (e.g., EU-Emission Trading System, Carbon Border Adjustment Mechanism (CBAM)). • Subsidies and grants: Providing financial support for industries to address the lack of capital and to invest in cleaner technologies and processes, e.g., carbon contracts for difference (CCfD)[1] (Lead markets for climate-friendly products /Green lead markets) • Tax incentives: Offering tax benefits or credits to industries adopting low-carbon practices or investing in industrial scale renewable energy applications improves access to capital and can lower the prices for low carbon technologies. It increases competitiveness and acceptance of the industry sector • Concessional financing to mitigate risk at the country, sector and project level by providing partial guarantees or subordinated debt or equity; dedicated transition finance to facilitate uptake of cleaner and more efficient technologies (IEA 2023a) • Investment in clean energy supply chains reduces risks and makes supply chains transparent • De-risking of green investments through financial guarantees
Regulation and non-economic instruments	• Standards and regulations: Enforcing strict limits on emissions, energy efficiency standards, material efficiency standards, quota obligations, etc. provide stable and clear regulation on a long-term horizon. • Permits and licenses: Requiring industries to obtain permits or licenses that consider environmental impacts and carbon emissions. This sets clear requirements for all market actors and creates a level playing field. If the regulation was implemented on an international basis, it has also the potential to address the mismatch between globalized nature and international climate policy and national regulations (carbon leakage) • Public (and private) green procurement: Taking greater account of climate protection aspects in public procurement creates a high market volume for

[1] Carbon Contracts for Difference: energy-intensive industries will be compensated by climate protection agreements for a period of several years to cover for their additional costs (OPEX and CAPEX) to convert their production (IEA, 2023b)

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	innovative and climate-friendly products. Market entry and market penetration can be achieved with guaranteed sales (economies of scale) • Extended producer responsibility: Making manufacturers and producers responsible for the entire lifecycle of their products in order to guarantee a transparent supply chain and to implement environmental standards • Strengthen the institutional capacity of emerging economies
Voluntary agreements	• Voluntary emission reduction agreements: Encouraging industries to voluntarily commit to specific emission reduction targets and actions. This increases participation and acceptance • Sector-specific agreements: Collaborative agreements within specific industries to promote and share best practices for decarbonisation. This can address technological barriers, foster innovation and facilitate knowledge transfer (complexity of implementing new technologies, readiness of climate-friendly technologies, uncertainties and existing structures)
Educational/informational/"Soft" instruments	• Research and development policies incl. funding for basic research, pilot and demonstration projects to promote innovations • Education, training and capacity building: Providing education and training programmes to promote awareness and skills for adopting low-carbon technologies and practices • Public awareness campaigns/acceptance: Raising public awareness about the importance of decarbonisation and the role of industries to address the lack of knowledge and information (information and search costs) • Knowledge sharing and transparency: Platforms for sharing knowledge, promotion of collaborations, best practices, and benchmarking among industries can facilitate knowledge transfer • Industry-specific guidance and toolkits: Developing resources, guidelines, and toolkits to assist industries in implementing decarbonisation strategies • Carbon footprint: Measuring and tracking GHG emissions associated with e.g., a product, activity, or organisation. This creates clear standards for the industry that provide a transparent basis for documenting reduction efforts and measuring potentials

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The following figure summarises the main policy instruments and sorts them according to their level of the value chain.

2.2.5 Industry concluding remarks

The industrial sector is a significant contributor to global greenhouse gas emissions, particularly from high-emitting industries such as steel, cement, and basic chemicals. Industrial emissions have been increasing at a faster rate compared to other sectors since 2000, and the sector accounts for a significant portion of global emissions. An important consideration for industry decarbonisation though lies in the heterogeneity of emissions sources in industry processes.

Achieving net-zero emissions in the industrial sector by mid-century requires a fundamental transformation of existing industrial systems, an implementation of a range of available and emerging options beyond incremental improvements in energy efficiency, and particular efforts in the Global South. These options include transformative changes in energy and feedstock sourcing, materials efficiency, circular material flows, and international financial support. Electrification utilising renewable electricity and hydrogen is gaining prominence as a crucial method for emissions mitigation in the industry sector. Additionally, carbon capture and utilisation, as well as carbon capture and storage, are envisaged to play essential roles in reducing residual emissions in heavy industries.

Each industrial sector presents unique opportunities for emissions reduction. For example, in the iron and steel industry, comprehensive policies integrating material efficiency, recycling, and production decarbonisation are needed. In the cement and concrete industry, implementing material efficiency measures and utilising alternative cementitious materials can significantly reduce emissions. The chemical industry can reduce emissions by employing alternative feedstocks such as hydrogen and carbon captured from the air or collected plastic waste.

However, achieving deep decarbonisation in the industrial sector is not without challenges. Economic, political, and structural obstacles pose barriers to the required transformation. Geophysical, environmental, technological, economic, sociocultural, and institutional factors need to be considered and addressed to accelerate the adoption of climate-friendly technologies and practices. To address these barriers, supportive policies and action, including research and development funding, regulation, financial incentives, and public procurement, are crucial for decarbonisation. The regulatory framework should encourage investment and location decisions that favor low-emission, innovative technologies and process solutions. Furthermore, international cooperation is essential to address the global nature of energy-intensive industries and prevent carbon leakage. Achieving successful decarbonisation necessitates additional funding, generation of employment opportunities, facilitation of technology exchange, coordination with sub-national and non-traditional stakeholders, as well as influencing societal attitudes and implementing new methods of global climate governance (Savacool et al. 2023).

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2.2.6 Industry Bibliography

- Agora Energiewende, Wuppertal Institute (2019). Climate-Neutral Industry (Executive Summary): Key Technologies and Policy Options for Steel, Chemicals and Cement. Berlin.
- Chung, C., Kin, j., Sovacool, B., Griffiths, S., Bazilian, M., Yang, M. (2023). Decarbonizing the chemical industry: A systematic review of sociotechnical systems, technological innovations, and policy options. Energy Research & Social Science. Volume 96
- Eike, L., De Blasio, N., (2022). Green hydrogen value chains in the industrial sector - Geopolitical market implications. Energy Research & Social Science. Volume 93, November 2022
- European Commission, Joint Research Centre, Muench, S., Stoermer, E., Jensen, K., et al. (2022). Towards a green & digital future. Key requirements for successfultwin transitions in the European Union, Publications Office of the European Union. https://data.europa.eu/doi/10.2760/977331
- Eurostat (2023). Production and international trade in chemicals. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Production_and_international_trade_in_chemicals. https://doi.org/10.1016/j.erss.2023.102955
- Furszyfer Del Rio, D., Kovacool, B., Griffiths, S., Bazilian, M., Kim, J.,Foley, A.,Rooney, D. (2022). Decarbonising the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options. Renewable and Sustainable Energy Reviews Volume 167 October 2022. https://doi.org/10.1016/j.rser.2022.112706
- Griffiths, S., Sovacool, B., Kim, J., Bazilian, M., Uratani, J. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. Energy Research & Social Science. Volume 80, 2021. https://doi.org/10.1016/j.erss.2021.102208
- Griffiths, S., Sovacool, B., Furszyfer Del Rio, D., Foley, A., Bazilian, M., Kim, J., Uratani, J. (2023). Decarbonizing the cement and concrete industry: A systematic review of socio-technical systems, technological innovations, and policy options. Renewable and Sustainable Energy Reviews. Volume 180, July 2023. https://doi.org/10.1016/j.rser.2023.113291
- IEA. (2019). The Future of Hydrogen. Paris. IEA (2019), The Future of Hydrogen, Paris https://www.iea.org/reports/the-future-of-hydrogen
- IEA. (2022a). Achieving Net Zero Heavy Industry Sectors in G7 Members. https://doi.org/10.1787/f25c9648-en
- IEA. (2022b). Industry (Tracking Industry). IEA. https://www.iea.org/reports/industry
- IEA. (2023). Light Industry. https://www.iea.org/energy-system/industry/light-industry
- IEA. (2023a). Scaling Up Private Finance for Clean Energy in Emerging and Developing Economies
- IEA. (2023b). Carbon Contracts for Difference (CCfD) program for energy-intensive industries. https://www.iea.org/policies/17538-carbon-contracts-for-difference-ccfd-program-for-energy-intensive-industries
- International Aluminium Institute (IAI). (2021). Aluminium Sector Greenhouse Gas Pathways to 2050. https://international-aluminium.org/resource/aluminium-sector-greenhouse-gas-pathways-to-2050-2021/
- IPCC. (2022a). Chapter 11 – Industry. In: Climate Change 2022: Mitigation of Climate Change (pp. 1161-1243). Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter11.pdf
- IPCC. (2022b). Chapter 4 – Mitigation and Development Pathways in the Near to Mid-Term. In: Climate Change 2022: Mitigation of Climate Change (pp. 409-502). Intergovernmental Panel on Climate Change

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(IPCC). https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter04.pdf

- Kim, J., Sovacool, B., Bazilian, M., Griffiths, S., Lee, J., Yang, M., Lee, J. (2022). Decarbonizing the iron and steel industry: A systematic review of sociotechnical systems, technological innovations, and policy options. Energy Research & Social Science Volume 89, July 2022. https://doi.org/10.1016/j.erss.2022.102565
- Kusuma, R., Hiremath, R., Rajesh, P., Kumar, B., Renukappa, S. (2022). Sustainable transition towards biomass-based cement industry: A review. Renwable and Sustainable Energy Reviews. Volume 163 July 2022. https://doi.org/10.1016/j.rser.2022.112503
- Löfgren, Å., & Rootzén, J. (2021). Brick by brick: Governing industry decarbonization in the face of uncertainty and risk. Environmental Innovation and Societal Transitions, 40, 189–202. https://doi.org/10.1016/j.eist.2021.07.002
- Madeddu, S., Ueckedt, F., Pehl, M., Peterseim, J., Lord, M., Kumar, K., Krüger, C., Luderer, G. (2020). The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat). Environmental Research Letters, Volume 15, Number 12. DOI 10.1088/1748-9326/abbd02
- Otto, S.; Oberthür, A.; Tönjes, A.; Peterson, L.; Trollip, H.; Vishwanathan, S. (2023): Are national policy frameworks for the decarbonisation of energy-intensive industries fit for purpose? Lessons from 13 countries. NDC ASPECTS (draft)
- Pachauri, S., Pelz, S., Bertram, C., Kreibiehl, S., Rao, N., Sokona, Y., Riahi, K. (2022). Fairness considerations in global mitigation investments. Current mitigation finance flows are inadequate and unfair. Science Vol 378 Issue 6624 DOI: 10.1126/science.adf0067
- Sovacool, B., Bazilian, M., Kim, J., Griffiths, S. (2023). Six bold steps towards net-zero industry. Energy Research & Social Science. Volume 99 https://doi.org/10.1016/j.erss.2023.103067
- Svensson E, Wiertzema H and Harvey S (2021). Potential for Negative Emissions by Carbon Capture and Storage From a Novel Electric Plasma Calcination Process for Pulp and Paper Mills. Frontiers in Climate. 3:705032. DOI: 10.3389/fclim.2021.705032
- Vandeplas, A., Vayolos, I., Vigani, M., Vogel, L. (2022): The Possible Implications of the Green Transition for the EU Labour Market. European Commission. Discussion Paper 176
- World Economic Forum (WEF). (2020). Why addressing the aluminium industry's carbon footprint is key to climate action. https://www.weforum.org/agenda/2020/11/the-aluminium-industry-s-carbon-footprint-is-higher-than-most-consumers-expect-heres-what-we-must-do-next/
- World Economic Forum (WEF). (2021). The answer to the aluminium industry's emission issue? Aluminium's infinite recyclability. https://www.weforum.org/agenda/2021/12/aluminium-emissions-recycling-circular-economy/

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2.3 Transport

2.3.1 Main mitigation strategies in the transport sector: What changes/transformations are needed in what timelines to achieve net-zero by mid-century?

2.3.1.1 Main mitigation strategies in the transport sector

The IPCC AR6 WGIII report stresses that development pathways taken by countries at all stages of economic development impact GHG emissions and shape mitigation challenges and opportunities (see chapters 3 and 4). This means that development choices and decisions, as well as enabling conditions for action largely determine climate outcomes. Shifting development pathways to increased sustainability seems to be the only possible way to deliver permanent emissions reductions at the scale required, accelerate efforts, and support transformation in the sector. This is precisely one of the main recommendations of the Report, also for efforts to be taken in the near- to medium-term (pp. 418 and 448-450). Mitigation strategies and their success depend on pathways taken and their consequences, but also on narratives of a desired future and the mobilisation of resources to change things through energetic, ambitious, and solution-oriented action.

Achieving net-zero emissions in the transport sector by mid-century requires multifaceted and fundamental transformations. These encompass policy and regulatory measures, technological advancements, infrastructure development, behavioural changes, social equity considerations (Dawkins et al., 2023), and international cooperation. They presuppose strong political will, adequate resources, and concerted efforts from all stakeholders to drive the necessary changes and achieve the emissions reductions within the required timeframe. Moreover, sectoral decarbonisation strategies should be framed within an overall sustainable transport pathway, which requires systematic efforts, coordination, synergy creation, and continuous progress monitoring (Wang-Helmreich et al., 2022). In their recommendations, five essential axes are recognised for their central role in achieving net-zero emissions in the transport sector:

- adapt decarbonisation strategies to different transport sub-sectors
- prioritise and significantly increase investment in zero-/low-carbon infrastructure
- massively invest in the development and rollout of zero-/low-emission technologies
- focus on a just transition to overcome social and political barriers
- increase international support and cooperation.
-

However, lower GHG emissions in developing countries require a comprehensive and context-specific approach that considers their unique challenges, opportunities, and sustainable development priorities (Emodi et al, 2022). This is because, in addition to policy interventions, it involves a combination of financial support, technology transfer, capacity-building efforts, and international cooperation to enable a transition toward low-carbon and sustainable transport systems.

The WGIII report of the IPCC's AR6 is highly confident that demand-side options and low-GHG emissions technologies can reduce transport sector emissions in developed countries and limit emissions growth in developing countries. According to the Report, electric vehicles powered by low-emissions electricity offer the largest decarbonisation potential for land-based transport on a life cycle basis, while energy-efficiency improvements and fuels like sustainable biofuels and low-emissions hydrogen can support mitigation benefits in land-based transport in the short- and medium-term but require decarbonisation of the electricity system, a massive increase in the production, and deployment of electric vehicles and cost reductions.

2.3.1.2 Policies and measures: What policies are needed to achieve net-zero by mid-century

To achieve a net-zero emissions target in the transport sector by mid-century, policymakers and stakeholders

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must adopt a holistic approach rooted in the Avoid-Shift-Improve (ASI) approach (Bakker et al, 2014). This strategy entails a series of largely interconnected policies and measures geared toward a collective reduction in GHG emissions while ensuring sustainable and efficient mobility. First, minimising the number and length of trips is a foundational step. For instance, this can be achieved through comprehensive urban and transportation planning that prioritises compact, pedestrian-friendly, and mixed-use urban environments. Implementing policies that endorse telecommuting, flexible work hours, and strategies aimed at curbing the need for daily commutes, along with promoting active modes of transportation like walking and cycling, can substantially curtail travel demand. Additionally, land-use policies that foster local access to essential services can further diminish the requirement for extensive travel. Second, shifting the remaining demand to low-emission modes is essential. This involves, among others, investing in efficient and affordable public transportation systems, expanding cycling and pedestrian infrastructure, and promoting ridesharing and carpooling. Implementing congestion pricing in urban areas can incentivise the use of sustainable modes and reduce traffic congestion. Additionally, policies that support electric vehicles, including incentives and charging infrastructure development, can facilitate the transition to low-emission transportation options. Third, improving vehicle technology is critical for achieving net-zero emissions. Governments should establish stringent vehicle emission standards, finance the adoption of cleaner fuels (e.g., via targeted incentives), and promote the development and deployment of zero-emission vehicles, such as battery electric and hydrogen fuel cell vehicles. Investing in research and development to advance vehicle efficiency and alternative propulsion technologies is imperative. The preceding points underscore the necessity for a departure from the past trajectory and emphasise the extensive array of policies and measures required within a complex, multifaceted, and interconnected strategy. Additionally, they stress the imperative of achieving a substantial degree of public engagement and fostering collaborative partnerships among governments, industries, and communities. These actions are indispensable to harmonise interests, ensure rational and effective policy formulation, and facilitate the seamless and efficient implementation of these policies and measures, ultimately culminating in the attainment of our goals.

In this regard, the following table presents some key strategies/policy fields and possible policy measures with a strong mitigation potential and actors potentially involved in strategy/policy design and implementation:

Table 7: Strategies, policy measures with mitigation potential, and main actors involved in policy design (A=Avoid, S=Shift, I=Improve)

Strategy/Policy Field	Policy Measures	Main actors/ stakeholders
Electrification of vehicles	• Scale up and accelerate transition to electric vehicles for both passenger and freight transport (S). • Develop supportive policies and incentives (S, I). • Avoid fossil fuels and encourage the use of renewable energy sources for electrification to ensure emissions reduction potential (A, S, I).	National governments, transport ministries, energy ministries, regulatory agencies, public transportation authorities, urban planning departments, industry.
Decarbonisation and increased efficiency of fuels	• Promote the use of low-carbon and renewable fuels, such as advanced biofuels and hydrogen (A, S). • Develop and scale up sustainable fuel production technologies, along with policies and incentives that support their deployment (I). • Improve the commercial viability of low-carbon alternative fuels (I). • Decrease energy intensity and improve fuel quality (I).	National governments, energy ministries, regulatory agencies, fuel producers, research institutions, technology development agencies, industry.

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Sustainable public transportation	• Expand and improve public transportation networks, making them more accessible, efficient, and affordable (A, S, I). • Prioritise investments in electrified mass transport systems like electric buses, trams, and trains (I). • Discourage private road transport and encourage modal shifts from road to rail (A, S). • Support multimodal and sustainable transport networks (I). • Incentives and infrastructure for walking, cycling, and other non-motorised transport modes (I).	Local authorities, transport agencies, public transportation authorities and operators, vehicle manufacturers, urban planning departments, community representatives.
Infrastructure development	• Invest in charging infrastructure for electric vehicles, including fast-charging stations, at strategic locations such as highways, parking areas, and urban centers (I). • Develop a comprehensive network of alternative fueling infrastructure (I). • Improve transport networks and their qualitative characteristics (I). • Improve rail and promote decarbonisation of ports, as well as On-shore Power Supply to ships at berth (I).	National governments, local authorities, transport ministries, urban planning departments, infrastructure development agencies, regulatory bodies, industry.
Efficient and intelligent transport systems	• Implement intelligent transportation systems, including smart traffic management, real-time information systems, and efficient logistics to optimise transport operations and reduce congestion (I). • Promote the use of advanced vehicle technologies such as vehicle-to-vehicle communication, autonomous driving, and eco-driving techniques to improve fuel efficiency and reduce emissions (I).	National governments, transport ministries, research institutions, universities, technology development agencies, industry, collaboration platforms.
Spatial planning and sustainable urban development	• Encourage compact and sustainable urban planning that reduces the need for long-distance commuting and enables active transportation modes (A, S). • Develop mixed-use neighbourhoods that integrate residential, commercial, and recreational areas to minimise travel distances and promote walkability (A, S).	National governments, urban planning departments, transport ministries, local authorities, research institutions, universities.
Behavioural change and demand management	• Reduce overall travel demand and encourage more sustainable modes of transport (A). • Use awareness campaigns, education, and information dissemination to promote sustainable transport choices, and using public transportation (S). • Congestion pricing and incentives for off-peak travel, parking policies (S, I).	National governments, local authorities, public, industry.

The specific timelines for the abovementioned changes/transformations vary across regions, since efforts required, enabling conditions, and barriers differ greatly. The success of the strategies and policy measures is uncertain, while their outcome and timelines cannot be easily predicted. These depend on the starting position of

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different regions and countries, regional and national targets, policies, governance, capacities, and available resources. However, in order to achieve net-zero emissions in the transport sector by mid-century, it is crucial to start implementing these changes promptly and accelerate efforts undertaken so far.

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2.3.2 Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction?

Mitigation enablers and barriers in the transport sector are to a certain extent universal, but they can also be very different, depending on a regional or national context (including between developed/developing countries). The table below provides a comprehensive overview of factors that can significantly contribute to or hinder emissions reduction, as they have an effect on the decarbonisation strategies listed in Table 1. It identifies seven key fields as crucial in terms of policy and governance, technology advancements and options, financial incentives and investment, systemic changes, public awareness and behaviour, knowledge and technology, and international cooperation. These key fields collectively address the multifaceted challenges and opportunities associated with transitioning to a low-carbon transportation system. Policy and governance set the framework, technology advancements drive innovation, financial incentives provide essential support, systemic changes restructure transportation, public awareness drives demand, knowledge and technology enable effective solutions, and international cooperation ensures a coordinated global effort. Within these fields, an analysis of enablers and barriers has been conducted, categorised according to their relevance at either the macro or micro level. Macro-level analysis provides a broad perspective on systemic issues, policy frameworks, overarching strategies and global trends that may impact emissions reduction efforts. Micro-level analysis, on the other hand, delves into specific, localised factors, including individual behaviours, technological innovations, and country/community-level challenges. Together, macro and micro-level analyses create a comprehensive understanding of the complex dynamics at play in the transport sector.

Table 8: Overview of factors contributing to emissions reduction

Enablers		Barriers	
Field	**Aspects**	**Field**	**Aspects**
Policy and governance	**Macro-level** • Enhanced political commitment and well-aligned multilevel governance. • Clear and supportive policies and regulatory framework. • Ambitious targets but also concrete emission reduction actions. • Mainstreaming of sustainable development and SDGs in national transport policies and other sectors, achievement of synergies. **Micro-level** • Coordination across multiple policy domains. • Adequate dedicated governance structures, procedures, and tools. • Increased participation in policy design and implementation and inclusive governance processes.	Policy and governance insufficiencies, regulatory gaps, and obstacles	**Macro-level** • Lack of political commitment. • Inconsistent or inadequate policies, lack of supportive policies, absence of long-term planning. • Inadequate regulatory framework, gaps and obstacles, regulatory uncertainty. **Micro-level** • Insufficient governance structures, procedures, and tools. • Lack of enforcement mechanisms for low-carbon transport in many developing countries
Technology advancements and options	**Macro-level** • Advancements in low-carbon technologies, e.g., electric vehicles, alternative fuels, batteries, etc. • Smart infrastructure systems.	Technological limitations and readiness, infrastructure gaps	**Macro-level** • Many low-carbon technologies still in early stages of development or not commercially viable for widespread use.

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	• Leapfrogging opportunities for developing countries. **Micro-level** • Improvements in battery technology. • Use of battery technology in segments of transport sector. • Improvements in ports, cargo handling, passengers' traffic, smart systems in ports, OPS, supply chains, etc,		• Still limited range for electric vehicles. • Availability and costs of critical minerals required to manufacture lithium-ion batteries and other renewable power technologies. • Limited access to sustainable fuels. **Micro-level** • Shortcomings of putting technological advancements into use. • Limited transportation infrastructure, especially in developing countries and in rural areas.
Financial incentives and investment	**Macro-level** • Adequate financial support in form of grants, loans, favourable financing options, guaranties, etc. • Financial resources allocation toward low-carbon transport solutions. **Micro-level** • Incentives and subsidies for low-carbon technologies. • Public and private sector investment in research and development, infrastructure development, and deployment of new technologies. • Technical support in order to identify needs and adequate solutions, assist possible investments and PPPs, secure funding opportunities and the use of available resources, etc.	Economic and financial challenges, affordability	**Macro-level** • Upfront costs and, in some contexts, high investment risk of transitioning to low-carbon transport technologies and infrastructure. • High costs of electric vehicles and infrastructure investments required. • Huge investments and planning required for largely missing infrastructure in developing countries such as charging networks or public transportation systems. • Resource constraints for transition. Developing countries cannot afford to invest in low-carbon transport technologies and infrastructure. **Macro-/Micro-level** • Limited access to adequate and sufficient financial resources and funding. • Very large parts of the population in developing countries cannot afford to buy electric vehicles.
Systemic changes	**Macro-level** • Broad use of remote work. • Smart mobility and smart cities technologies. • E-commerce. • Improvements in supply chains and logistics **Micro-level** • Shared mobility.	Systemic changes	**Micro-level** • Increased demand for freight transport and particularly last-mile delivery.

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Public awareness and behaviour	**Macro-/Micro-level** • Increased awareness and demand for sustainable transport options among the general public. • Public support for sustainable transport policies and practices.	Behavioural changes, socio-economic conditions	**Macro-level** • Persistently limited awareness regarding environmental issues and sustainable transport **Micro-level** • Resistance to change, maintenance of consumption and production patterns, transportation habits, etc. • Vested interests, especially in industries heavily reliant on fossil fuels, road transport operators, supply chains, etc., due to concerns about profitability, job displacement, or operational disruptions. • High levels of poverty in developing countries and informal transportation sectors and ways.
Knowledge and technology	**Macro-level** • Expanding and deepening of knowledge. **Micro-level** • Knowledge-sharing. • Sharing of know-how and best practices exchange of experiences, expertise. • Technology transfer and technical support for developing countries regarding sustainable transport transition and emission reduction.	Capacities	**Macro-level** • Capacity insufficiencies and limited capacity building in developing countries. **Micro-level** • Challenges in accessing and adopting low-carbon technologies due to limited technical capacity and expertise.
International cooperation	**Macro-level** • Collaboration between countries, international organisations, NGOs, industry stakeholders, development cooperation agencies, financial institutions, and funds, etc. with regard to concrete programs and actions on the above. **Micro-level** • Capacity building in developing countries.	Actors / stakeholders	**Macro-level** • Very complex environment and relationships among actors/stakeholders. **Micro-level** • Many different actors / stakeholders involved with different characteristics, concrete interests, many different roles and priorities, capacity, etc. • Difficulties for harmonised and concerted action, serious conflict potential. • Different levels of action. Communication between levels is difficult and often not possible.

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In addition to this analysis, and from a different perspective to that of Table 2, Table 3 presents a comprehensive overview of factors that could significantly affect the implementation of the decarbonisation strategies described above and related transformative processes in the transport sector and transport-related emissions, organised around six main categories of feasibility: geophysical, environmental-ecological, technological, economic, sociocultural, and institutional. These categories provide a structured framework for systematically assessing prevailing conditions, contextual elements, and various constraints. They may be either challenges to or opportunities for achieving transformative objectives, offering a perspective revolving around the feasibility of decarbonising the transport sector.

Table 9: Overview of factors affecting the transformation in transport sector and transport-related emissions

Dimension	Possible enhancements/possible barriers
Geophysical feasibility	**Enhancements** • Geophysical considerations to be integrated into transport planning, land use and spatial planning. • Favourable geography, landscape morphology and topography conditions to be taken advantage of by designing and implementing or reshaping transport systems. • Exploitation of renewable energy sources for powering electric vehicles. • Exploitation of critical minerals required to manufacture lithium-ion batteries and other renewable power technologies. **Barriers** • Adverse geography, landscape morphology and topography for transport systems and services. • Low potential in renewable energy sources and lack of critical resources. • Availability and supply of critical materials.
Environmental-ecological feasibility	**Enhancements** • Vulnerability to climate risks and awareness of these risks. • Strong environmental pressures (e.g., air pollution, noise pollution, congestion, bottlenecks, etc.) that may prompt demand for more ambitious strategies and policy measures. • Environmental legislation. **Barriers** • Low level resilience of transport infrastructure and systems. • Possible limitations through environmental legislation and designated protected areas/zones.
Technological feasibility	**Enhancements** • R&D, rapid progress of problem-adequate technological solutions. • Progressive automation and digitalisation of the transport sector, use of smart solutions, advanced technologies, and innovation in the entire sector and in different transport modes. • Technology scalability. • Development of seamless and efficient transport corridors, networks, and logistic/supply chains, following high qualitative standards and procedures. **Barriers** • Still low maturity level and technology readiness. • High costs of state-of-the-art/cutting-edge technology. • Limited access to new technology and insufficient technology transfer.
Economic feasibility	**Enhancements** • Decoupling strategies. • Potential and opportunities for structural change, modernisation, rationalisation,

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	and business profitability in the sector. • Secure benefits in medium- and long-term. • Still very limited use of economic instruments and therefore plenty of room for smart solutions and soft measures. **Barriers** • Structure of the economy and economic trends, especially in developing countries. • Poor economic conditions. • Huge costs of transformations/changes in the sector. • Upfront financing requirements. • Limited access to capital/funding. • Low efficiency of economic tools so far. • Fear of possible adverse effects on employment and growth.
Sociocultural feasibility	**Enhancements** • Sustainability paradigm and dynamic. • Public acceptance. • Knowledge and information, environmental education. • Gradual inclusion of actors/stakeholders and general public into policy design and implementation. • Capacity-building measures. • Focus events (e.g., floods, international meetings, cases before courts, activism, etc.) **Barriers** • Adverse socioeconomic conditions. • Maintenance of non-sustainable patterns, behaviour, and trends. • Limited public engagement and support.
Institutional feasibility	**Enhancements** • Normative pressure. (e.g., Paris Agreement). • Political acceptance, sustainability rhetoric, and gradual support by political elites. • Agenda 2030 and Sustainable Development Goals. • Incremental improvement of institutional capacity. • International cooperation, important intranational meeting (e.g., COP, sustainable development conferences, G20 meetings, etc.), possibilities for non-state actors to be heard and participate in decision-making. • NGO activity. **Barriers** • Still low-level prioritisation in the political agenda. • Limited adoption of targets and support by the administration at all levels. • Very slow development of adequate and efficient governance structures and processes. • Very limited cross-sectoral coordination and policy integration of relevant non-climate policies. • Inadequacies of the international system/architecture regarding policy implementation and governance. • Limited power of civil society and organised interest groups in favour of the environment and limited influence on the political processes and output.

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2.3.3 Typology of public policy and governance instruments

There is a wide range of policy and governance instruments available to public authorities supporting decarbonisation / GHG emissions reduction in the transport sector. The table below provides a comprehensive overview of policy options categorised into six main types of instruments. These instruments encompass governance and planning, economic, regulatory, "non-economic", educational and informational, international cooperation, and other instruments. Each type of instrument is further delineated by public policy instruments, the governance dimension involved, the anticipated results, and the underlying factors that facilitate or impede their successful implementation and results, intricately linked to the prior discussion presented in Section 3.

Table 10: Overview of policy instruments

Instrument Type	Public Policy Instruments	Governance Dimension	Expected Result	Enablers/Barriers addressed
Governance and planning instruments	• Transport strategies. • Integrated transport planning. • Urban, spatial, and regional planning.	• Policy integration and coherence. • Multi-level governance. • Enhancement of institutional capacity / institutional coordination. • Collaboration among actors/stakeholders. • Planning procedures, technical dimension, and participation / stakeholder engagement. • Monitoring and assessing policy/strategy implementation and feedback.	• Long-term strategies that outline vision, objectives, policies, and measures for sustainable and low-carbon transport systems, incorporating GHG reduction targets. • Coherent and holistic approach to transport planning. • Policy integration and coherence among various sectors to align goals and actions for emissions reduction. • Frameworks for integrated transport planning that prioritise sustainable modes of transport, promote modal shifts, and optimise transport networks and systems to reduce emissions. • Integrating sustainable urban, spatial, and regional planning principles and land-use and development into the planning considerations and development of public transportation	• Political commitment. • Policy integration and coherence. Strategic planning. • Regulatory framework. • Governance structure, procedures and mechanisms. • Enforcement mechanisms

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			systems in order to reduce transport demand, minimise travel distances and congestion, promote walkability and support emissions reduction.	
Economic instruments	• Economic incentives (tax incentives or rebates to individuals or businesses, subsidies and grants to individuals, businesses, or organisations to promote the purchase or adoption of sustainable transport options, lowering or waiving registration fees for vehicles, incentives for carpooling or ridesharing, voucher programs for low-income individuals to access public transportation or sustainable transport options, etc.). • Economic disincentives (carbon pricing, emission or energy taxes and levies, particularly fossil fuel	• Institutional and regulatory frameworks. • Enhancement of institutional capacity and implementatio n/enforcement mechanisms. • Adequate administrative procedures. • Monitoring compliance, assessing implementatio n and feedback. • Revenue allocation. • Capacity building. • Funding mechanisms, schemes and capacities, consulting, and technical support for potential investors.	• Shift consumer behaviour towards sustainable transport choices and support the transition to a low-carbon and sustainable transportation system. • Encourage and promote the adoption of environment-friendly and energy-efficient modes of transport. • Internalise negative externalities of transport. • Discourage undesirable behaviours or activities associated with transport in favour of cleaner and more sustainable alternatives.	• Consumption and production patterns, behaviour, trends. • Decoupling, system change, structural change, rationalisation. • Economic feasibility of efforts. • Affordability, financial support for investments, funding. • Technological feasibility through funding and investments. • Investment risk

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	taxes and levies, congestion charging, road tolls, parking fees, etc.). • Financial support schemes such as grants, tax credits or subsidised loans/loan guarantees for low-carbon or zero-emission technologies, as • Public investments and funding.			
Regulatory, "non-economic" instruments	• Vehicle emission standards. • Speed limit and low-emission zones. • Modal shift policies.	• Regulatory framework • Monitoring compliance. • Enhancement of institutional capacity and implementatio n/enforcement mechanisms. • Technical procedures and public participation. • Policy coordination and cooperation across different government departments, the public administration, and agencies.	• Establishing and enforcing strict emission standards for vehicles and promote the adoption of cleaner vehicle technologies and market transformation toward cleaner vehicles. • Reduced emissions by restricting the entry of polluting vehicles or incentivizing the use of low-emission vehicles within designated areas. • Implementing policies to encourage a modal shift from private vehicles to more sustainable modes of transport, such as public transportation, cycling, and walking.	• Consumption and production patterns, behaviour. • Standards, thresholds and limits. • Compliance. • Failure of economic and other instruments.

Educational and informational instruments	• Knowledge-sharing. • Public awareness campaigns. Information dissemination. • Training.	• Capacity building and stakeholder engagement. • Technology transfer	• Solid knowledge as a necessary background for decisions. • Awareness raising, behavioural change, encouraging sustainable transport choices, support transformations. • Information on sustainable transport options, emission reduction technologies, data on emissions, etc.	• Knowledge and information background / sharing. • Capacity building. • Awareness and engagement. • Consumption and production patterns, behaviour, trends.
Other instruments	• Public procurement policies. • Partnerships and collaboration. • Research and Development.	• Transparent and accountable procurement procedures. • Public-Private Partnerships (PPPs). Collaborative governance. • Technological advancement and innovation. • Capacity building.	• Promote sustainable solutions in the transport sector and support transitions through "soft" policy instruments. • Support research and development initiatives to drive technological advancements in the transport sector accelerate the adoption of transformative technologies and practices.	• Governance and smart solutions. • Capacity building. • Technological advancement and innovation. • Partnerships and collaboration.
International cooperation instruments	• Bilateral and multilateral agreements. • Harmonised policies and regulations. • Development cooperation. • Collaboration with private sector entities through PPPs. • Support developing countries.	• Coordination and cooperation among countries, international organisations, and relevant stakeholders. • Funding mechanisms and schemes. • Involvement of civil society organisations, NGOs, and community stakeholders in international governance and inclusive	• International agreements and commitments. • Global coordination. • Policy harmonisation and integration. • Transparency and accountability. • Secure funding for sustainable transport projects, infrastructure development, and emission reduction initiatives. • Development and deployment of low-emission technologies and	• Political commitment. • Architecture of the international system, international governance, procedures and mechanisms. • Development cooperation framework and actions. • Capacity building in the international system / developing countries.

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		decision-making processes. • Participation in international emissions reporting and monitoring systems. • Research and development collaborations. • Knowledge sharing networks and peer-to-peer exchanges.	infrastructure in the transport sector. • Stakeholder engagement.	• Financial and technical support. • Knowledge sharing, technology transfer. • Institutional development and compliance.

2.3.4 Transport concluding remarks

The transport sector has significant decarbonisation potential and can substantially contribute to carbon emissions reduction and climate neutrality. To this end, the sector needs to better mainstream environmental considerations and make some bold choices, but also to move onto a transformative path towards sustainability, taking a great leap forward. While policy and governance provide the framework for goal setting and implementation efforts at all levels, the transport sector's transition also largely depends on all actors of the economy (e.g., businesses, financial institutions, and the society overall), to shift to new patterns, behaviours, and trends, and thus towards a new paradigm. Although technological advancements are a critical element of this difficult transition, by means of innovative, state-of-the-art, or cutting-edge technological solutions for different problems, challenges and risks, efforts should also focus on fundamental changes in our way of thinking mobility and related actions. However, even incremental changes are very important and perhaps more likely in the short- to medium-term. Strategies, policy measures, and instruments are hereby crucial, especially in consideration of critical synergies at the sectoral policy level. It is critical to mobilise the necessary financial resources for this transition and support those who cannot afford to be on board. Actors/stakeholders need to adapt to a new reality, embrace change, as well as enhance and accelerate their efforts. Enablers or barriers will largely determine the outcome of the efforts. In any case, significant results presuppose political will, effective governance and implementation work, cooperation, and collaboration on the part of all parties involved in any given process. Developing countries could find new ways to break away from existing global development trajectories, leverage the lessons learnt in developed countries and eventually leapfrog technology stages, skipping less efficient and higher carbon-intensive transport technologies; they could also develop new solutions that are more relevant to their national context or even prove helpful in transforming the transport sectors in developed countries.

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2.3.5 Transport Bibliography

- Bakker, S., Zuidgeest, M., de Coninck, H., & Huizenga, C. (2014). Transport, Development and Climate Change Mitigation: Towards an Integrated Approach. *Transport Reviews*, 34(3), 335–355. https://doi.org/10.1080/01441647.2014.903531.
- Biermann, F., Hickmann, T., Sénit, C.-A., & Grob, L. (2022). The Sustainable Development Goals as a Transformative Force?: Key Insights. In C.-A. Sénit, F. Biermann, & T. Hickmann (Eds.), *The Political Impact of the Sustainable Development Goals: Transforming Governance Through Global Goals?* (pp. 204–226). Cambridge University Press. https://doi.org/DOI: 10.1017/9781009082945.009.
- Dawkins, E., Strambo, C., Xylia, M., Gong, J., Axelsson, K., & Maltais, A. (2023). Who is most at risk of losing out from low-carbon transition in the food and transport sectors in Sweden? Equity considerations from a consumption perspective. *Energy research & social science,* 95, 102881.
- Emodi, N. V., Okereke, C., Abam, F. I., Diemuodeke, O. E., Owebor, K., & Nnamani, U. A. (2022). Transport sector decarbonisation in the Global South: A systematic literature review. *Energy Strategy Reviews*, 43, 100925. https://doi.org/https://doi.org/10.1016/j.esr.2022.100925.
- IPCC (2023). *Climate Change 2023: Synthesis Report.* A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds)]. IPCC, Geneva, Switzerland.
- IPCC (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi: 10.1017/9781009325844.
- IPCC (2022). *Climate Change 2022: Mitigation of Climate Change*. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.
- IPCC (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, doi: 10.1017/9781009157896.IPCC (2014). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds)]. IPCC, Geneva, Switzerland, https://www.ipcc.ch/report/ar5/syr/.
- International Transport Forum (2023). *ITF Transport Outlook 2023*, OECD Publishing, Paris, https://doi.org/10.1787/b6cc9ad5-en.
- IEA (2023), Tracking Clean Energy Progress 2023, IEA, Paris https://www.iea.org/reports/tracking-clean-energy-progress-2023
- Lennert, F., & Schönduwe, R. (2017). Disrupting mobility: Decarbonising transport?. *Disrupting mobility: Impacts of sharing economy and innovative transportation on cities*, 213-237.
- Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., Sethi, M., & Barau, A. (2017). Exploring the governance and politics of transformations towards

sustainability. *Environmental Innovation and Societal Transitions*, 24, 1–16. https://doi.org/https://doi.org/10.1016/j.eist.2016.09.001.SLOCAT Transport (2023). *Climate and Sustainability Global Status Report. Transport Pathways to Reach Global Climate and Sustainability Goals* – 3rd edition (Preliminary Insights), https://tcc-gsr.com.

- SLOCAT Transport (2023). *Climate and Sustainability Global Status Report. Regional Trends in Transport Demand and Emissions, and Policy Developments* – 3rd edition (Preliminary Insights), https://tcc-gsr.com.
- SLOCAT (2021). *Tracking Trends in a Time of Change: The Need for Radical Action Towards Sustainable Transport Decarbonisation*, Transport and Climate Change Global Status Report – 2nd edition, https://tcc-gsr.com/home.
- United Nations (2021). *Sustainable Transport, Sustainable Development*. Interagency report for second Global Sustainable Transport Conference, issued by the Department of Economic and Social Affairs, New York, https://sdgs.un.org/publications/interagency-report-second-global-sustainable-transport-conference.
- United Nations (2019). *Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development*, issued by the Department of Economic and Social Affairs, New York, https://sdgs.un.org/gsdr/gsdr2019.
- Waisman H., Torres Gunfaus M., Pérez Català A., Svensson J., Bataille C., Briand Y., Aldana R., Anggreni L., Angulo-Paniagua J., Argyriou M., Benavides C., Bergamaschi L., Berghmans N., Boer R., Buira D., Bukowski M., Calderón W., D'Agosto M., de León F., Deprez A., Díaz M., Dorina A., Dubeux C., Fall S., Fei T., Filcak R., Foerster A., Garg A., Goes G. ., Gonçalvez D.., Healy C., Hosek E., J.-Vinois A., Kobyłka K., La Rovere E., Leonardi M., Levai D., Major M., Malos A., Maurtua Konstantinidis E.., McCall B., Montedonico M., Mosnier A., Nogueira E., Nyiro F., Okereke C., P.-Nguyen V., Palma R., Peterson E., Potashnikov V., Predassi J R., Pye S., Quirós-Tortós J., Rossita A., Safonov G., Safonov M., Sanz Sánchez M. J., Sarr S., Sawyer D., Schaffhauser T., Siagian U., Stetsenko A., Sudharmma Vishwanathan S., Tamura K., Torres R., Trollip H., Valenzuela M. J., Walter M., Watson J., Wetmańska Z., Wills W., Yun J., Zevallos P. (2021). *Climate ambition beyond emission numbers: taking stock of progress by looking inside countries and sectors.* Deep Decarbonization Pathways (DDP) Initiative-IDDRI. Paris, https://www.iddri.org/en/publications-and-events/report/climate-ambition-beyond-emission-numbers-taking-stock-progress.
- Wang-Helmreich et al., 2022)Wang-Helmreich, H., Obergassel, W., & Lah, O. (2022). *Moving transport to net zero: What it takes to decarbonise the global transport sector*. Issue 199. Wuppertal Institut für Klima, Umwelt, Energie. https://doi.org/10.48506/opus-8043
- Weiland, S., Hickmann, T., Lederer, M., Marquardt, J., & Schwindenhammer, S. (2021). The 2030 agenda for sustainable development: Transformative change through the sustainable development goals? *Politics and Governance*, 9(1), 90–95. https://doi.org/10.17645/PAG.V9I1.4191.

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2.4 Buildings

2.4.1 Introduction

As of 2019, buildings were responsible for 31% of global final energy demand 128 EJ). Residential buildings consumed 70% of global building energy demand. Energy consumption in residential and non-residential buildings accounted for 50% and 32% of the global CO2 emissions from buildings, respectively. From 1990 to 2019, space heating dominated energy consumption in residential buildings globally, followed by water heating, cooking, and small appliances. By 2050, global final energy demand from buildings is expected to range from 86 to 138 EJ in different scenarios. Projections indicate a substantial global mitigation potential of at least 8.2 GtCO2, equivalent to 61% of the baseline scenario. Developing countries contribute the most with 5.4 GtCO2, while developed nations account for 2.7 GtCO2 (Cabeza et al., 2022a). Space heating demand is projected to decrease from 2020 to 2050 in all scenarios. Cooling demand is on the rise, partly due to increased room air-conditioner ownership driven by rising wealth and higher ambient temperatures caused by global warming (Liddle & Huntington, 2021).

Global GHG emissions from buildings amounted to 12 Gt CO2-eq, 21% of total global emissions. (Pathak, Slade, Pichs-Madruga, et al., 2022). Of these, 57% were indirect CO2 emissions from off-site generation of electricity and heat, 24% were direct CO2 emissions produced on-site, and 18% were from the production of cement and steel used for building construction and refurbishment. Halocarbon emissions accounted for 3% of global building GHG emissions (Cabeza et al., 2022a).

Thus, buildings and their construction are key for achieving the Paris Agreement. So far, however, energy demand in buildings has continually increased, driven by building floor growth in combination with improved energy access and living standards(IEA, 2021e). Between 1990 and 2019, global CO2 emissions increased by 50%. This increase resulted mostly from an increase of global indirect CO2 emissions of 92%, caused by the increase of fossil-based electrification, while direct emissions decreased by 1% globally. In terms of regional distribution, emissions from residential buildings in so-called developed countries decreased (except for Australia, Japan and New Zealand), while they increased in so-called developing countries. Indirect emissions from non-residential buildings increased in all regions, ranging between a growth of 1202% in Eastern Asia growth and 4% in Europe and Central Asia, while direct emissions from non-residential buildings decreased by 51% in the latter regions. Embodied emissions increased in all regions, ranging between 334% in Southern Asia and 4% in North America. In terms of future scenarios, the IEA net-zero scenario projects 2050 emissions at 29 Mt CO2, compared to a range of between 1.7 Gt CO2 and 13.5 Gt CO2 in various reference scenarios (Cabeza et al., 2022a).

2.4.2 Main mitigation strategies in the target sector: What changes/transformations are needed in what timelines to achieve net-zero by mid-century?

To achieve the Paris Agreement target, the building sector needs to be decarbonized through the following five interlinked strategies:

1) First and foremost, improving **building envelope performance** is the most important measure to reduce heating and cooling demand and is thus key for building decarbonisation. New construction offers the best opportunity for deploying an energy efficient envelope. For existing buildings, energy renovation needs to be deepened and accelerated (OECD/IEA, 2013).
2) Shift from fossil-fuel-based and low-efficient to low carbon **heating, cooling, and cooking**:
3) Energy efficient appliance and lighting: Ownership of appliance is expecting to increase rapidly in developing economies. Ensuring best available energy efficient appliances to be used in these countries and only light-emitting diode (LED) lamps to sold in the middle term is crucial for reducing building electricity demand and net zero emissions of the building sector (Cabeza et al., 2022a; IEA, 2021d).
4) Minimize embodied carbon of building materials: Embodied energy and emissions in building materials will

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play an increasingly important role when buildings become more efficient (Ürge-Vorsatz et al., 2020b). Embodied emissions can be reduced by using low-carbon materials, in particular wood an earth, re-using building materials, and extending lifetime of building components (Cabeza et al., 2022a; Churkina et al., 2020).

5) Sufficiency measures: these measures avoid the demand of energy and materials and thus tackle the causes of GHG emissions, but also make it easier to provide basic needs to all, through optimizing the use of buildings, repurposing unused existing buildings, prioritizing multi-family homes over single-family buildings, and adjusting the size of buildings to the evolving needs of households. In contrast to efficiency, sufficiency includes consideration of distributional equity in the consumption of space and resources and aims at delivering decent living standards for all within planetary boundaries (Cabeza et al., 2022a; Saheb, 2021)

The following table provides more details on the technical measures needed and the actors who would need to take action.

Table 11: Mitigation strategies and related technical measures and actors in the buildings-sector

Mitigation strategies	Technical measures	Actors
S1: Reducing energy demand through **building envelope design and technologies, efficient operation**	• Well-insulated, thermal bridge free building envelope • Deploying passive cooling methods to minimize the yearly demand for air conditioning. • Utilizing passive heating strategies, including optimal building orientation towards the south, incorporating north and south-facing glazing, maximizing daylight penetration, promoting natural ventilation, and implementing a structure that efficiently stores thermal energy. • Energy efficient building operation to reduce energy demand and avoid rebound effects. (Bienvenido-Huertas et al., 2020; Ürge-Vorsatz et al., 2020a)	• Property development, e.g., property development companies, (social) housing companies, investor-occupier • Financing, e.g., banks, equity funders, public-private partnership (PPP), insurances, property valuers • Design, e.g., architects, engineering consultants • Component supply, e.g., component manufacturers, wholesale, and retail • Construction, e.g., general management companies, construction companies and contractors, manufacturers of pre-fabricated houses • Installation of systems, e.g., system suppliers, installation contractors • Sale/Letting, e.g., property development companies (as sellers or landlords), manufacturers of pre-fabricated houses, housing corporations, real estate agents, landlords/landladies, buyers, tenants • Commissioning, e.g., commissioning providers, engineering consultants, facility managers • Operation/Use, e.g., investor-occupiers (as developers or as buyers of completed

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		buildings), landlords/landladies, tenants, employees, customers, visitors, guests etc., facility managers
S2: Shift from fossil-fuel-based and low-efficient to low carbon **heating, cooling, and cooking**	• electrification through heat pumps (Bloess et al., 2018). • direct use of renewable energies, e.g., solar thermal, biomass energy (IEA, 2021d). • increasing energy efficiency of cooling equipment and the dominant use of ultra-low GWP refrigerants (Carbon Trust, et al., 2020; IEA, 2018, 2021d). • solar cooling solutions, including air conditioners powered by PV and solar thermal collectors combined with a chiller (IEA, 2018). • district heating and cooling based on the direct use of renewable energy, excess heat, and renewable electricity, in particular in compact urban areas (Fonseca & Schlueter, 2015; IEA, 2018) • Clean and low carbon cooking through efficient electric cooking (based on renewable electricity) and use of modern bioenergy, such as improved biomass cookstoves and bio-sourced butane and propane (bioLPG) based on municipal solid waste other sustainable biomass feedstock (IEA, 2021d).	For building-level centralized HVAC, the same as actors above; For decentralized HVAC within each apartment: tenants and owners For district heating/cooling: municipal government, district heating/cooling service provider, utilities, building owners
S3: Use of **highly energy efficient appliance and lighting**	Ensuring best available energy efficient appliances to be used, in particular, in developing countries (IEA, 2021d)	Consumers
S4: Minimize embodied carbon of buildings, which will	Embodied emissions can be reduced by:	Building materials and components manufacturers

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play an increasingly important role when buildings become more efficient	● improving whole-building design: through adaptive reuse and extending lifetime of building components, decreasing the total project size, adopting more efficient structural systems or alternative construction methods, employing prefabricated systems or components, and designing with a focus on waste minimisation (Jungclaus et al., 2021) ● Substituting material by low-embodied-carbon materials. (Churkina et al., 2020) ● Establishing a value or limit for a material characteristic that dramatically reduces embodied carbon content. (Jungclaus et al., 2021)	Design (e.g., architects, engineering consultants), Sale/Letting (e.g., property development companies (as sellers or landlords), manufacturers of pre-fabricated houses, housing corporations, real estate agents, landlords/landladies, buyers, tenant)
S5: Sufficiency measures	Downsizing dwellings through cohousing strategies a) involves repurposing existing buildings and clustering apartments during renovations; b) prioritizing multi-family buildings in new developments over single-family homes (Kuhnhenn et al., 2020; Mckinlay et al., 2017; Sandberg, 2018; Thomas et al., 2019)	Local government Property development Design (e.g., architects, engineering consultants) Sale/Letting (e.g., property development companies (as sellers or landlords), manufacturers of pre-fabricated houses, housing corporations, real estate agents, landlords/landladies, buyers, tenant)

2.4.3 Policies and measures: What policies are needed to achieve net-zero by mid-century?

The previous chapter shows that multiple types of barriers have impeded building decarbonisation, which cannot be addressed by a single policy instrument. Thus, policy-makers need to find a balanced policy package[2], which combines a broad range of policy instruments that reinforce each other to decarbonise the building sector (Hoefele & Thomas, 2011; Kern et al., 2017; Rosenow et al., 2017).

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[2] Policy mixes for sustainability transitions: an extended concept and framework for analysis. Res. Policy, 45 (8) (2016), pp. 1620-1635, 10.1016/j.respol.2016.04.004

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The table below presents how the primary functions of these policy instruments address each type of barrier. The description is shorthand for the complex reality and consider only the primary policy functions.

Table 12: Policy instruments and how they can address existing barriers in buildings

Barriers	Primary functions: How policy instruments can address each barrier	
Institutional	**Governance and planning instruments**	• *(S1-5) Policy roadmaps* define clear targets, milestones, and action plans for all decarbonisation strategies, providing a reliable planning framework for market actors and reduce risk for investors • *(S1-5) Establishing a dedicated political body* (ministry or department) taking political responsibility related to building decarbonisation, and ***coordination mechanisms*** among ministries, and among national, subnational and local governments, and for the involvement of various stakeholder groups, are important for effective implementation of the roadmap (IEA, 2022a). • *(S1-3) Energy efficiency funds* Dedicated funds by the government or by energy companies provides stable funding sources to financing the upfront costs of decarbonisation options and can also address the split incentives by reducing the burden of compliance by landlords; • ***(S1-3) Removing subsidies for fossil fuel, carbon financing, and energy taxes, levies and surcharges*** on energy carriers reflecting their GHG emissions intensities a) levels the playing field for low carbon heating by increasing the costs of the fossil fuel alternatives for both upfront and operation costs (IRENA, IEA and REN21, 2020); b) provides a long-term vision for building decarbonisation.
	Regulatory instruments	• *(S1-2, S4) Building energy codes* make building energy efficiency and low carbon heating/cooling for buildings the standard sending a clear signal to market actors. Progressive code also include requirements on sufficiency and embodied emissions (Cabeza et al., 2022b; World Green Building Council, 2019) • *(S2) Phasing out fossil fuel boilers* sends a signal to the market on the exclusion of fossil fuel alternatives in the near- and medium-future. • *(S3) Product-specific minimum Energy Performance Standards (MEPSs),* have proven to be most cost-effective policy measure for boosting the efficiency of appliances, including heating and cooling equipment (IEA, 2018; Ürge-Vorsatz et al., 2007).
	"Soft" instruments	• *(S1-5) Leading* **by example** in the decarbonisation of public buildings helps to establish a vision of building sector decarbonisation and raise investors' confidence.

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Economic	**Governance and planning instruments**	• ***(S1-2, S5) Energy Efficiency Obligations*** can help financing upfront costs of decarbonisation options by obligating energy suppliers to carry out measures that deliver energy savings. In return, energy suppliers have the right of cost recovery for organizing and funding energy efficiency programs (*bigEE*, n.d.; Rosenow et al., 2019).
	Economic instruments	• ***(S1-3, S4) Financial incentives*** for highly energy efficient buildings, heating and cooling system, and appliance, on-site renewable energy, and manufacturing of low-embodied emission building products may be required to overcome their higher upfront costs and can take different forms, ranging from grants, soft loans, rebates for purchasing products, to tax incentives, targeting different target groups (Lowes et al., 2020) . • ***(S5) Financial incentives*** promote the alternative forms of housing such as communal housing and energy sufficiency appliance (Thomas et al., 2019) • ***(S1-2,4)Emission pricing mechanisms*** make investments in building energy efficiency and on-site renewable energies more attractive; revenues can be used to further support mitigation (Lowes et al., 2022b; Thomas et al., 2021) • ***(S1-2) Energy saving auctions*** call for competition among market actors for funding budgets on energy efficiency projects in a most cost-benefit manner. • ***(S1-2) Financing instruments:*** Loans provide liquidity and direct access to capital important in energy renovations and on-site renewable energy deployment. Policy instruments in this regard include low-interest loans, loan guarantees, combination of grants and subsidised loans, setup of publicly capitalised entities (Cabeza et al., 2022b). Other innovative mechanisms include On-bill financing (OBF) in which utilities take over the investment and consumers pay it back through a surcharge on the energy bill over time. (Johnson et al., 2016). Property Assessed Clean Energy (PACE) providing funds using specific bonds offered by municipal governments to investors (Mills, 2016), revolving funds recovering and reinvesting the savings generated (Setyawan, 2014)
	Regulatory instruments	• ***(S1-2) Building energy codes*** address split incentives by requiring a reasonable level of energy efficiency of rental buildings (*bigEE*, n.d.). • ***(S5)*** Governments can set ***energy sales cap scheme*** to incentivize suppliers to assist their customers in reducing their electricity consumption (Thomas et al., 2019)

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	"Soft" instruments	• ***(S1-2) Policies promoting energy services*** Energy Service Companies (ESCOs) can provide property owners information on energy saving potentials and cost-effective holistic solutions for energy renovation including low carbon heating & cooling solution (Boza-Kiss et al., 2017), promotion can include e.g. financial support, standards and certification, information provision and capacity building. • ***(S1-2) Policies promoting intermediaries / one-stop shops (OSS)***, which provide property owners easy access to integrated technical and financial information (Boza-Kiss et al., 2021). • *(S1-3, 4)* **Scaling up building decarbonisation options in public buildings** helps to increase market penetration and thus reduce market prices for these technologies. Governments can apply net zero embodied carbon standards for new public buildings and large public building renovations (World Green Building Council, 2019)
Technological	**Governance and planning instruments**	• ***(S2) District energy planning*** takes a systemic approach integrating energy demand (considering energy performance of new buildings and energy retrofits) and supply at district level; renewable-based modern district heating network in place. • ***(S2)*** Government promotes the development of efficient renewable-based ***district energy networks*** • ***(S2) Mandatory planning requirements*** to investors regarding building shape, size, and siting, and integration of low carbon energy supply
	"Soft" instruments	• ***(S1-2, 4) RD&D policies*** foster innovations of design concepts for highly energy efficient buildings and novel heating/cooling technologies, serial building renovations (*bigEE*, n.d.), low-embodied emission buildings(World Green Building Council, 2019). • ***(S1-2, 4) Training and education*** to provide the workforce with the necessary knowledge and skills (European Commission, 2011). • ***(S1-2, 4) Certification of qualified actors*** to ensure accurate, optimal, and safe services and to enhancing confidence of investors/users on the services delivered (*bigEE*, n.d.)
Sociocultural	**"Soft" instruments**	• ***(S1-2) Building rating and disclosure policies*** inform building owners and occupants regarding the energy use of the building. (*bigEE*, n.d.; BPIE, 2014; Subramanian et al., 2022). • ***(S3) Energy labelling schemes for products*** inform consumers about energy consumption of the products, aiming to pull the market towards higher efficiency (*bigEE*, n.d.). The labels can also provide a basis for incentive programs (IEA, 2022a) • ***(S1-2) Feedback measures***, such as smart metering, informative/comparative billing, energy saving contests, dedicated

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		apps, combined with practical tips for energy-efficient behaviour and its potential energy and cost savings, could potentially motivate users to change their behaviour (*bigEE*, n.d.). • *(S4)* Requiring the ***disclosure of environmental data*** for building products and materials in accepted forms (e.g., EPDs)(World Green Building Council, 2019) • ***(S1-5) General information provision*** raises awareness about decarbonisation options and their cost-effectiveness among key stakeholders*;* • *(S1-2)* Policies ***supporting target energy advices*** helps property owners to identify concrete energy saving opportunities and to assess the related costs and benefits • ***(S5) Policies supporting energy sufficiency advice*** to inform consumers about their alternatives to save energy when they purchase or use appliances (Thomas et al., 2019)

S1: Reducing energy demand through building envelope design and technologies, efficient operation

S2: Shift from fossil-fuel-based and low-efficient to low carbon heating, cooling, and cooking

S3: Use of highly energy efficient appliance and lighting

S4: Minimize embodied carbon of buildings, which will play an increasingly important role when buildings become more efficient

S5: Sufficiency measures

2.4.4 Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction

Depending on implementation, mitigation action in the buildings sector can contribute positively to no less than 16 of the 17 Sustainable Development Goals (SDGs), which can be leveraged to promote respective activities. Positive impacts are for example health and environmental benefits due to reduced local air pollution, poverty alleviation due to decreased energy expenditures, job creation, and reducing gender inequalities by reducing the need for collecting fuel wood (Cabeza et al., 2022a).

However, existing work has characterised incumbent buildings, construction and energy companies as an institutionalised force actively perpetuating conservative, unsustainable building practices (Gibbs & O'Neill, 2015; Lowes, Woodman, et al., 2020; Reda et al., 2021; Smith, 2007). Another fundamental issue is the high number of relevant actors (constructors, building product producers, building managers, architects, engineers, owners, occupants, investors, trades people, equipment manufacturers, suppliers, lenders, insurers, codes and standards setters, zoning officials, realtors and others), many of which have low degrees of capacity and knowledge about climate-friendly design options. Effective policies are therefore needed to align all of these actors towards decarbonisation (Cabeza et al., 2022a; Höfele & Thomas, 2011). In addition, there is a broad range of further barriers.

Table 1 summarises major barriers identified from literature review. The table categorises enablers and barriers according to their relevance at either the macro or micro level. The macro-level includes systemic issues, policy frameworks, overarching strategies and global trends that may impact emissions reduction efforts. The micro-level analysis comprises specific, localised factors, including individual behaviours, technological innovations, and

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country/community-level challenges.

Table 13: Overview of factors affecting the transformation in the buildings sector and buildings-related emissions

Dimensions	Enablers	Barriers
Geophysical feasibility	Macro • Most sustainable building technologies are not limited by materials (Cabeza et al., 2022a) • Measures to promote sufficiency, energy efficient building construction/renovations, as well as low carbon heating and cooling reduce natural resource consumption (fossil fuels, metal ores, minerals) associated with final energy consumption (Thema et al. 2017 in Pathak et al., 2022) • Advanced construction methods and reuse of building materials can reduce consumption of raw materials (Cabeza et al., 2022a) • Much room for improvements in energy efficiency, especially in developing countries (Cabeza et al., 2022a) Micro • Green roofs reduce heat gains and losses (Cabeza et al., 2022a) • New sustainable insulation materials have been developed (Cabeza et al., 2022a)	Macro • Using biomass for heating and cooking may reduce the available land for food production (Cabeza et al., 2022a) • Potential regional scarcity of renewable resources and low carbon construction materials depending on scale of adoption (Cabeza et al., 2022a) Micro • Limited suitability of renewable-based heating and cooling in certain buildings with limited roof space for solar thermal, historical/heritage buildings with planning limits, etc. (IRENA, IEA, et al., 2020); • Production of sustainable materials requires significant energy consumption (Cabeza et al., 2022a)
Environmental-ecological feasibility	Macro • Sufficiency and building energy measures that reduce fossil fuel demand can improve air quality and biodiversity (Cabeza et al., 2022a) • New building modelling approaches can improve the assessments of environmental impacts (Cabeza et al., 2022a).	Macro • switch to more efficient appliances could result in negative impacts from increased resource use, which can be mitigated by avoiding premature replacement and maximising the recycling of old appliances (Cabeza et al., 2022a) Micro • Low carbon construction materials like wood and bamboo normally use petroleum-based

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	Micro • Clean heating and cooking can reduce a) indoor air pollution and thus adverse health impacts on households; b) reduce fossil fuel use for heating and cooking and thus improve outdoor air quality Karlsson et al. 2020; Balaban and 22 Puppim de Oliveira 2017; MacNaughton et al. 2018; Levy et al. 2016 in Pathak et al., 2022 • Green roofs and walls and reduced air pollution enhance biodiversity (Cabeza et al., 2022a) • Reducing water consumption through reduced energy demand (Cabeza et al., 2022a)	adhesives, which can release toxic gases (Cabeza et al., 2022a) • Those materials could lead to an increased water demand and support monoculture forest production (Cabeza et al., 2022a) • Bioenergy may have both positive and negative impacts on biodiversity (Cabeza et al., 2022a)
Technological Feasibility	Macro • Many advanced construction methods are widespread in developed countries (Cabeza et al., 2022a) • Insulation technologies are generally well-developed, while transparent insulation materials and phase change materials need further R&D (Cabeza et al., 2022a) • Sustainable heating and cooling technologies are widely implemented at all scales (Cabeza et al., 2022a) • Hybridisation between several technologies can achieve better results (Cabeza et al., 2022a)	Macro • Challenges to the power grid system due to the increasing electrification of heating and cooling (Love et al., 2017; Lowes, Rosenow, et al., 2020a). • Limited maturity of specific technologies such as solar cooling (Sheldon et al., 2018); • Circular solutions have varying technological complexity (Cabeza et al., 2022a) • It is difficult to use advanced construction methods on larger scale projects (Cabeza et al., 2022a) Micro • Shortage of skilled workers for energy retrofits and heat pumps installation (IEA, 2022b), • Lack of technical capacity of implementing low-embodied-carbon building solutions and applying life cycle approach (World Green Building Council, 2019) • Lack of high quality, robust data for building energy performance and life cycle analysis of building materials (Cabeza et al., 2022a)

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		• Some bio-based materials such as bio-concrete aren't widely spread right now. Others are still in research phase (Cabeza et al., 2022a) • Missing technical support at local places to implement technologies (Cabeza et al., 2022a)
Economic feasibility	Macro • Jobs creation from investment in building retrofits or the construction of new energy efficient buildings (International Energy Agency, 2020 in Pathak et al., 2022). estimated 9-30 jobs generated for every million dollars of investment. Micro • Improvements in labour productivity (Cabeza et al., 2022a) • Renewable energies have become cost-effective in several regions (Cabeza et al., 2022a) • Demand-side management measures (e.g., sensors, controls, energy consumption feedback measures) are mature and usually cost-effective (Cabeza et al., 2022a)	Macro • Increasing population, rapid urbanisation and building stock growth drive increase in energy demand, outweighing efficiency improvements (Zhou et al., 2018; IEA, 2021b) Micro • Incumbent heating infrastructure associated with significant sunk costs invested by gas utility companies (Lowes et al., 2022a; Nadel, 2019) • Higher upfront costs and longer payback time to invest in building energy efficiency measures, renewable energy technologies, and low-embodied carbon materials (e.g. Ürge-Vorsatz et al., 2020; Cohn & Esram, 2022; IEA, 2020), which is aggravated by split incentives (Höfele & Thomas, 2011; Cohn & Esram, 2022; IEA, 2020; IRENA et al., 2020; IEA, 2022) • Potentially high operational costs for electrification (IRENA et al., 2020; Lowes et al., 2022; IEA, 2022) • Lack of access to affordable finance by investors (e.g., Climate Action Tracker, 2022), to a large extent due to lacking technical knowledge among capital providers, perception of high lending and investment risk due to the lack of track records of lenders, low collateral asset value, long project lifetimes, high performance risks, small size of individual building projects and correspondingly high transaction costs (G20 EEFTG, 2017). • It is costly for suppliers of components and material to transition, which is aggravated by high uncertainty about market demand

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		for energy efficiency options (Höfele & Thomas, 2011; Cohn & Esram, 2022; Park et al., 2021). • Perception of higher costs of circular construction methods (Cabeza et al., 2022a)
Sociocultural feasibility	Macro • Improvement of energy security and reduction of fossil fuel dependence (Cabeza et al., 2022a) Micro • Energy efficiency measures result in reduced energy expenditures for households and thus help to alleviate poverty (Cabeza et al., 2022a) • Envelope, heating and cooling improvements and efficient appliances usually perceived as increasing comfort and status (Cabeza et al., 2022a) • Improved indoor temperature and thermal comfort due to improved building envelope and adequate ventilation could a) reduce winter mortality and morbidity rates due to respiratory and cardiovascular diseases, arthritic and rheumatic illnesses, asthma, etc. (Camprubí et al., 2016; Wilson et al., 2016; Thema et al. 2017 in Pathak et al., 2022) b) improve mental health caused by chronic discomfort and high energy bills Howden-Chapman et al. 2012; Payne et al., 2015; Wilson et al. 2016 in Pathak et al., 2022). • Clean heating and cooking can reduce the time that women spend collecting fuel and thus increase other activities (Jeuland et al., 2018 in Pathak et al., 2022)	Micro • Building occupants' value and behaviour, e.g. demand for more living space (Bierwirth & Thomas, 2015). • Lack of information and knowledge about building energy efficiency and low carbon heating/cooling options along the whole value chain (Höfele & Thomas, 2011; IEA, 2020; IRENA, IEA, et al., 2020; Mata et al., 2021) • Barriers to new construction methods include information interaction between softwares, insufficient technical training for employees, cultural resistance (Cabeza et al., 2022a) • presence of volatile organic compounds in biomaterials, which can impede social acceptance (Cabeza et al., 2022a) • Energy performance improvements and deployment of cleaner fuels can lead to rebound effects (Cabeza et al., 2022b) • Embodied energy and carbon are not well understood and there is false perception that embodied carbon is relatively insignificant(World Green Building Council, 2019)

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	• Bio-based materials can be well accepted for being natural and aesthetically pleasing, but in many developing countries are associated with low building quality (Cabeza et al., 2022a) • Reduced consumption of natural resources improves quality of life (Cabeza et al., 2022a) • Efficient appliances are resulting in lower energy bills and decrease long term poverty (Cabeza et al., 2022a) • Digitalisation can enable dynamic tariff schemes, management of peak demand, reduce price volatility etc. (Cabeza et al., 2022a)	
Institutional feasibility	Micro • Generally high acceptance and promotion of renewable energy systems in many countries (Cabeza et al., 2022a) • Strong support for appliances labelling and standards in many countries (Cabeza et al., 2022a)	Micro • Mismatch between long-term commitment needed given long lifetimes and investment cycles on the one hand and short-term election cycles on the other (UNEP, 2020) • Absence of clear policy signals to the market, e.g. ambitious targets, roadmaps and policy instruments such as building codes, and lack of enforcement (Cabeza et al., 2022a; Gaur et al., 2021; IEA, 2021a, 2022b; UN Climate Change, 2021). E.g., in 2020, still about two-thirds of countries lacked mandatory building energy codes (IEA, 2021b). • Permitting installation of fossil-fuel heating in new buildings and replacement in existing buildings (Lowes et al., 2022a) • Subsidies for fossil fuels and fossil boilers (IRENA, IEA, et al., 2020). • Low or area-based energy prices for residential use creating little incentives for saving, e.g., in China (Zhu, 2020), Turkey (Taranto et al., 2019), Mexico (WRI, 2019); • A lack of information and knowledge about building energy efficiency and low carbon heating/cooling options along the whole value chain (Höfele & Thomas, 2011; IEA,

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		2020; IRENA, IEA, et al., 2020; Mata et al., 2021) • A lack of reliable data on energy performance and cost savings after the implementation of measures (Criado-Perez et al., 2020) • barriers to the uptake of alternative materials include perceptions of high cost, ineffective allocation of responsibility, industry culture, lack of skills of technicians and companies, and the poor availability of product and building-level carbon data and benchmarks (Cabeza et al., 2022a) • Legal and administrative barriers to demand-side management (Cabeza et al., 2022a)

2.4.5 Buildings Bibliography

- Bienvenido-Huertas, D., Rubio-Bellido, C., Pérez-Fargallo, A., & Pulido-Arcas, J. A. (2020). Energy saving potential in current and future world built environments based on the adaptive comfort approach. *Journal of Cleaner Production*, *249*, 119306. https://doi.org/10.1016/j.jclepro.2019.119306
- Bierwirth, A., & Thomas, S. (2015). Almost best friends: Sufficiency and efficiency. Can sufficiency maximise efficiency gains in buildings? *ECEEE SUMMER STUDY PROCEEDINGS*.
- *bigEE*. (n.d.). Retrieved 30 June 2022, from https://bigee.net/
- Bloess, A., Schill, W.-P., & Zerrahn, A. (2018). Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials. *Applied Energy*, *212*, 1611–1626. https://doi.org/10.1016/j.apenergy.2017.12.073
- Boza-Kiss, B., Bertoldi, P., Della Valle, N., & Economidou, M. (2021). *One-stop shops for residential building energy renovation in the EU: Analysis & policy recommendations.* Publications Office of the European Union. https://data.europa.eu/doi/10.2760/245015
- Boza-Kiss, B., Bertoldi, P., & Economidou, M. (2017). *Energy Service Companies in the EU: Status review and recommendations for further market development with a focus on Energy Performance Contracting* (EUR 28716 EN). Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC106624
- BPIE. (2014). *Energy performance certificates across the EU*. BPIE - Buildings Performance Institute Europe. https://www.bpie.eu/publication/energy-performance-certificates-across-the-eu/
- Cabeza, L. F., Bai, Q., Bertoldi, P., Kihila, J., Lucena, A. F. P., Mata, É., Mirasgedis, S., Novikova, A., & Saheb, Y. (2022a). *Chapter 9: Buildings Supplementary Material. In: IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.
- Cabeza, L. F., Bai, Q., Bertoldi, P., Kihila, J. M., Lucena, A. F. P., Mata, É., Mirasgedis, S., Novikova, A., & Saheb, Y. (2022b). *Buildings. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on*

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Climate Change (P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley, Eds.). Cambridge University Press. https://doi.org/10.1017/9781009157926.011

- Cao, X., Dai, X., & Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. *Energy and Buildings*, *128*, 198–213. https://doi.org/10.1016/j.enbuild.2016.06.089
- Carbon Trust, et al. (2020). *CLIMATE ACTION PATHWAY Net-Zero Cooling*.
- Churkina, G., Organschi, A., Reyer, C. P. O., Ruff, A., Vinke, K., Liu, Z., Reck, B. K., Graedel, T. E., & Schellnhuber, H. J. (2020). Buildings as a global carbon sink. *Nature Sustainability*, *3*(4), Article 4. https://doi.org/10.1038/s41893-019-0462-4
- Climate Action Tracker. (2022). *Decarbonising buildings: Achieving zero carbon heating and cooling*. Climate Action Tracker. https://climateactiontracker.org/publications/decarbonising-buildings-achieving-net- zero-carbon-heating-and-cooling
- Cohn, C., & Esram, N. W. (2022). *Building Electrification: Programs and Best Practices*. American Council for an Energy-Efficient Economy. aceee.org/researchreport/ b2201
- Criado-Perez, C., Collins, C. G., Jackson, C. J., Oldfield, P., Pollard, B., & Sanders, K. (2020). Beyond an 'informed opinion': Evidence-based practice in the built environment. *Architectural Engineering and Design Management*, *16*(1), 23–40. https://doi.org/10.1080/17452007.2019.1617670
- Fonseca, J. A., & Schlueter, A. (2015). Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. *Applied Energy*, *142*, 247–265. https://doi.org/10.1016/j.apenergy.2014.12.068
- G20 EEFTG. (2017). *G20 Energy Efficiency Investment Toolkit*. G20 Energy Efficiency Finance Task Group.
- Gaur, A. S., Fitiwi, D. Z., & Curtis, J. (2021). Heat pumps and our low-carbon future: A comprehensive review. *Energy Research & Social Science*, *71*, 101764. https://doi.org/10.1016/j.erss.2020.101764
- Gibbs, D., & O'Neill, K. (2015). Building a green economy? Sustainability transitions in the UK building sector. *Geoforum*, *59*, 133–141. https://doi.org/10.1016/j.geoforum.2014.12.004
- Hoefele, V., & Thomas, S. (2011, June 6). *Combining theoretical and empirical evidence*. ECEEE 2011 Summer Study.
- Höfele, V., & Thomas, S. (2011). *Combining theoretical and empirical evidence: Policy packages to make energy savings in buildings happen. Conference paper for the 2011 eceee Summer Study*. 1321–1327. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2011/5-saving-energy-in-buildings-the-time-to-act-is-now/combining-theoretical-and-empirical-evidence-policy-packages-to-make-energy-savings-in-buildings-happen/
- IEA. (2018). *The Future of Cooling*. https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf
- IEA. (2021a). *Building Envelopes*. International Energy Agency. https://www.iea.org/reports/heating
- IEA. (2021b). *Building Envelopes*. https://www.iea.org/reports/building-envelopes
- IEA. (2021c). *India Energy Outlook 2021*. OECD. https://doi.org/10.1787/ec2fd78d-en
- IEA. (2021d). *Net Zero by 2050—A Roadmap for the Global Energy Sector*.
- IEA. (2021e). *Tracking Buildings 2021*. International Energy Agency. https://www.iea.org/reports/tracking-buildings-2021
- IEA. (2022a). *Roadmap for Energy-Efficient Buildings and Construction in ASEAN: Timelines and actions*

towards net zero-carbon buildings and construction. OECD. https://doi.org/10.1787/bda80fad-en

- IEA. (2022b). *The Future of Heat Pumps* (p. 110). IEA.
- IEA. (2020). *Tracking Cooling 2020 – Analysis*. IEA. https://www.iea.org/reports/tracking-cooling-2020
- IRENA, IEA, & REN21. (2020). *Renewable Energy Policies in a Time of Transition: Heating and Cooling*. IRENA, OECD/IEA and REN21.
- IRENA, OECD/IEA, & REN21. (2020). *Renewable energy policies in a time of transition: Heating and cooling*. IRENA, OECD/IEA and REN21. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_IEA_REN21_Policies_Heating_Cooling_2020.pdf
- Jeuland, M., Tan Soo, J.-S., & Shindell, D. (2018). The need for policies to reduce the costs of cleaner cooking in low income settings: Implications from systematic analysis of costs and benefits. *Energy Policy*, *121*(C), 275–285.
- Johnson, K., Volker, M., Bhedwar, C., & Ambach, G. (2016). *Digging Deeper for Energy Savings: A Look at Successful On-Bill Financing Program Designs*. 12.
- Jungclaus, M., Olgyay, V., Rempher, A., & Esau, R. (2021). *Reducing Embodied Carbon in Buildings: Low-Cost, High-Value Opportunities*. RMI.
- Kern, F., Kivimaa, P., & Martiskainen, M. (2017). Policy packaging or policy patching? The development of complex energy efficiency policy mixes | Elsevier Enhanced Reader. *Energy Research and Social Science*, *23*, 11–25. https://doi.org/10.1016/j.erss.2016.11.002
- Kuhnhenn, K., Costa, L., Mahnke, E., Schneider, L., & Lange, S. (2020). *A Societal Transformation Scenario for Staying Below 1.5C.pdf*. Heinrich Böll Foundation. https://www.boell.de/sites/default/files/2020-12/A%20Societal%20Transformation%20Scenario%20for%20Staying%20Below%201.5C.pdf
- Liddle, B., & Huntington, H. (2021). How prices, income, and weather shape household electricity demand in high-income and middle-income countries. *Energy Economics*, *95*, 104995. https://doi.org/10.1016/j.eneco.2020.104995
- Lin, B., & Liu, H. (2015). China's building energy efficiency and urbanization. *Energy and Buildings*, *86*, 356–365. https://doi.org/10.1016/j.enbuild.2014.09.069
- Love, J., Smith, A. Z. P., Watson, S., Oikonomou, E., Summerfield, A., Gleeson, C., Biddulph, P., Chiu, L. F., Wingfield, J., Martin, C., Stone, A., & Lowe, R. (2017). The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy*, *204*, 332–342. https://doi.org/10.1016/j.apenergy.2017.07.026
- Lowes, R., Rosenow, J., Qadrdan, M., & Wu, J. (2020a). Hot stuff: Research and policy principles for heat decarbonisation through smart electrification. *Energy Research & Social Science*, *70*, 101735. https://doi.org/10.1016/j.erss.2020.101735
- Lowes, R., Rosenow, J., Qadrdan, M., & Wu, J. (2020b). Hot stuff: Research and policy principles for heat decarbonisation through smart electrification. *Energy Research & Social Science*, *70*, 101735. https://doi.org/10.1016/j.erss.2020.101735
- Lowes, R., Rosenow, J., Scott, D., Sunderland, L., Thomas, S., Graf, A., Baton, M., Pantano, S., & Graham, P. (2022a). *The perfect fit: Shaping the Fit for 55 package to drive a climate-compatible heat pump market*. Regulatory Assistance Project, Agora Energiewende, CLASP, Global Buildings Performance Network.
- Lowes, R., Rosenow, J., Scott, D., Sunderland, L., Thomas, S., Graf, A., Baton, M., Pantano, S., & Graham,

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P. (2022b). *The perfect fit: Shaping the Fit for 55 package to drive a climate-compatible heat pump market*. Regulatory Assistance Project, Agora Energiewende, CLASP, Global Buildings Performance Network. https://www.raponline.org/wp-content/uploads/2022/03/RAP-heat-pump-report-FINAL_2022_03.pdf

- Lowes, R., Woodman, B., & Speirs, J. (2020). Heating in Great Britain: An incumbent discourse coalition resists an electrifying future. *Environmental Innovation and Societal Transitions*, *37*, 1–17. https://doi.org/10.1016/j.eist.2020.07.007
- Mata, É., Peñaloza, D., Sandkvist, F., & Nyberg, T. (2021). What is stopping low-carbon buildings? A global review of enablers and barriers. *Energy Research & Social Science*, *82*, 102261. https://doi.org/10.1016/j.erss.2021.102261
- Mckinlay, A., Baldwin, C., & Stevens, N. (2017). Size Matters: Dwelling Size as a Critical Factor for Sustainable Urban Development. *Urban Policy and Research*, *37*, 1–16. https://doi.org/10.1080/08111146.2017.1374944
- Mills, E. (2016). Job creation and energy savings through a transition to modern off-grid lighting. *Energy for Sustainable Development*, *33*, 155–166. https://doi.org/10.1016/j.esd.2016.06.001
- Nadel, S. (2019). Electrification in the Transportation, Buildings, and Industrial Sectors: A Review of Opportunities, Barriers, and Policies. *Current Sustainable/Renewable Energy Reports*, *6*(4), 158–168. https://doi.org/10.1007/s40518-019-00138-z
- OECD/IEA. (2013). *Technology Roadmap Energy Efficient Building Envelopes*.
- Park, W. Y., Shah, N., Vine, E., Blake, P., Holuj, B., Kim, J. H., & Kim, D. H. (2021). Ensuring the climate benefits of the Montreal Protocol: Global governance architecture for cooling efficiency and alternative refrigerants. *Energy Research & Social Science*, *76*, 102068. https://doi.org/10.1016/j.erss.2021.102068
- Pathak, M., Slade, R., Pichs-Madruga, R., Ürge-Vorsatz, D., Shukla, P. R., Skea, J., Abdulla, A., Al Khourdajie, A., Babiker, M., Bai, Q., Bashmakov, I., Bataille, C., Berndes, G., Blanco, G., Cabeza, L. F., Carraro, C., Clarke, L., de Coninck, H., Creutzig, F., … Winkler, H. (2022). *Working Group III contribution to the IPCC Sixth Assessment Report (AR6). Technical Summary*.
- Pathak, M., Slade, R., Shukla, P. R., Skea, J., Pichs-Madruga, R., & Ürge-Vorsatz, D. (2022). *Climate Change 2022 Mitigation of Climate Change Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.
- Reda, F., Ruggiero, S., Auvinen, K., & Temmes, A. (2021). Towards low-carbon district heating: Investigating the socio-technical challenges of the urban energy transition. *Smart Energy*, *4*, 100054. https://doi.org/10.1016/j.segy.2021.100054
- Rosenow, J., Cowart, R., & Thomas, S. (2019). Market-based instruments for energy efficiency: A global review. *Energy Efficiency*, 37. https://doi.org/10.1007/s12053-018-9766-x
- Rosenow, J., Kern, F., & Rogge, K. (2017). The need for comprehensive and well targeted instrument mixes to stimulate energy transitions_ The case of energy efficiency policy | Elsevier Enhanced Reader. *Energy Research & Social Science*, *33*(95–104). https://doi.org/10.1016/j.erss.2017.09.013
- Saheb, Y. (2021). *COP26: Sufficiency Should be First*. https://www.buildingsandcities.org/insights/commentaries/cop26-sufficiency.html
- Sandberg, M. (2018). Downsizing of Housing: Negotiating Sufficiency and Spatial Norms. *Journal of Macromarketing*, *38*(2), Article 2. https://doi.org/10.1177/0276146717748355
- Setyawan, D. (2014). Formulating Revolving Fund Scheme to Support Energy Efficiency Projects in Indonesia. *Energy Procedia*, *47*, 37–46. https://doi.org/10.1016/j.egypro.2014.01.194

Funded by the European Union

- Sheldon, M., Sethuvenkatraman, S., & Goldsworthy, M. (2018). *Promoting the Use of Solar Cooling and Heating in Australia Buildings (PUSCH): An Industry Roadmap*. Australian Renewable Energy Agency.
- Smith, A. (2007). Translating Sustainabilities between Green Niches and Socio-Technical Regimes. *Technology Analysis & Strategic Management*, *19*(4), 427–450. https://doi.org/10.1080/09537320701403334
- Subramanian, S., Bastian, H., Jennings, B., Tolentino, C., Vaidyanathan, S., & Nadel, S. (2022). *INTERNATIONAL ENERGY EFFICIENCY SCORECARD*.
- Thomas, S., Sunderland, L., & Santini, M. (2021). *Pricing is just the icing: The role of carbon pricing in a comprehensive policy framework to decarbonise the EU buildings sector* (p. 55). RAP.
- Thomas, S., Thema, J., Brischke, L.-A., Leuser, L., Kopatz, M., & Spitzner, M. (2019). Energy sufficiency policy for residential electricity use and per-capita dwelling size. *Energy Efficiency*, *12*(5), Article 5. https://doi.org/10.1007/s12053-018-9727-4
- UN Climate Change. (2021). *Climate Action Pathway Human Settlements 2021. Vision and Summary*. https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/human-settlements-climate-action-pathway#eq-1
- UNEP. (2020). *Adopting decarbonization policies in the buildings & construction sector: Costs and Benefits*. United Nations Environment Programme. https://globalabc.org/resources/publications/adopting-decarbonization-policies-buildings-and-construction-sector
- Ürge-Vorsatz, D., Khosla, R., Bernhardt, R., Chan, Y. C., Vérez, D., Hu, S., & Cabeza, L. F. (2020a). Advances Toward a Net-Zero Global Building Sector. *Annual Review of Environment and Resources*, *45*(1), 227–269. https://doi.org/10.1146/annurev-environ-012420-045843
- Ürge-Vorsatz, D., Khosla, R., Bernhardt, R., Chan, Y. C., Vérez, D., Hu, S., & Cabeza, L. F. (2020b). Advances Toward a Net-Zero Global Building Sector. *Annual Review of Environment and Resources*, *45*(1), 227–269. https://doi.org/10.1146/annurev-environ-012420-045843
- Ürge-Vorsatz, D., Koeppel, S., & Mirasgedis, S. (2007). Appraisal of policy instruments for reducing buildings' CO2 emissions. *Building Research & Information*, *35*(4), 458–477. https://doi.org/10.1080/09613210701327384
- World Green Building Council. (2019). *Bringing embodied carbon upfront*.
- WRI. (2019). *Accelerating Building Decarbonization: Eight Attainable Policy Patways to Net Zero Carbon Buildings for All*. 84.
- Zhou, N., Khanna, N., Feng, W., Ke, J., & Levine, M. (2018). Scenarios of energy efficiency and CO2 emissions reduction potential in the buildings sector in China to year 2050. *Nature Energy*, *3*(11), Article 11. https://doi.org/10.1038/s41560-018-0253-6
- Zhu, X. (2020). China's Remarkable Success in Developing ESCOs: Current Status, Policy Drivers, and Prospects. In *Incorporating Energy Service Companies in Nationally Determined Contributions—The potential of ESCOs for meeting the climate goals in the Paris Agreement* (pp. 119–133).

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2.5 AFOLU

2.5.1 Introduction

Land, including its water bodies, provides the basis for human livelihoods and well-being through primary productivity, the supply of food, freshwater and other ecosystem services (IPCC, 2019). In the context of national greenhouse gas (GHG) inventories under the United Nations Framework Convention on Climate Change (UNFCCC), AFOLU is the sum of the GHG inventory sectors Agriculture and Land Use, Land-Use Change and Forestry (LULUCF) (Nabuurs et al., 2022). It includes activities related to agriculture, forestry, and land use that contribute to GHG emissions or removals.

The AFOLU sector has unique characteristics that differentiate it from other sectors in the context of climate change mitigation: the sector possesses the capacity to reduce emissions naturally (without relying solely on low carbon technology), remove significant amounts of carbon from the atmosphere affordably, and provide raw materials for mitigation efforts in other sectors, such as in power, industry or the built environment (Nabuurs et al., 2022). AFOLU activities accounted for 13% of CO2 emissions, 44% of methane (CH4) emissions, and 81% of nitrous oxide (N2O) emissions globally from 2007 to 2016 (Nabuurs et al., 2022). However, there is a discrepancy in the reported AFOLU GHG emissions fluxes magnitude because of alternative methodological approaches[3].

By 2015, about three-quarters of the global ice-free land surface was affected by human use (IPCC, 2019). The AFOLU sector can contribute up to 30% of global mitigation efforts in deep mitigation scenarios (Nabuurs et al., 2022). Despite this potential, the AFOLU sector has only modestly contributed to global emissions reduction so far (Nabuurs et al., 2022). During the period of 2010-2019, past policies achieved approximately 0.65 GtCO2 per year of mitigation, which accounts for only 1.4% of global gross emissions (Nabuurs et al., 2022). The majority of these emission reductions came from forestry measures (Nabuurs et al., 2022).

The implementation of AFOLU mitigation measures faces persistent barriers, including economic and political feasibility or cultural values, governance, accountability, and institutional capacity (Nabuurs et al., 2022). Climate change itself could become a barrier, although there is medium confidence that the capacity of natural sinks may increase despite climate changes (Nabuurs et al., 2022). The ongoing loss of biodiversity reduces ecosystem resilience to climate extremes and may jeopardise the attainment of AFOLU mitigation potentials (Nabuurs et al., 2022). Overcoming the barriers mentioned before is crucial for achieving significant short-term mitigation. Collaborative efforts are needed among diverse stakeholders, including businesses, producers, consumers, land managers, indigenous communities, and policymakers, to establish favourable conditions for adopting response strategies (IPCC, 2019). Different response options are available across various scales, forming a mix of measures implemented by different parties, from local to global levels (IPCC, 2019). The success of these actions also relies on broader scales, such as national and international markets, trade agreements, and consumer preferences (IPCC, 2019). The land and food sectors struggle with fragmented institutions and limited interaction among stakeholders at different levels (IPCC, 2019).

[3] Three categories of processes contribute to GHG fluxes: direct human-induced effects, indirect human-induced effects and natural effects. The IPCC and FAOSTAT use the 'managed land' concept, but FAOSTAT may overestimate anthropogenic fluxes. Bookkeeping models and dynamic global vegetation models (DGVMs) estimate anthropogenic land GHG fluxes but may not include all relevant practices covered by inventories. DGVMs tend to yield higher emissions estimates compared to bookkeeping models (Nabuurs et al., 2022).

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2.5.2 Main mitigation strategies in the target sector: What changes/transformations are needed in what timelines to achieve net-zero by mid-century?

Table 14: Mitigation Options and GHG emission reduction potential in the AFOLU-sector

Sub-sector	Mitigation Option	Mitigation Potential (tCO2-eq per year)[4]
Agriculture		4.1. (1.7. - 6.7)^{S} 1.8 (0.7 - 3.3)^{I}
	Carbon Sequestration (soil carbon management in croplands, agroforestry, and biochar)	3.4. (1.4 - 5.5)^{S}
	Reduce CH_4 and N_2O emissions (improve enteric fermentation, manure management, nutrient management, and rice cultivation)	0.6 (0.3 - 1.3)^{S} 1.8 (0.7 - 3.3)^{I}
Forests and other ecosystem		7.3 (3.9 - 13.1)^{S} 4.2 (0 - 12.1)^{I}
	Protection (reduce deforestation, loss and degradation of peatlands, coastal wetlands, and grasslands)	4.0 (2.5 - 7.4)^{S}
	Restoration (Afforestation, reforestation, peatland restoration, coastal wetland restoration)	2.1 (0.8 - 3.8)^{S} 0.7 (0.07 - 6.8)^{I}
	Management (Improve forest management, fire management)	1.2 (0.6 - 1.9)^{S}
Demand-sides measures	shift to healthy diets, reduce food waste, and improved use of wood products	2.2 (1.1 - 3.6)^{S}

[4] Option's combined potential per sub-sector and mitigation strategy (average, span). Values refer to mitigation potential at <USD 100 tCO2-eq–1. In the IPCC's AR6 report this cost is deemed the price at which society is willing to pay for mitigation and is used as a proxy to estimate the proportion of technical mitigation potential that could realistically be implemented. Higher mitigation is limited by technical potential and requires more investment. Values illustrate the cumulative global estimates for the individual measures (sectoral potentials S) and IAM (I) estimates where data is available (Nabuurs et al., 2022).

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BECCS	-	1.6. (0.5 - 3.5)[S] 1.8 (0.2 - 9.9)[I]

Two main approaches to estimating mitigation potentials are sectoral assessments and integrated assessment models (IAM) (Nabuurs et al., 2022). Sectoral assessments focus on individual measures or sectors, while IAMs assess the climate impact of multiple practices across sectors (Nabuurs et al., 2022). Three concepts—additionality, permanence, and leakage—are critical in evaluating and designing effective climate change mitigation strategies in the AFOLU sector (Nabuurs et al., 2022). Additionality aims for climate change mitigation efforts in the AFOLU sector that go beyond business-as-usual scenarios, and also preventing double-counting of emissions reductions. Permanence refers to long-term carbon storage or reduction, ensuring that the benefits derived from mitigation projects in the AFOLU sector are sustained and not reversible. Leakage refers to unintended consequences where emissions reductions in one area are offset by increased emissions in another, undermining overall mitigation effectiveness (Nabuurs et al., 2022).

2.5.2.1 Agriculture[5]

Carbon Sequestration

- **Soil carbon management** in croplands involves agricultural practices that increase soil organic matter and carbon sequestration, such as crop rotation, cover cropping, reduced tillage, and nutrient management.
- **Biochar** is a carbon-rich material produced through low-oxygen heating of organic matter, possessing long-lasting soil-enhancing properties when applied.
- **Agroforestry** encompasses land management approaches that integrate trees and shrubs with crops and/or livestock, either concurrently or sequentially, fostering carbon sequestration, heightened land productivity, diversified livelihoods, diminished soil erosion, enhanced water quality, and favourable regional climates.

Reduce CH_4 and N_2O emissions:

- **Improve enteric fermentation** involves reducing methane emissions from ruminant animals (the digestive process in ruminants is the primary source of CH4 emissions in agriculture) by modifying diet composition, using supplements and additives, implementing vaccination programs, and adopting livestock breeding and husbandry practices to enhance production efficiency and decrease emission intensity per unit of product.
- **Improved rice management** encompasses practices such as enhanced water management, residue handling, optimised fertiliser application, and the utilisation of soil amendments, aiming to reduce methane and nitrous oxide emissions, optimise nutrient uptake, and improve soil fertility during rice cultivation.
- **Crop nutrient management** entails optimising fertiliser use through strategies such as precise timing, appropriate rates, and suitable fertiliser types to minimise nitrous oxide emissions from agricultural soils, while integrated approaches like crop rotations, reduced tillage, and soil testing enhance nutrient uptake and tailored approaches like the 4R nutrient stewardship ensure efficient nutrient supply while minimising emissions.

[5] The following mitigation options were derived from Nabuurs et al. (2022).

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- **Manure management** encompasses various practices such as anaerobic digestion, inhibitors, composting, improved storage and application techniques, grazing practices, and dietary adjustments for livestock, aiming to mitigate methane and nitrous oxide emissions, minimise nitrogen excretion, and foster sustainable handling of manure.

2.5.2.2 FOLU

Protect

- **Reduce deforestation and degradation** involves implementing activities to prevent the loss and disturbance of tree cover, thus conserving existing carbon pools in forest vegetation and soil.
- **Reduce degradation and conversion of grasslands and savannas** involves preventing the conversion of these ecosystems into croplands, which helps avoid soil carbon losses and biomass carbon loss due to vegetation clearing.
- **Reduce degradation and conversions of peatlands activities** The mitigation option involves preventing the conversion of peatlands, which are carbon-rich wetland ecosystems with high concentrations of organic soil. By avoiding vegetation clearing, fires, and peat decomposition from drainage, emissions of above- and belowground biomass and soil carbon can be minimised.
- **Reduce conversion of coastal wetlands** Reducing the conversion of coastal wetlands, including mangroves, marshes, and seagrass ecosystems, helps avoid emissions from above and below-ground biomass and soil carbon through avoided degradation and loss.

Restore

- **Afforestation, reforestation, and forest ecosystem restoration** (A/R) encompass activities that involve converting land into forested areas, with reforestation focusing on restoring forests on previously forested land, afforestation targeting historically non-forested areas, and forest restoration emphasising ecological integrity alongside managed forests.
- **Peatland restoration** involves the rehabilitation of degraded and damaged peatlands through activities such as rewetting and revegetation. This restoration process increases carbon accumulation in vegetation and soils while avoiding ongoing CO2 emissions.
- **Coastal wetland restoration** Coastal wetland restoration involves restoring degraded or damaged coastal wetlands, including mangroves, salt marshes, and seagrass ecosystems. This restoration process promotes the sequestration of "blue carbon" in wetland vegetation and soil.

Management

- **Improved forest management** refers to sustainable practices implemented in already managed forests to enhance carbon stocks, improve wood quality and productivity, and mitigate the impacts of disturbances
- **Fire Management (Forest and Grassland/Savanna fires)***:* Fire management involves the prevention, detection, control, restriction, and overall management of fire in natural ecosystems with the objectives of safeguarding life, property, and resources.

2.5.2.3 Demand-side measures

- **Shift to sustainable healthy diets:** Refers to promoting dietary patterns that prioritise individuals' health and well-being while minimising environmental impact. These diets are characterised by a transition towards plant-based consumption, reduced consumption of animal-based foods, especially from ruminant animals.
- **Reduced food loss and waste** entails implementing strategies to minimise the loss and waste of edible

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food throughout the supply chain, involving investments in post-harvest technologies, incentives, regulations, reporting targets, and behavioural changes to reduce waste at various stages and ensure more efficient resource utilisation**.**

- **Improved and enhanced use of wood** products entails maximising the utilisation of harvested wood for materials, emphasising carbon storage and material substitution, achieved through sustainable management practices, prioritising long-lived products, extending product lifetimes, promoting recycling, and utilising wood as a substitute for energy-intensive materials like concrete or steel to reduce lifecycle emissions.
- **Fostering energy self-consumption** through renewable energy facilities (biomass, solar energy, etc.) and reducing transport losses (thereby increasing energy efficiency). This allows to indirectly occupying more land for energy purposes (areas occupied by solar infrastructure and power lines, bioenergy crops, etc.) (IEA, 2023).

2.5.2.4 Bioenergy and BECCS

Bioenergy and Bioenergy with Carbon Capture and Storage (BECCS) refers to the utilisation of renewable biomass sources to produce energy in the form of solid, liquid, or gaseous fuels, electricity, and heat. Bioenergy systems can reduce greenhouse gas (GHG) emissions by replacing fossil fuels with renewable biomass, thus contributing to climate change mitigation. When combined with carbon capture and storage (BECCS) and/or biochar production, bioenergy systems can also provide negative emissions by storing biogenic carbon in geological, terrestrial, or ocean reservoirs or in products. This approach has the potential to mitigate GHG emissions and facilitate carbon dioxide removal (CDR).

2.5.2.5 Solar energy deployment in land

A quick energy transition means a significant deployment of solar power energy on land, which can lead to land competition and local conflicts with other land resources (such as food), including impacts on biodiversity, carbon emissions (due to land use changes) and landscape. To avoid these negative consequences and promote a sustainable deployment of ground-based solar energy, some land-based measures can be adopted (Hernandez et al., 2019):

- **Prioritise construction of photovoltaic plants in areas not suitable for other uses.** Example of these suitable areas can be rooftops/buildings, on water bodies (e.g. floating solar photovoltaic panels), or on degraded and contaminated land.
- **Wind and solar repowering.** Upgrading or retrofitting renewable energy sources components. It exploits existing land sites, in which renewables have been operating for years.
- **Spatial planning for the deployment of energy on land.**
    - **Land protection of areas with ecological value** such as forests or grasslands.
    - **Sitting of power energy infrastructure** in places where they are more efficient (not only in terms of land price), and also in areas with scarce vegetation, avoiding those that have productive uses (e.g. forestland or cropland)
- **Agrivoltaics:** Solar-panel farms that provide biodiversity-friendly soil cover, and sustainable bioenergy. It can be combined with croplands and grasslands. It allows ecological restoration of the land under and around the PV panels (ENEL, 2022).

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2.5.3 Main mitigation enablers and barriers: Which factors are driving or holding up change, or currently driving change in the wrong direction?

Table 15: Overview of factors affecting the transformation in the AFOLU sector and AFOLU-related emissions

Sub-sector	Dimension	Enablers[6]	Barriers[7]
Agriculture (including livestock)	Geophysical feasibility	• Soil carbon management in croplands is feasible anywhere, while in grasslands, it is most effective in areas where degradation has occurred, and soil organic carbon is depleted • Maximising benefits of biochar application depends on context-specific factors, considering factors like feedstock, production conditions, and post-production treatments • Successful agroforestry implementation relies on contextual factors like water availability, soil fertility, seed access, land policies, tenure systems, credit access, and species suitability. Some of the co-benefits of its implementation consist of a better erosion control and an improved soil health (Jinger et al., 2022). • Tailored nutrient management, such as 4R nutrient stewardship optimises supply, minimises emissions, and enhances fertiliser performance • Manure management measures are applicable in all regions. They hold significant mitigation potential in Developed Countries and intensive production systems. While small-scale solutions like anaerobic digestion and manure spreading are effective in Asia, the Pacific, and Africa, developed countries could prioritise measures like tank or lagoon covers and large-scale anaerobic digestion for intensive production systems	• Soil types, percolation/seepage rates, precipitation fluctuations, water infrastructure and necessity of irrigation, paddy surface level, field size limit adoption of improved rice cultivation • Regional imbalances in nutrient availability, including surpluses from over-fertilisation and shortages with chronic deficiencies, can hinder effective crop nutrient management practices

[6] The following enablers for each individual mitigation option were derived from Nabuurs et al., 2022.
[7] The following barriers for each individual mitigation option were derived from Nabuurs et al., 2022.

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	Environmental-ecological feasibility	• Biochar has been associated with persistent yield response, improved crop water use efficiency, and reduced greenhouse gas and ammonia emissions from compost and manure, which further enhance its mitigation potential • Agroforestry leads to biodiversity that can support natural pest control, nutrient cycling, and overall ecosystem stability. • Practices of conservation agriculture (crop diversification, minimum soil disturbance, etc.) decrease land degradation and raise sustainability and biodiversity. Agriculture in urban and peri-urban areas enhances biodiversity as well as human well-being (Nunez et al., 2020).	• Additional fertilisation inputs can negate soil carbon sequestration, potentially increasing N2O emissions • Agroforestry can alter habitats, impacting plant and animal diversity • Rice water management practices can have opposing effects on methane (CH_4) and nitrous oxide (N_2O) emissions during the drying period, potentially offsetting mitigation benefits • Enteric fermentation measures risk long-term effectiveness, ecological impact from feed, additive toxicity, and animal welfare • Climate change can affect nutrient use efficiency and the effectiveness of crop nutrient management practices, impacting their mitigation potential • Limited evidence suggests that there may be eco-toxicity risks associated with certain manure management measures • Forest protection options like reduced deforestation or avoided forest conversion have moderate to high potential leakage risk. This situation is generated as a result from displacing land use or deforestation and, therefore, reducing biodiversity (Nunez et al., 2020).
	Technological feasibility	• Soil carbon management is already widely deployed globally, indicating a high level of technology readiness • Extensive studies have confirmed the long-term persistence of biochar carbon in soils, providing confidence in its potential as a carbon sequestration strategy • Research about the interactions between biochar, soil, microorganisms, and plants have provided insights into the potential benefits and optimisation of biochar application • Medium technical potential for enteric CH_4 emissions reduction technologies, research efforts in advancing these technologies can create a supportive environment • Advancements in precision fertilisation and nutrient management technologies enhance crop nutrient efficiency and fertiliser	• Difficulty in monitoring and verifying soil carbon management practices poses a barrier to implementation • Concerns exist regarding soil carbon storage capacity saturation and the permanence of carbon sequestration, potentially limiting the effectiveness of these practices • The absence of widespread and efficient biochar production facilities may restrict the capacity to produce and distribute biochar on a larger scale • The lack of comprehensive understanding, standardised practices, and quality control measures can undermine user confidence in biochar as a mitigation option • Early-stage development of manure management measures can hinder their practical implementation and effectiveness • Farmers may require training and guidance to implement nutrient management practices correctly, including understanding optimal fertiliser delivery, rates, timing, and

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		application (nutrient management) • Agroforestry, to obtain maximum yields, requires the development of technical advisory (mainly for a careful design and an initial planning and monitoring), as well as the establishment of professional training and the investment in R&D. One of the benefits of this practice is to increase the resilience of livestock by improving fodder production and providing additional sources of feed (Mosquera-Losada et al., 2017).	types for their specific crops and soil conditions • Fugitive emissions can diminish the potential mitigation benefits of biogas production, thereby limiting the effectiveness of manure management practices • There can be an antagonistic relationship between greenhouse gas and ammonia mitigation for manure management practices • Regarding agroforestry, limited access to some necessary resources such as tree seeds or machinery (IAEA & FAO, 2008). Disease management is another important barrier since its complexity is higher than in monoculture systems (Schroth et al., 2000).
	Economic feasibility	• Soil carbon management in croplands and grasslands is considered a low-cost option • Soil carbon management practices in croplands and grasslands provide co-benefits for livelihoods, biodiversity, water provision, and food security • Agroforestry offers multiple co-benefits beyond carbon sequestration, such as increased land productivity (and, therefore, an increase in income), diversified livelihoods, decrease in charges of fertilisers/pesticides, reduced soil erosion, and improved water quality. Additionally, it enhances the development of local rural economy including creating jobs and eco-tourism (Augere-Granier, 2020). • The economic viability of enteric fermentation measures is an important enabling condition for widespread implementation (e.g. circular economy is amplified through the use of biomass coming from trees).	• The lack of adequate financial resources and funding can hinder the scaling up of biochar production and implementation • Biochar production costs can be high, particularly when operating at a small scale, which may limit its affordability and widespread adoption • Agroforestry systems should be carefully managed to avoid food production impact compromising crop and livestock productivity when incorporating trees and shrubs. Moreover, agroforestry benefits take long periods to materialize, making it less attractive to farmers than other types of agriculture (Luedeling et al., 2016). • Improved crop nutrient management practices may be inaccessible or expensive for farmers due to limited access and affordability of resources such as precision fertilisers, organic manures, composts or nitrification inhibitors • High implementation costs, especially for anaerobic digestion, can pose a major obstacle to the adoptions of manure management measures
	Sociocultural feasibility	• Soil carbon management practices in croplands and grasslands provide co-benefits for livelihoods, biodiversity, water provision, and food security • Agroforestry supports recreational activities	Potential social barriers to the adoption of new practices in agriculture can be classified based on different groups (Dorner et al., 2018) including: • Behavioural: initial cost price influence behaviour, difficulties also

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		(hunting, fishing, horse-riding, mountain biking, wildlife watching, etc.) as well as offers a pleasant looking landscape. There are a lot of enablers for agroforestry such as the contribution to animal welfare, the development of student education (Mosquera-Losada et al., 2018), the reduction of risk fires, etc. • The adoption of mitigation measures for enteric fermentation can provide co-benefits such as enhanced climate change adaptation and increased food security • Improved rice management benefits resource utilisation, including water consumption and fertiliser application, water use efficiency, reduces overall water use, enhances drought adaptation, improves yield, reduces production costs and increases farm income • Improved crop nutrient management practices can generate co-benefits such as enhanced soil quality, carbon sequestration in soils and biomass, improved soil water holding capacity, adaptation capacity, increased crop yields, higher farm incomes, improved water quality, and reduced air pollution • Manure management measures can provide co-benefits such as enhanced nutrient recovery, improved fertiliser value, and secondary processes like biogas production	in the adoption of new practices (change of habits e.g. cutting trees is frowned upon in some cultures), etc. • Arguably efficient. • Informational barriers (not sufficient availability of information). • Externalities: e.g. GHG emissions, learning from others, etc. • Risk and uncertainty: as for example perceived risk due to not consolidated markets related to new farming activities, new skills that should be developed, etc. • Regulation and policy: due to the policies or the law. They can be a barrier or decrease the speed to the adoption of a policy. • Market structure and institutions (failure in these areas that can difficult the adoption, e.g. lack of training programmes). Examples: • Implementation of soil carbon management in croplands and grasslands may face challenges in specific regional contexts despite low overall socio-cultural and institutional barriers • Social implications and inequalities can arise in agroforestry systems due to factors like land access, credit, information, and resources. • Improved rice management farms may face challenges due to farmer perceptions, pump ownership, and difficulties in coordinating water management practices among neighbouring farms and pumping stations
	Institutional feasibility	• IPCC guidelines should include a quantification method for biochar properties, enabling precise assessment and reporting of biochar's mitigation potential in non-CO2 greenhouse gas inventories • For successful agroforestry implementation, support systems should offer tools, information, and resources to farmers, including policy reforms, improved extension	• Standardised methods and protocols are needed for monitoring, reporting, and verifying the carbon sequestration and other benefits resulting from biochar application • Implementing measures to mitigate CH4 emissions from enteric fermentation may face challenges related to feeding and administration practices as well as legal restrictions on emerging technologies • In some jurisdictions, the widespread application of certain manure management measures like

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		systems, and enhanced market opportunities	nitrification inhibitors may be limited due to concerns about residues in food products Unclear property rights of land in certain regions could lead to agroforestry being seen as an insecure practice (Murken & Gornott, 2022).
FOLU	Geophysical feasibility	• Coastal wetlands, particularly mangroves, have substantial carbon stocks • Especially peat forests located in tropical regions have high carbon stocks • Coastal wetland restoration has significant mitigation potential in countries with extensive coastlines and small island states where wetlands contribute significantly to carbon stocks	• Reducing peatland conversion limits the land available for alternative uses such as agriculture or other land-based mitigation options • Coastal wetlands could vanish from coastal squeeze without adjacent uplands for migration as sea levels increase • In severely degraded peatlands, restoration of peatland hydrology and vegetation may not be feasible
	Environmental-ecological feasibility	• Prioritising ecological integrity in forest restoration enhances the overall effectiveness of afforestation and reforestation • Strategic and sustainable approaches to afforestation and reforestation, taking into account factors like location, scale, tree species, and management practices, can maximise their benefits • Regional considerations, such as surface albedo and land conditions, further optimise outcomes • Climate change underscores the need for prioritising fire management strategies in response to more frequent extreme fire weather events	• Climate change can harm coastal wetlands, impacting productivity, and sediment build-up, undermining climate mitigation and conversion reduction efforts • Poorly planned afforestation can lower water yield, biodiversity, causing local trade-offs • Non-native species and monocultures in afforestation and reforestation can harm ecosystem structure, function, and water availability, especially in dry regions. • Climate change can influence the mitigation potential of afforestation and reforestation by impacting forest growth, composition, and disturbances like fire. • Rewetting of peatlands, while reducing the risk of fire, may mobilise salts and contaminants in soils, posing a potential risk • Coastal wetland restoration can sequester carbon, but there are potential offsets from increased methane and nitrous oxide release and carbonate formation, partially counteracting the mitigation potential of restoration efforts
	Technological feasibility	• While global estimates are absent, regional studies proof the mitigation benefits of avoiding grassland conversion	• Reducing deforestation might increase reliance on insecure external funding. • Inadequate funding poses a challenge to implementing conservation measures against deforestation

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			• Pressures from agriculture, resource exploitation, and infrastructure drive deforestation • Avoiding grassland and savanna conversion incurs annual operations costs and opportunity costs for foregone income • Converting peatlands poses a challenge in balancing economic losses from agricultural income with mitigation benefits • Coastal wetland preservation conflicts with competing land uses, such as aquaculture, agriculture, and human development • Large-scale afforestation and reforestation efforts may negatively impact food security by driving up food prices due to land competition • Restoration of peatlands drained for agriculture could displace food production at a local level, potentially impacting local food supply. However, impacts on regional and global food security are expected to be minimal
	Economic feasibility	• Preserving biodiversity and ecosystem services more effectively and at lower costs compared to afforestation/reforestation • Controlled burning, as a method of fire management, is considered economically effective in reducing fire danger and stimulating natural regeneration	
	Sociocultural feasibility	• Conserving grasslands brings socio-economic, biodiversity, water cycle, and environmental benefits • Preserving coastal offers co-benefits like biodiversity conservation, fisheries production, and water regulation • Afforestation and reforestation provide co-benefits and ecosystem services, promoting climate resilience, biodiversity, water regulation, soil protection, and renewable resources • Peatland restoration delivers co-benefits for biodiversity, water regulation, flood prevention, and fire risk reduction, supporting restoration projects	• Reducing deforestation may restrict local rights and access to forest resources • Forest owners and managers may be resistant to adopting new management practices due to perceived risks, uncertainties, or conflicting economic interests • Fire management activities may raise concerns about equity and rights, particularly in relation to land ownership, traditional practices, and indigenous rights

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		• Coastal wetland restoration offers co-benefits, including enhanced water quality, biodiversity, fisheries production, and protection from sea-level rise and storms • Fire management offers various co-benefits, such as reduced air pollution, prevention of soil erosion and land degradation, biodiversity conservation, and improvement of forage quality	
	Institutional feasibility	• To conserve carbon stocks in grasslands, savannas, and coastal areas, key strategies include protected areas, improved governance, community forest management, forest certification, enhanced policies, and integrated planning • Collaborative planning, enhanced frameworks, and community involvement are crucial for successful restoration initiatives • Building capacity and providing training programs to enhance knowledge and expertise in improved forest management practices can facilitate their adoption • Access to financial resources, technology, equipment, and infrastructure can enable forest owners and managers to implement and sustain improved forest management techniques • In regions with savannas, existing methodologies and experiences offer guidance for implementation of prescribed burning with low-intensity fires • Effective fire management requires preventive measures, early detection systems, and rapid response capabilities to control fires before they become unmanageable	• Unclear land tenure poses a barrier for implementing measures to reduce deforestation • Ineffective governance and management practices fail to reduce peatland conversion, lacking control over drivers such as agriculture, mining, and urban expansion • A potential barrier to peatland restoration projects are inadequate resources which can hinder the engagement of local communities and the maintenance of livelihoods • Coastal wetland restoration efforts often fail to address underlying degradation drivers, including pollution, habitat loss, and unsustainable land use practices, hindering successful restoration • Enhancing forest management practices in one area can lead to increased harvesting pressures or deforestation in other areas (leakage), undermining the effectiveness of mitigation efforts • Existing institutional frameworks and policies may not support or incentivize improved forest management practices, hindering their adoption • Fire management is challenged by legal and policy barriers, such as regulations, permits, and conflicting interests among stakeholders that can hinder effective implementation • Inadequate governance that fails to establish suitable structure and coordination among organisations and stakeholders, hampers the implementation of fire management strategies • Limited capacity, including insufficient funding, trained personnel, and equipment, can hinder the effective implementation of fire management strategies that

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			require trained personnel, resources, and infrastructure
Demand-side measures	Geophysical feasibility		
	Environmental-ecological feasibility		• Wood products processing and disposal can have environmental impacts such as energy consumption, water pollution, and waste generation that must be carefully managed to preserve the overall benefits of wood products
	Technological feasibility	• Research and innovation drive sustainable and healthy food alternatives • Technology and innovation reduce food loss and waste through improved storage, logistics, and tracking systems in the supply chain • Advanced manufacturing technologies improve wood product efficiency, lifespan, and recycling, leading to higher carbon storage and reduced environmental impacts	
	Economic feasibility	• Investment in R&D promotes availability and affordability of sustainable diets • Circular economy promotes converting food waste into valuable resources like fertiliser or renewable energy, creating economic opportunities and reducing waste	• Lack of financial resources, technology, infrastructure, and equipment can pose barriers to implementing and sustaining improved forest management • Limited accessibility and affordability of sustainable and healthy food options, such as fresh fruits and vegetables, can hinder their availability in certain regions or communities, with cost considerations exacerbating the issue • Shifting to sustainable and healthy diets can have negative economic impacts on the agricultural sector, especially for livestock farmers and related industries • The food supply chain may not be well-equipped to accommodate a shift towards sustainable and healthy diets, including adjustments to infrastructure, distribution, and processing systems to meet the demand for plant-based and sustainable food options • Inadequate infrastructure in developing countries contributes to food loss and waste due to

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			insufficient storage, transportation, and processing facilities • Limited funding and incentives hinder the adoption of technologies and practices to reduce food loss and waste, including efficient post-harvest handling, storage, and waste management systems • Limited energy access hinders efforts to reduce food loss and waste in post-harvest processing and refrigeration
	Sociocultural feasibility	• Consumer preferences and demand can drive market forces and motivate the food industry to provide more sustainable products	• Cultural and societal norms pose challenges in changing dietary habits due to resistance or lack of acceptance of new food choices • Limited awareness and education on the environmental and health impacts of dietary choices hinder the adoption of sustainable and healthy food options • Changing consumer attitudes and habits is a complex challenge in reducing food waste caused by preferences and behaviours like overbuying, discarding based on appearance, and improper storage.
	Institutional feasibility	• Supportive policies, regulations, and incentives at the local, national, and international levels and stakeholder engagement foster sustainable forest management. Innovations improve wood product efficiency and recycling capabilities	
Bioenergy and BECCS[8]	Geophysical feasibility	• Marginal, abandoned and degraded lands offer potential of utilisation for bioenergy and BECCS without competing with other land uses • in certain regions bioenergy crops might not require artificial irrigation, thereby avoiding competition for water with food crops	• Limited biomass availability and the need for sustainable sourcing hinder biomass supply
	Environmental-ecological feasibility	• cultivating bioenergy crops on degraded land has the potential to enhance soil carbon levels and improve	• depending on the level of deployment Bioenergy and BECCS can result in large expansion of cropland area, significant

[8] The enablers for Bioenergy and BECCS were derived from IPCC, 2019 and Nabuurs et al., 2022.

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		the overall quality of ecosystems, including biodiversity, which contributes to the preservation of soil health, counteracting land degradation, mitigating desertification, and alleviating food insecurity • utilising low fossil fuel and chemical inputs, along with limited irrigation and heat/drought tolerant species on marginal land, biofuel programs can enhance ecosystem adaptation.	deforestation, and increased irrigation water use and water scarcity • intensive agricultural practices for high crop yields may impair soil health (depletion of soil organic matter) leading to land degradation and desertification • the use of residues could result in land degradation or decreased soil organic matter
	Technological feasibility	• Spatially explicit data and advanced modelling techniques analyse factors like crop productivity, land use, carbon stocks, and ecosystem properties improves assessments of bioenergy and BECCS potential, co-benefits, and side effects	• difficult to assess when bioenergy and BECCS deployment negative impacts outweigh benefits
	Economic feasibility		• the production of bioenergy crops and feedstocks can result in increased food prices and can lead to higher share of the population at the risk of hunger
	Sociocultural feasibility		
	Institutional feasibility	• The use of sustainable biomass feedstocks, including organic waste, harvest residues, and biomass processing by-products, can provide an enabling condition for bioenergy and BECCS • Integrating bioenergy and BECCS with other AFOLU mitigation options, like agroforestry and anaerobic digestion, enhances their effectiveness and generates synergistic effects	• Land use conflicts with other mitigation measures such as afforestation
Solar energy deployment on land	Geophysical feasibility	• Marginal, abandoned and degraded lands offer potential of utilisation for solar land	• Suitability of land for solar power: geographical factors needed such as elevation, minimum solar irradiance, etc (Noorollahi et al., 2016).

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	Environmental-ecological feasibility	• Agrivoltaics and ecological restoration measures of the land under and around PV panels can add benefits on biodiversity and ecosystems (ENEL, 2022). • If appropriately planned (avoiding their placement in carbon-rich land use types, such as forests), solar energy deployment can avoid carbon emissions with respect fossil places.	• Depending on the case study particularities concentrated large solar farms can affect landscape and also have impacts on biodiversity. • Competition with other land uses: e.g. cropland (agricultural lands are the best areas for solar energy deployment) (Szabadi et al., 2023).
	Technological feasibility	• Spatially explicit data and advanced modelling techniques analyse factors solar irradiance, land use, carbon stocks, and ecosystem properties improves assessments of its potential, co-benefits, and side effects.	• Difficult to assess when bioenergy and BECCS deployment negative impacts outweigh benefits
	Economic feasibility	• Financing through Europe: energy transition	• The need of evacuate electricity in cases of large solar farms can increase the costs (new power grid needed) that can make some areas unfeasible.
	Sociocultural feasibility	• Enhance of local communities or local actors.	• Social opposition at local scale due to the fact that they are perceived as threat to their rich and diverse natural environment.
	Institutional feasibility	• Integrating solar energy with other AFOLU mitigation options, like agrivoltaics, enhances their effectiveness and generates synergistic effects	• Land use conflicts with other mitigation measures such as afforesation

2.5.4 Policies and measures: What policies are needed to achieve net-zero by mid-century?

Table 16: AFOLU policy options per mitigation strategies based on Nabuurs et al., 2022

Policies	Agriculture	FOLU	Demand-sides measures	Bioenergy and BECCS
Governance and planning	• Development of national	• well-planned and sustainable	• comprehensive food-system	• Bioenergy targets

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instruments	roadmaps for sustainable fertilisation (nutrient) management→ e.g.: NITRATE EU (Nitrates Directive)	approach for afforestation and reforestation→ e.g.: FOR_COMM (EU Stepping up EU Action to Protect and Restore the World's Forests) • Improving law enforcement, forest governance, and land tenure • proactive fire management • integrated planning approaches • enhanced framework coastal wetland restoration	oriented reform policies→ e.g.: F2F (EU Farm to Fork Strategy) • sustainable forest management (wood products)→ e.g.: DEF (EU Proposal for a Regulation on deforestation-free products)	• integrated planning approaches
Economic instruments	• emissions trading/carbon tax(offset) • agri-environmental payments/Payment for ecosystem services (e.g. agroforestry) • removal of adverse agriculture subsidies, insurance incentives → e.g.: AGR_COMM (common agricultural policy (CAP)	• emissions trading/carbon tax(offset)→ e.g.: EU_ETS (EU Emissions Trading System) • REDD+/Payment for Ecosystem Services (PES) • access to financial resources, technology, equipment, and infrastructure for sustainable forest management	• R&D funding (sustainable food alternatives, wood product efficiency) • taxes on food waste • public procurement policies	

	• beyond 2020) • R&D funding (biochar, technologies for enteric fermentation, water and nutrient management, precision fertilisation)			
Regulatory instruments	• water efficiency requirements • land-use zoning	• legal measures for environmental protection • set aside and protected areas • community forest management (CFM) • standard and certification programme • land-use moratoriums	• improved shelf life • Circulating the economy to produce substitute goods → e.g.: CEAP (EU New circular economy action plan)	• standards and certification for sustainability of biomass and land-use
voluntary actions and agreements			• emissions forest certification programs (FSC) • supply chain management (food sector)	
education/informational/"soft" instruments	• ecological service mapping and stakeholder-based quantification	• knowledge and expertise development in improved forest management • Savanna burning emissions abatement methodologies	• educational programs and awareness campaigns through nudges, synergies with health policies • consumer empowerment (for sustainable	

			and healthy food options, reduce food waste) • standardisation and labelling→ e.g.: FIC (EU Food Information to Consumers). • market demand and consumer awareness	

*The examples are policies already implemented that can be related to the proposed mitigation measures.

2.5.4.1 Governance aspects for the AFOLU sector

Roughly one-third of the mitigation efforts committed by countries in their NDCs for the year 2030 are projected to stem from land mitigation strategies (IPCC, 2019). However, many of these strategies lack comprehensive specifics. Among these, most countries focus on diminishing deforestation and enhancing forest sinks, while only a few also incorporate practices such as soil carbon sequestration, agricultural management, and bioenergy utilisation (IPCC, 2019).

The policy options listed in Table 2 are embedded into the complexity of various actors, processes, structures, and traditional rules that govern collective behaviour.

Land tenure is critical for climate efforts in the AFOLU sector. In developing countries, informal customary land tenure systems cover 65% of the land, with only 15% recognized by governments (IPCC, 2019). Much of the world's carbon is stored in biomass and soil on these territories (IPCC, 2019). Where customary systems are unrecognised or weakened by governments, tenure insecurity disincentives climate change mitigation efforts (IPCC, 2019).

Climate change mitigation in the AFOLU sector can be significantly improved by implementing adaptive institutions (IPCC, 2019). Adaptive institutions are organisations designed to tackle complex challenges related to land management, food systems, and water supply (IPCC, 2019). They prioritise learning through information sharing, experimentation, and collaboration (IPCC, 2019). These institutions have flexible regulatory frameworks and focus on creating innovative solutions by considering longer-term perspectives and alternative pathways for change (IPCC, 2019). Their goal is to adapt and respond effectively to dynamic and uncertain conditions, driving sustainable outcomes (IPCC, 2019).

2.5.4.2 Policy Packages

Sanz, Ruiz, and Rouhette present a concept of policy mixes, referring to the effective combination of individual policy options into a cohesive package, aiming to facilitate transformative changes within the AFOLU sector (2023). They have outlined five themes for categorising policy instruments, which have been tailored and applied to the AFOLU sector for driving transformative shifts (Sanz et al., 2023):

- **Directionality** and stable frameworks for actions and sustained finance
- Technology and innovation in ways system of practices are deployed to accelerate implementation

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- **Reshaping market for key commodity chains**
- **Policy coherence and integration** within the subsectors and international coherence
- **Public capacity and knowledge** to enable the transition and reduce the risk of and potential social and environmental impacts

Furthermore, they emphasise the crucial connections to adaptation, given the escalating impact of climate change on diverse terrestrial and maritime ecosystems, which could potentially undermine mitigation strategies (Sanz et al., 2023).

These themes are similar to the classification framework outlined in this report. Of significant importance, they highlight that each of these themes serves distinct policy functions aimed at tackling particular barriers or leveraging on enabling conditions (Sanz et al., 2023).

Table 17: Policy mixes in the AFOLU sector

Topic	Policy Function	Potential Policy Options & Instruments
Directionality	**Clarity and guidance**	o Mitigation targets, laws defining overall policy direction/ambition o Plans/strategies outlining overall decarbonisation visions and sectoral interdependencies. o Biodiversity protection laws o Detailed Agriculture, Forest sector specific plans/roadmaps o Land use and restauration laws and policies (i.e. reforestation and afforestation) o Land use laws and regulations, including land use conversion moratoria (i.e. forest conversion) o Land tenure legal frameworks
	Sustained finance	o Sustained finance mix of mechanisms to enable investments o Stable funding for shifting systems of practices (i.e. up-front public finance, subsidies, low interest loans, etc) o Mutual consideration of species protection issues in climate finance and climate-change impacts in biodiversity finance, payments for ecosystem services (PES) o Payments for environmentally sustainable practices, public investment in structural adjustment towards "greener" agricultural systems
Innovation	**Enhance public Research Development and Demonstration (RD&D)**	o Public RD&D policies, incl. funding of basic research, pilot demonstrators o Support for innovation in MRV systems and business models throughout AFOLU value chains o Promoting of collaboration and knowledge exchange across stakeholders

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		o Farming innovation (rethinking transport, digitalisation, inputs, pest and diseases control)
	Accelerate early changes	o Direct subsidies and technical support to introduce high-impact, quickly implementable technical options (i.e. new breeds and varieties) that can be easily accessed and do not require completely new management practices or inputs o Voluntary instruments of sustainable forest management o Education and training programs for practitioners (farmers and foresters)
	Reshaping of existing markets	o Regulating global markets for relevant primary goods and creating incentives for deforestation free supply chains (i.e. industry standards for supply chains) o CO2 price in emissions trading schemes, tradeable offset schemes o Food systems transformation regulations and circularity strategies and plans o Subsidies and tax incentives for consumer behavioural changes o Other financial incentives low GHG emissions agriculture and forest products o Disincentives, i.e. taxes to products with embedded deforestation
	Transparency and information	o Carbon footprint tracing systems o Free-deforestation tracing and/or certification of goods o GHG emissions food print certifications
Policy coherence & integration	**Reducing demand**	o Circular economy measures across the food system o Health policies towards healthy diets to reduce animal proteins consumption
	International coherence	o International agreements on coordination and orchestration of multiple actors o Alignments with agreed multilateral frameworks (i.e. Warsaw

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		Framework for REDD+) o Common standards and rules for carbon markets
	Socio-economic implications	o Just transition policies, incl. transitional assistance policies for displace communities o Structural policies such as welfare and increase the involvement of indigenous and local communities in environmental policy in the interests of sustainable land use
	Regulatory environment	o Regulatory alignment across subsectors (agriculture, Forestry and other land uses) o Simplification of regulatory environment o Integrated land use policies o Input standards, technology standards, performance (output) standards o Subsidised crop insurance subject to cross compliance requirements has strengthened conservation incentives o Promotion of alternatives to wood fuel (energy sector)
Knowledge & Capacity	**Public capacity**	o Institutional capacity to understand challenges of transformation in government bodies from local to national scale o Information systems for farmers, including early warning systems for disturbances (fires, droughts, etc) o Facilitating stakeholder engagements o Public training and capacity building, i.e. extension services
	Monitoring and evaluation	o Systems for monitoring and evaluation, and projects registries o National forest monitoring systems, GHG inventories, Safeguards information systems, verification of timber legality
Adaptation linkages		o Impacts of climate change and needs for adaptation are considered explicitly in mitigations instruments
Main sources of information: Kissinger et al. (2012), Nabuurs et al. (2022), DeBoe et al. (2020), OCED (2020), and policy data bases indicated in the reference section.		

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2.5.5 AFOLU Bibliography

- Augere-Granier, M.-L. (2020). *Agroforestry in the European Union*. European Parliamentary Research Service.
- Dorner, Z., Djanibekov, U., Soliman, T., Stroombergen, A., Kerr, S., Fleming, D., Cortes-Acosta, S., & Greenhalgh, S. (2018). *Land-use Change as a Mitigation Option for Climate Change*. Motu Economic and Public Policy Research.
- ENEL. (2022). *All the benefits of agrivoltaics*. https://www.enelgreenpower.com/stories/benefits-agrivoltaics
- Hernandez, R. R., Armstrong, A., Burney, J., Ryan, G., Moore-O'Leary, K., Diédhiou, I., Grodsky, S. M., Saul-Gershenz, L., Davis, R., Macknick, J., Mulvaney, D., Heath, G. A., Easter, S. B., Hoffacker, M. K., Allen, M. F., & Kammen, D. M. (2019). Techno–ecological synergies of solar energy for global sustainability. *Nature Sustainability*, *2*(7), Article 7. https://doi.org/10.1038/s41893-019-0309-z
- IAEA, & FAO. (2008). *Management of Agroforestry Systems for Enhancing Resource use Efficiency and Crop Productivity*. https://www-pub.iaea.org/MTCD/Publications/PDF/te_1606_web.pdf
- IEA. (2023). *Renewable power growth is surging – driven by the global energy crisis and policy momentum*. IEA. https://www.iea.org/energy-system/renewables
- IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.001
- Jinger, D., Kumar, R., Kakade, V., Dinesh, D., Singh, G., Pande, V. C., Bhatnagar, P. R., Rao, B. K., Vishwakarma, A. K., Kumar, D., & Singhal, V. (2022). Agroforestry for controlling soil erosion and enhancing system productivity in ravine lands of Western India under climate change scenario. *Environmental Monitoring and Assessment*, *194*(4), 267. https://doi.org/10.1007/s10661-022-09910-z
- Kissinger, G., Herold, M., Sy, V.D., (2012). Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers. Lexeme Consulting, Vancouver, Canada.
- Luedeling, E., Smethurst, P. J., Baudron, F., Bayala, J., Huth, N. I., van Noordwijk, M., Ong, C. K., Mulia, R., Lusiana, B., Muthuri, C., & Sinclair, F. L. (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs. *Agricultural Systems*, *142*, 51–69. https://doi.org/10.1016/j.agsy.2015.11.005
- Mosquera-Losada, M. R., Santiago-Freijanes, J. J., Rois-Díaz, M., Moreno, G., den Herder, M., Aldrey-Vázquez, J. A., Ferreiro-Domínguez, N., Pantera, A., Pisanelli, A., & Rigueiro-Rodríguez, A. (2018). Agroforestry in Europe: A land management policy tool to combat climate change. *Land Use Policy*, *78*, 603–613. https://doi.org/10.1016/j.landusepol.2018.06.052
- Mosquera-Losada, M. R., Santiago-Freijanes, J., Pisanelli, A., Rois, M., Smith, J., Herder, M., Moreno, G., N., M., J.R., M., N., L., Ferreiro-Domínguez, N., F., B., Pantera, A., A., R.-R., Gonzalez, P., Lorenzo, J. L., Romero, R., A., C., García de Jalón, S., & Burgess, P. (2017). *How can policy support the uptake of agroforestry in Europe?*
- Murken, L., & Gornott, C. (2022). The importance of different land tenure systems for farmers' response to climate change: A systematic review. *Climate Risk Management*, *35*, 100419. https://doi.org/10.1016/j.crm.2022.100419
- Nabuurs, G-J., R. Mrabet, A. Abu Hatab, M. Bustamante, H. Clark, P. Havl.k, J. House, C. Mbow, K.N.

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Ninan, A. Popp, S. Roe, B. Sohngen, S. Towprayoon, 2022: Agriculture, Forestry and Other Land Uses (AFOLU). In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.009

- Noorollahi, E., Fadai, D., Shirazi, M., & Ghodsipour, S. (2016). *Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy Process (FAHP)—A Case Study of Iran*. https://www.mdpi.com/1996-1073/9/8/643
- Nunez, S., Verboom, J., & Alkemade, R. (2020). Assessing land-based mitigation implications for biodiversity. *Environmental Science & Policy*, *106*, 68–76. https://doi.org/10.1016/j.envsci.2020.01.006
- Schroth, G., Krauss, U., Gasparotto, L., Aguilar, J., & Vohland, K. (2000). Pests and diseases in agroforestry systems of the humid tropics. *Agroforestry Systems*, *50*, 199–241. https://doi.org/10.1023/A:1006468103914
- Sanz, Mariá José (2023). Are national policy frameworks for the AFOLU sector aligned to increase mitigation ambition? Less from 10 countries.
- Szabadi, K. L., Kurali, A., Rahman, N. A. A., Froidevaux, J. S. P., Tinsley, E., Jones, G., Görföl, T., Estók, P., & Zsebők, S. (2023). The use of solar farms by bats in mosaic landscapes: Implications for conservation. *Global Ecology and Conservation*, *44*, e02481. https://doi.org/10.1016/j.gecco.2023.e02481

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3 Ethiopia - Case Study

3.1 Big picture: Current national-sectoral decarbonisation status and prospects

Ethiopia, with a population of approximately 126.5 million in 2023, stands as Africa's second most populous nation after Nigeria and exhibits rapid economic growth, estimated at 7.2% in FY2022/23. Despite this, it remains one of Africa's poorest countries, with a per capita gross national income of $1,020, aiming to attain lower-middle-income status by 2025 which would imply an income greater than $1,135 (World Bank, 2024). Over the past 15 years, Ethiopia has maintained an impressive average annual GDP growth rate of nearly 10%, largely attributed to substantial investments in public infrastructure. However, growth slowed in recent years due to various shocks, including the COVID-19 pandemic. Although agriculture, employing over 70% of the population, remained resilient, other sectors saw slowdowns. Positive strides in poverty reduction have been made, but inequality has risen, and internal conflicts pose threats to ongoing development efforts. The government's 10-Year Development Plan, based on the 2019 Home-Grown Economic Reform Agenda, seeks to sustain growth, promote private sector involvement, enhance efficiency, and address macroeconomic challenges (World Bank, 2024).

Ethiopia has been embroiled in a civil war since late 2020, leading to a severe humanitarian crisis and stalling climate policy advancements. Despite these challenges, Ethiopia submitted an updated Nationally Determined Contribution (NDC) in July 2021, though without increasing its mitigation target ambition. The Climate Action Tracker (CAT) rates Ethiopia's climate efforts as "Almost Sufficient," indicating they are close to a fair share of global efforts but not fully aligned with limiting warming to 1.5°C (Climate Action Tracker, 2022). The updated NDC is integrated into Ethiopia’s Ten-Year Development Plan (2020) and will update the 2011 Climate Resilient Green Economy (CRGE) strategy, though no release date has been provided. Current projections suggest Ethiopia will exceed its unconditional and conditional NDC targets by 2030, yet these do not account for the conflict's potential impact on emissions. The IMF has projected a significant GDP growth rate drop in 2022 due to the conflict (Climate Action Tracker, 2022).

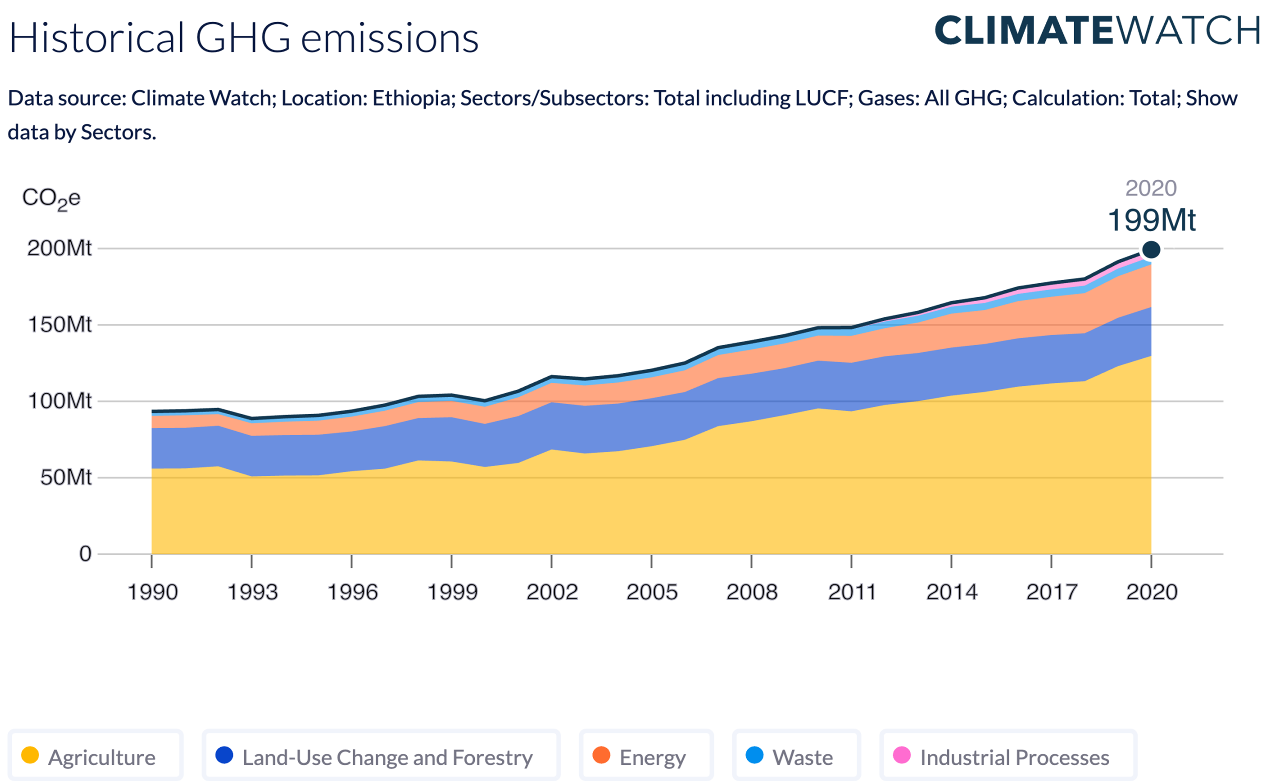

Figure 10: Historical GHG emissions Ethiopia

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Source: https://www.climatewatchdata.org/

In figure 10, the historical greenhouse gas emissions in Ethiopia from 1990 until 2020 are shown with regard to the different sectors. This data originates from Climate Watch, PIK, UNFCCC and GCP. If the data is compared to the BAU scenario in table 18 as shown in Ethiopia's NDC, the numbers differ which can have multiple reasons such as different metrics, sectoral measurements or methodologies used. However, the trend that the land use sector including livestock and agriculture accounts for most emissions in both sectors is visible in the NDC as well as in the Climate Watch charts.

As the country reported to the UNFCCC, its GHG emissions in 1995, were 38 to 48 Mt CO_2e, which rose to 150 Mt CO_2e in 2010. The main contributors are: livestock 43%, forestry 37%, crop 7% and other sectors (power, transport, industry and building) 3% each. Under the BAU scenario, emissions are predicted to grow more than double to about 400 Mt CO_2e in 2030 (Michal, N. et al, 2015).

Table 18: GHG emission projections in BAU, unconditional and conditional pathways

Sector	BAU emission projection (Mt CO_2eq)			Unconditional emission projection (Mt CO_2eq)		Conditional emission projection (incl. unconditional) (Mt CO_2eq)	
	2020	2025	2030	2025	2030	2025	2030
Industry	5.9	12.7	26.1	12.9	27.3	10.2	22.6
Energy	10.7	14.4	20.0	12.7	14.9	10.4	9.5
LUCF	125.0	133.8	140.2	112.6	91.8	21.4	-99.9
Livestock	146.4	169.5	194.8	168.7	192.9	162.8	180.0
Managed Soils	5.8	8.1	11.0	8.0	10.9	8.0	10.6
Waste	9.1	10.3	11.5	9.4	9.5	6.0	2.9
TOTAL (Mt CO_2eq)	**302.9**	**348.8**	**403.5**	**324.3**	**347.3**	**218.8**	**125.8**

Source: Updated NDC July 2021, p. 10

The updated Ethiopian NDC from 2021 (Table 18) shows the projected overall and sector-specific greenhouse gas emissions from 2020 to 2030. For 2020 the Ethiopian government indicated emissions of 302.9 Mt CO_2 eq. In a business as usual (BAU) scenario, those emissions would rise to 348.8 Mt CO_2 eq in 2025 and 403.5 Mt CO_2 eq in 2030. Those projections depend on the two versions of the Ethiopian NDC, the unconditional version which shows the contribution depending on own resources and capabilities, and the conditional version which incorporates international means of support for meeting more ambitions reduction goals. In an unconditional scenario those emissions would decrease to 324.3 Mt CO2 eq in 2025 and 347.3 Mt CO2 eq in 2030. A conditional emission projection scenario however projects 218.8 Mt CO2 eq in 2025 and 125.8 Mt CO2 eq in 2030 (a reduction of 68.8%).

In this light, this paper examines the current enablers, barriers and policy options in five key sectors, namely industry (3.2), energy (3.3), transport (3.4), buildings (3.5) and land use (3.6). Each sector is discussed in an own chapter following the same structure: introduction, enablers and barriers, the current status of national climate policy and policy recommendations based on the analysis. A detailed analysis of the enablers, barriers and policy options can be found in sector-related tables in the annex (3.9).

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3.2 Industry

3.2.1 Current national-sectoral decarbonisation status and prospects

Ethiopia's industrial sector has been evolving rapidly over the past few decades, driven by diverse industries, a growing workforce, and significant investments in infrastructure. The sector's composition reflects a mix of traditional and modern industries, contributing substantially to the nation's economic development. Key sectors within Ethiopia's industry include agriculture-based industries, manufacturing and construction, each playing a pivotal role in shaping the country's industrial landscape.

In 2019/20 fiscal year, the industry sector has registered an average annual growth rate of 17.2% (TYDP, n.d.). The final energy consumption of the country is roughly 40,000 GWh, of which only 3% is consumed by the industry sector (Girma, K., 2023). Roughly 20% of the energy needs of Ethiopian industries are supplied by electricity while more than 80% is provided by fossil fuels like oil and coal products (Sigra Group AS, 2019). The industrial sector consumes 38% of the electricity generated primarily from hydroelectric sources. The industrial sector in Ethiopia was expanding in terms of the number of firms, employment, output, value addition, exports, and investment, however, in terms of GDP share, it remained low in 2019 at 7.4%. This is significantly below the average for Africa and well below the 17% projected under GTP II (Gebeyehu W., 2022).

The manufacturing sector encompasses a wide range of activities, from textile and garment production to machinery and chemical manufacturing (UNIDO, 2018). Government initiatives, such as the establishment of industrial parks, have bolstered this sector, attracted foreign investment and boosted export potential (Fanuel et al. 2022). Cement, steel, sugar, textiles, and leather are the five industries in Ethiopia that consume the greatest amounts of energy. They use around 79% of the industrial sector's overall energy requirement (Sigra Group AS, 2019). Under the BAU scenario, the total industrial emissions are projected to rise by 16% each year, from 4 Mt CO_2e in 2010 to 71 Mt CO_2 in 2030 (Mahlet, 2022). Ethiopia aims to cut the BAU based prediction by 64% in 2030. Off this, the industry intends to reduce emissions by 20 Mt CO_2e (COMESA, n.d.).

3.2.2 National-sectoral mitigation enablers and barriers

3.2.2.1 Enablers

In terms of enablers, Ethiopia's industrial sector is supported by a variety of initiatives and policies designed to promote manufacturing, enhance productivity, and align with climate goals through energy efficiency and sustainability. The establishment of industrial parks across different geographical locations has been a significant driver in encouraging manufacturing and export-oriented industries (UNIDO 2018). These parks not only provide the necessary infrastructure but also create a conducive environment for businesses to thrive. Additionally, the development of energy efficiency standards and labeling for products such as Electric Injera Mitad demonstrates Ethiopia's commitment to reducing energy consumption and promoting sustainable practices within the manufacturing sector (Danas Electric Engineering, 2015). Technological advancements and increased productivity in large- and medium-sized manufacturing sectors further underscore the progress being made.

Financial incentives play a crucial role in fostering low-carbon solutions as well. Grants, loans, subsidies, tax exemptions, carbon credits, and green bonds are effective mechanisms that are being used to lower the initial costs and mitigate the risks associated with investing in these solutions (World Bank 2023) (UNDP 2021b). Moreover, technical support measures such as energy audits, training, awareness campaigns, demonstration projects, and technology transfer are essential for building the capacity and skills of industrial actors and stakeholders. These efforts are instrumental in driving the sector towards more energy-efficient and environmentally friendly practices (EEA, n.d.).

Policy and regulatory frameworks are also pivotal in supporting the implementation of energy efficiency and renewable energy measures. Strategies such as the Climate-Resilient Green Economy (CRGE) strategy, the National Electrification Program (NEP), and the Feed-in Tariff (FiT) program are key components of Ethiopia's approach to promoting the growth of renewable energy sources and ensuring a sustainable industrial sector. Yalew (2022) points out that the CRGE strategy as a cornerstone of Ethiopia's climate policy, aimed at achieving

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a green economy that is resilient to climate change (Yalew, 2022). These enablers collectively contribute to an industrial sector that not only drives economic growth but also attempts to align with Ethiopia's climate goals, ensuring a sustainable and energy-efficient future.

3.2.2.2 Barriers

Despite Ethiopia's efforts towards aligning its industrial sector with climate goals, several barriers persist, impeding progress and sustainability. Those barriers are closely interlinked with the energy sector and while ambitious plans such as the National Electrification Plan 2.0 have many enabling components in principle, they turn into barriers if not sufficiently implemented. Traditional fuels, such as charcoal, fuel wood, dung cakes, and agricultural residues, account for a staggering 87% of the country's energy consumption. This reliance not only poses severe health and environmental risks but also highlights the urgent need for transitioning to cleaner energy sources. In 2019, a significant portion of the population, 55.2%, lived without access to electricity, underscoring the energy accessibility challenges the nation faces (Girum, A.T., et al., 2021). In addition to these issues are the prevalent lack of skilled manpower and maintenance capabilities, which hamper the efficient operation and upkeep of energy infrastructure (Girum, A.T., et al., 2021).

The development of renewable energy technologies in Ethiopia is further hampered by a lack of investment capital (Mulualem G.G. 2021). This financial constraint is critical, as substantial investment is required to drive innovation and large-scale implementation of renewable energy solutions. Additionally, the country's institutional capacity limits the effective utilisation and integration of renewable energy technologies (Negussie R. 1999). Without robust institutions capable of managing and supporting these technologies, sustainable progress remains difficult. This is also visible with the implementation of the NEP

Moreover, the industrial sector suffers from a lack of motivation and effective planning and monitoring, which are essential for fostering a proactive and responsive industrial environment. Desalegn A. and Solomon N. (2021) emphasize that coordination and cooperation among industrial actors and stakeholders are vital for achieving cohesive and sustained industrial growth aligned with climate goals. The absence of such coordination leads to fragmented efforts and diminished overall impact. These barriers collectively present significant challenges to Ethiopia's industrial sector, underscoring the need for comprehensive strategies that address these multifaceted issues to achieve a sustainable and climate-aligned industrial future.

3.9.1 (Quicklink to table on enablers and barriers)

3.2.3 Current status of national-sectoral climate policy

Ethiopia has implemented a variety of policies and measures aimed at fostering industrial growth while mitigating the adverse effects of climate change.

Central to these efforts is the establishment of Monitoring, Reporting, and Verification (MRV) systems for the industry and agriculture sectors. These systems, operationalized through significant investments and staffing, ensure accurate tracking of emissions and adherence to climate goals (Climate Governance, 2020). The Ethiopian Energy Authority (EEA) has developed energy efficiency programs and activity plans, including voluntary-based energy audits for industries, promoting efficient energy use and reducing wastage (EEA, n.d.).

The formation of the Environmental Policy of Ethiopia underscores the government's commitment to environmental protection. The Environmental Protection Authority (EPA), established through proclamation no. 9/1995, oversees comprehensive environmental protection. The policy, developed in 1997, includes stringent emission limits for stationary sources, ensuring that industrial activities do not exceed the maximum allowable levels of pollutants (ESIPC, n.d.). This regulatory framework is crucial in minimizing industrial pollution and protecting public health.

Ethiopia's industrial policy, active since the early 2000s, employs a range of policy instruments to stimulate industrialisation. This policy framework, supported by the Climate Resilient Green Economy (CRGE) Strategy, aims to avoid reliance on outdated technologies and promote sustainable practices (CRGE, 2011). A significant step towards reducing greenhouse gas emissions is the gradual phase-out of fossil fuels and fossil fuel boilers, despite

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predictions from the International Energy Agency (IEA) that fossil fuel consumption might rise in the coming years (IEA, 2019). The Ethiopian government's revision of petroleum product subsidies since July 2022 is a proactive measure to encourage the use of renewable energy sources and reduce fossil fuel dependence (Reporter, 2024). The Green Manufacturing Strategy, introduced in 2019, offers tax exemptions for purchasing select testing equipment, fostering innovation and the adoption of green technologies (GMSE, 2019). Environmental permits and fees, managed by the EPA, ensure that potentially polluting businesses cannot operate without proper authorisation. This regulatory approach allows the government to assess potential pollution and adjust permission fees based on the probable environmental and economic impact (Krueger K, et al., 2012).

To attract investment in key sectors such as manufacturing, agriculture, and agro-processing, Ethiopia offers extensive financial incentives. These include exemptions from customs charges on capital goods and building supplies, along with substantial income tax exemptions for agricultural and manufacturing investments (EIC, n.d.). The Ethiopian government has implemented various financial incentives, including the Scaling-Up Renewable Energy Program (SREP), public-private partnership (PPP) policy, and fiscal incentives for renewable energy and energy efficiency (EVR, 2022). Ethiopia is promoting the use of Energy Performance Certifications (EPCs) for the industrial sector to achieve its goals under the Paris Climate Agreement and green economy vision. Ethiopian Energy Authority plans national energy efficiency labelling scheme and energy audits for commercial, industrial, and public sectors, as part of Green Economy strategy (Eucker et al., 2019).

The Ethiopian Cleaner Production Centre (ECPC) promotes resource efficiency in small and medium-sized enterprises (SMEs) through the Joint UNIDO-UNEP Program on Resource Efficient and Cleaner Production (RECP) (UNDP 2021a). This initiative supports the adoption of sustainable practices in the SME sector. Furthermore, the Environmental Impact Assessment (EIA) process mandates that firms complete an EIA before starting certain projects, ensuring that environmental considerations are integrated into their planning (Damtie M. and Bayou M., 2008). The Ethiopian Standard Industrial Classification (ESIC) system aids in data collection and analysis for the industrial sector, providing a structured approach to categorize industries into ten major groups (ESIC, 2010). Collectively, these policies and measures create a robust framework for industrialisation in Ethiopia, emphasizing sustainability and climate change mitigation. By promoting energy efficiency, regulating emissions, incentivizing green practices, and ensuring environmental oversight, Ethiopia aims to achieve balanced industrial growth that aligns with its climate goals and sustainable development objectives.

Table 19: Analysed policies in Ethiopia's industry sector

Type of instrument	Policy
Governance and planning instruments	Industrial Policy in Ethiopia, 201 Climate Governance, December 2020 Ethiopia's Climate Resilient Green Economy, Green Economy strategy, 2011 Green Manufacturing Strategy for Ethiopia: Growing Industry Sustainably, 2019
Regulatory instruments	Energy Efficiency Program and activity plan Ethiopian Energy Authority
Market-based instruments	Ethiopia Investment Policies and Incentives and opportunities
Information instruments	Environmental standards for industrial pollution control Ethiopian Standard Industrial Classification (ESIC) (First Publication-January 2010) Ethiopian Voluntary National Review, 2022

3.2.4 How to strengthen national-sectoral climate policy?

Ethiopia has made significant strides in aligning its industrial policies with national Science, Technology, and

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Innovation (STI) policies and intellectual property rights (IPR) frameworks. This alignment fosters an environment conducive to innovation and the protection of new technologies and ideas, which is crucial for sustained industrial growth. The establishment of comprehensive standards across various industrial processes further ensures that industrial activities meet high environmental and operational benchmarks. These standards are detailed across different parts, including guidance on interpretation, specific industrial sectors, general industrial effluents, gaseous emissions, and noise limits. Such a structured approach promotes consistency and quality in industrial operations.

Financial incentives play a pivotal role in attracting investment to the manufacturing sector. By offering exemptions from taxes on select testing equipment and providing extensive support for laboratory and testing facilities, the government creates an appealing environment for investors who comply with regulations. These measures not only attract capital but also encourage adherence to environmental and operational standards. Additionally, the government's focus on strengthening institutional capabilities by equipping them with skilled personnel and necessary instruments further enhances the sector's capacity to innovate and improve efficiency. The development of integrated toolkits aimed at building the capacities of National Cleaner Production Centers highlights Ethiopia's commitment to sustainable industrial practices. These toolkits are designed to support resource efficiency and cleaner production, helping industries minimize their environmental footprint. This initiative aligns with global trends towards sustainability and positions Ethiopia as a forward-thinking player in industrial development.

Despite these positive developments, several challenges remain that need to be addressed to strengthen the sectoral policy in terms of climate change mitigation. One significant challenge is the lack of effective collaboration among diverse bodies involved in the industrial ecosystem. The coordination among these actors is essential for seamless technology transfer, research and development (R&D), and innovation efforts. Addressing this requires creating robust frameworks that facilitate cooperation and communication among stakeholders. The imbalance between fast-growing imports and slow-growing exports presents a structural challenge that affects the economy's stability. Developing strategies to boost export growth while managing import levels is crucial. This can involve enhancing the competitiveness of local industries through innovation, quality improvements, and marketing strategies that open new markets for Ethiopian products.

Technological development and adoption practices are another area where the sector faces challenges. The usage of outdated import technologies due to limited regulatory coverage and incentives hampers progress. Strengthening regulations that govern technology transfer and providing more robust incentives for adopting new technologies can help overcome this barrier. Additionally, addressing the weak coordination among ecosystem actors can ensure that technological advancements are effectively disseminated and utilized. Regular monitoring and inspections for employee health and safety are currently inadequate, which affects environmental and social planning. Strengthening these monitoring mechanisms and ensuring regular inspections can help organisations comply with health and safety standards. Moreover, promoting public awareness about environmental planning through NGOs and activists can foster a more informed and proactive community that supports sustainable practices. Lastly, the capacity problems and lack of awareness about the Environmental Impact Assessment (EIA) process hinder its effectiveness. Developing comprehensive training programs for stakeholders involved in the EIA process and creating effective mechanisms for its implementation can enhance its impact. Additionally, making industry codes available and accessible can standardize practices and improve compliance across the sector.

In conclusion, while Ethiopia has made considerable progress in developing its industrial sector, addressing these challenges mentioned in the paragraph before is essential for further growth and effective climate change mitigation. By enhancing collaboration, improving technological adoption, and strengthening regulatory frameworks, Ethiopia can build a more resilient and sustainable industrial sector.

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3.3 Energy

3.3.1 Current national-sectoral decarbonisation status and prospects

In 2018, Ethiopia was placed as the 3rd largest CO_2 emitter in the SSA region at 15 Mt CO_2 (Gideon et al, 2020). Furthermore, the energy-related emission stood at about 19.5 Mt CO_2 (elec. & heat, transport, other industries, buildings and others) in 2020 (IRENA, 2023). The authors (Gideon et al, 2020) also outlined that the country showed a massive carbonisation in its 1990-2017 CO_2 emission levels which spiked by 450%. The contributing factors for the rising CO_2 emissions were found to be due to the effects of economy, population, and fossil fuel mix in order of their influence. However, it is pointed out that energy intensity has a negative effect.
The BAU economic activity and development would lead to an overall GHG emission of 400 Mt CO_2e by 2030 from the baseline 150 Mt CO_2e in 2010. Of these 2010 emissions, more than 85% came from the agricultural and forestry sectors. The other (power, transport, industry and buildings) sectors contributed about 3% each following agriculture and industry in the same year. The CRGE path targeted to achieve limiting the GHG emissions in 2030 to its baseline value – 150 Mt CO_2e (CRGE, 2011).

The Climate Action Tracker (CAT) rated Ethiopia as "almost sufficient", which highlights that it is not in line with reaching the Paris Agreement of limiting warming to 1.5°C (ClimateActionTracker).

The revised national energy policy recognizes a vast spectrum ranging from the *basic energy poverty, energy security, inefficient value chain and lack of data* **TO** *limited technological capacity and lack of standards/regulations* **TO** *financing constraints and climate change*. It scrutinizes the challenges across the whole energy value chain for the different energy resources available.

The National Electrification Program v2.0 (NEP v2.0), which was first developed in 2017 and revised in 2019, outlines the target of achieving universal electricity access (of 100%) by 2025 [*NEP 2.0*]. The electrification target was projected to have 65% grid access and 35% from off-grid solutions, mainly solar PV mini-grids.

The installed electricity capacity in 2022 was hydro (86%), wind (7%), and bioenergy (6%) (IRENA, 2023). Thus, the electricity supply is heavily reliant on hydropower, and Ethiopia plans to further increase the installed capacity. The total power demand is predicted to increase from 4 TWh (2010) to more than 75 TWh by 2030 (CRGE 2011). In 2010, despite the huge renewable potential, biomass accounted for 92% of the total energy consumption (ENEP[1], 2013). Traditional biomass use accounted for around 46% of forest degradation, which in turn was a source of about 37% CO_2 emissions (CRGE, 2011). Still, it is this polluting fuel that most of the population, nearly 96%, relies on to meet the cooking demand, where firewood is the first-ranking fuel for 82% of the population (endev, MECS 2022). Only about 4.1% of all households use electricity as a primary cooking fuel.

Resource	Unit	Exploitable Reserve	Exploited Percent
Hydropower	MW	45,000	<10 percent
Solar/day	kWh/m²	Avg. 5.5	<1 percent
Wind power	GW	1,350	<1 percent
Wind speed	m/s	> 6.5	
Geothermal	MW	7,000	<1 percent
Wood	Million tons	1,120	50 percent
Agricultural waste	Million tons	15–20	30 percent
Natural gas	Billion m³	113	0 percent
Coal	Million tons	300	0 percent
Oil shale	Million tons	253	0 percent

Figure 11: Energy resources and exploitable potential (Ethiopia)
Source: NEP v2.0.

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3.3.2 National-sectoral mitigation enablers and barriers

3.3.2.1 Enablers

Ethiopia's energy sector is undergoing a transformative shift towards sustainability, heavily leveraging its vast indigenous energy resources, particularly renewable resources. A significant portion of Ethiopia's electricity supply already comes from renewable sources, with hydropower accounting for approximately 92% of the total (Hannah, R. et al, 2022; Yalew, 2022). This renewable foundation is further strengthened by initiatives such as the replacement of incandescent lamps with energy-efficient LEDs, spearheaded by the Ethiopian Electric Power (EEP).

The Scaling Solar program, supported by the World Bank, provides financial and risk management assistance to boost solar energy development in Sub-Saharan Africa, complementing Ethiopia's renewable energy efforts (FDRE Ministry of Water Irrigation and Energy, 2019). However, the country faces a challenge with electricity tariff reforms, balancing cost recovery with affordability, which risks pushing consumers towards non-renewable energy sources. Programs like the National Improved Cook-Stove Program (NICSP) aim to reduce the use of traditional biomass fuels (Richard S. et al, 2022; FDRE CRGE, 2011), promoting energy-saving practices such as turning off lights, as advocated by the Ethiopian Petroleum and Energy Authority (EPEA).

The legal framework to unbundle government-owned electric power and utilities under the National Electrification Program (NEP 2.0) is a crucial step towards increasing efficiency and transparency in the energy sector. This framework also encourages private sector participation through Independent Power Producers (IPPs), fostering a more competitive and innovative energy market (FDRE Ministry of Water Irrigation and Energy, 2019; MoWE ENEP, 2013). Ethiopia is also focusing on rural energy solutions, with initiatives like the national biogas program (NBPE), driven by SNV, and Solar Home Systems (SHS) targeting rural communities, health centers, schools, and street lighting (FDRE Ministry of Water Irrigation and Energy, 2019).

These programs not only improve energy access but also contribute to environmental sustainability by reducing reliance on traditional biomass and fossil fuels. Additionally, the promotion of energy-efficient electric mitads (electrical injera stoves) and the energy efficiency labeling initiative by the EPEA aim to enhance consumer awareness and adoption of efficient technologies. Overall, these enablers collectively support Ethiopia's climate goals by promoting renewable energy sources, improving energy efficiency, and enhancing access to sustainable energy solutions across the country. By integrating these diverse initiatives, Ethiopia is paving the way towards a resilient and sustainable energy future.

3.3.2.2 Barriers

Despite Ethiopia's significant progress in aligning its energy sector with climate goals, several barriers continue to impede development and hinder the sector's sustainability. The hydro-dominated power sector faces considerable risks from the negative impacts of climate change, which can lead to variability in water availability and, consequently, power generation (MoWE ENEP, 2013). Additionally, the transmission and distribution (T&D) systems are less efficient and wasteful, contributing to energy losses and further straining the sector. The energy generation portfolio remains limited, with an over-reliance on hydropower and unsustainable traditional biomass usage, exacerbating environmental degradation and health issues (MoWE ENEP, 2013). The traditional three-stone open fire stove is the primary predominant cooking technology facing multifaceted challenges on top of the highly depleting biomass resource. These barriers to this sub-sector include lack of grid access and its unreliability, unaffordable eCooking technologies and other efficient fuels (such as LPG), socio-cultural to traditional cooking and lack of awareness. Other impediments also range from policy frameworks to sub-sectoral data and poor sector investment lacking multi-stakeholder coordination (Richard S. et al, 2022; GIZ 2022). The recent increments in electricity tariffs, aimed at cost recovery, have rendered electricity unaffordable for many consumers, prompting a switch to non-renewable alternatives, thus undermining the shift towards sustainable

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energy sources. The sector also suffers from a lack of financing, which stifles growth and innovation (MoWE ENEP, 2013).

The importation of sub-standard solar PV systems and components due to the absence of mandatory national standards and laws further challenges the sector's reliability and efficiency (Gebreslassie, M. G., 2020; MoWE ENEP, 2013). This problem is compounded by a lack of human and institutional capacity to effectively manage and implement renewable energy projects (MoWE ENEP, 2013). Moreover, the absence of reliable and updated data hampers informed decision-making and strategic planning, limiting the sector's ability to respond to challenges and optimize resource allocation (ENEP, 2013). These barriers collectively hinder Ethiopia's energy sector from achieving its full potential and aligning with the climate goals outlined in the Nationally Determined Contributions (NDCs). Addressing these challenges is crucial for the country to build a resilient, efficient, and sustainable energy sector that can support its economic development and environmental objectives.

3.9.1 (Quicklink to table on enablers and barriers)

3.3.3 Current status of national-sectoral climate policy

Ethiopia has made substantial efforts to regulate and structure its energy sector with policies that align with climate change mitigation goals. The revised National Energy Policy (NEP) recognizes critical national energy issues such as energy poverty, energy security, inefficient value chains, and the lack of reliable data (MoWE ENEP, 2013). This policy outlines the limitations in technological capacity, the absence of standards and regulations, financial constraints, and the impacts of climate change. The Ethiopian National Energy Policy (ENEP) effectively identifies specific energy sub-sectors, challenges, and policy issues, allowing for targeted interventions (MoWE ENEP, 2013). This detailed approach aids in creating tailored policy objectives and instruments crucial for reducing greenhouse gas emissions and improving energy efficiency (MoWE ENEP, 2013). However, the NEP lacks a specific focus on renewable energy sources and detailed strategies for their deployment. It also overlooks essential financial planning and fails to engage key stakeholders adequately (MoWE ENEP, 2013). These gaps hinder the policy's effectiveness in promoting sustainable energy development and climate change mitigation. In summary, while the NEP provides a solid foundation, it needs a stronger emphasis on RE, comprehensive financial planning, and better stakeholder engagement to enhance its impact on climate change mitigation.

Another major initiative is the Ethiopia National Electrification Program 2.0 (NEP 2.0), which aims for universal electricity access by 2025 (FDRE Ministry of Water Irrigation and Energy, 2019). This ambitious plan targets 65% grid access and 35% off-grid solutions, primarily solar PV mini-grids, significantly increasing the use of renewable energy sources (FDRE Ministry of Water Irrigation and Energy, 2019). However, a major challenge remains, with no clear investment and financing schemes to achieve the targets.
Ethiopia's Climate Resilient Green Economy (CRGE) strategy, launched in 2011, aims to avoid technology lock-in and reduce greenhouse gas emissions (FDRE CRGE, 2011). The country's Nationally Determined Contribution (NDC) sets a conditional target to reduce emissions by 220.59 Mt CO2e (53.5%) by 2030 from the 2010 business-as-usual scenario, with an unconditional target of a 12.4% reduction (51.24 Mt CO2e) (GoE, 2020). The Growth and Transformation Plan II (GTP II) further supports these efforts by promoting economic growth through sustainable energy practices (National Planning Commission, 2016).

The Ethiopian government has implemented several financial incentives and tax subsidies to promote renewable energy technologies. These incentives include exemptions from customs duties on capital goods and building materials, as well as income tax exemptions for agricultural and manufacturing investments (UNDP, 2021a) (UNDP, 2021b). These measures are designed to attract more foreign investments in the renewable energy sector and stimulate local market growth. To enhance energy efficiency, Ethiopia has introduced standards and labeling for home appliances and initiated energy efficiency programs for buildings. The Ethiopian Petroleum and Energy Authority (EPEA) has conducted training and capacity-building activities for electric mitad and stove manufacturers to improve energy efficiency and promote efficiency labelling (Viegand Maagøe A/S, 2023; EEA, Energy Center,

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2018). Furthermore, the government has mandated a power factor (PF) of 0.9 for industrial consumers to incentivize for operating above 0.95 PF, encouraging the adoption of energy-efficient technologies (Ethiopian Energy Authority, 2018).

Table 20: Analysed policies in Ethiopia's energy sector

Type of instrument	Policy
Governance and planning instruments	Growth and Transformation Plan II Climate Resilient Green Economy Strategy Ethiopian National Energy Policy (revised, draft) National Electrification Plan 2.0
Regulatory instruments	Energy efficiency standards and labelling for some products like Electric Injera Mitad manufacturing
Market-based instruments	Financial incentives and tax subsidies
Information instruments	

3.3.4 How to strengthen national-sectoral climate policy?

To overcome the barriers in the sector, Ethiopia needs to strengthen its regulatory frameworks and implement effective policies that promote private investment in renewable energy. Enhancing research and development (R&D) for innovation, fostering international collaboration for technology transfer, and improving institutional capacities are crucial steps. Economic incentives such as feed-in tariffs (FiTs) and tax exemptions can further stimulate growth in the renewable energy sector. Establishing clear performance and technical standards for renewable energy technologies, along with professional training and capacity-building programs, will ensure the sustainable development of Ethiopia's energy sector and contribute significantly to climate change mitigation.
Renewable energy targets – establish clear and quantified renewable energy targets, with a focus on time-bound and precise implementation strategies.

Modern energy access – this can be done by identifying and prioritizing sub-sectoral decarbonisation potential such as the cooking sub-sector by promoting energy efficiency, access to fuel substitutes like LPG among various users such as in refugees and a switch to low-carbon alternatives (like replacing with biofuels, hydrogen (H2), ammonia, syngas). Moreover, a steady and massive renewable energy capacity expansion leveraging Ethiopia's abundant renewable resources will also aid the E-cooking solution.

Policy instruments and regulatory Framework – Develop a clear and reliable regulatory framework to attract and create an enabling environment for private investment in renewable energy, and to also ensure performance and technical standards of renewable energy technologies. In addition to formulate effective policies including behavioural interventions and economic incentives.
R&D and international collaboration – strengthening and funding the R&D, developing institutional capacities and establishing international cooperation that will facilitate knowledge exchange and effective technology transfer for low- or net-zero emission in the country.

3.4 Transport

3.4.1 Current national-sectoral decarbonisation status and prospects

Transport plays a critical role in the national economy, which is highly dependent on perishable agricultural products. The road (freight and construction vehicles, and merely from passenger vehicles) and air transports in

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Ethiopia account about 75% and 23%, respectively, of all the transport-related emissions, with the inland water transport contributing very little to the sectoral emissions (CRGE 2011). The transport sector emission is expected to increase from about 5Mt CO_2 of the 2010 BAU emission to 40 Mt CO_2 in 2030 (an average of nearly about 11% p.a.), of which the main emission contributors are the freight and passenger transport sub-sectors. However, in its INDC, Ethiopia intends to achieve 10 Mt CO_2 emission reductions from this sector by 2030 (INDC 2015), of which, the largest potential would be from electric rail development for freight sub-sector with about 8.9 Mt CO_2 reductions seconded by bioethanol and biodiesel use (nearly 1 Mt CO_2) (CRGE 2011).

Ethiopia had more than 1.2 mil. registered vehicles at the end of Jul 2020, of which, about 53% of the vehicles are registered in the capital, Addis Ababa [Yonas A., The Reporter, 2020]. The transport sector in Ethiopia is predominantly run by imported fossil fuels, which account for about 4% of the final energy consumption [FDRE Ministry of Planning and Development, 2022]. The process of industrialisation, urbanisation, and more trade interactions led to an annual rate of increase of more than 10% in total fleet size (Kaleab E. & Mengesha Y., 2023). The transport sector facing the challenges of high fuel consumption and air pollution due to the large number of old vehicles, is currently in the process of banning the import of combustion engine automobiles (Zachary S., 2024). It is also recently reported that the number of electric vehicles, both imported and locally assembled, in Ethiopia has reached 100,000 (Addis Standard (X), 2024).

Moreover, the GoE is working on transport infrastructure expansion and promoting its efficient use for sustainable economic growth through an integrated transport infrastructure and logistics plan (FDRE CRGE, 2011). To achieve the emission abatement potential from the transportation sector, the GoE in its CRGE strategy projected to enhance fuel efficiency through efficiency standards; develop an electric rail system powered by renewable energy; enhance the public transportation system in the capital (Addis Ababa); and expand biofuel use. Additionally, the LT-LEDS (*Long-term Low Emission and Climate Resilient Development Strategy*) states three emission mitigation targets in the sector electrification: max ambition scenario, NDC-aligned scenario, and late action scenario with a reduction target of 15%, 10%, and 7% by 2030 respectively, with 75% target each by mid-century (FDRE Planning and Development Ministry, 2020].

3.4.2 National-sectoral mitigation enablers and barriers

3.4.2.1 Enablers

Ethiopia's transport sector is advancing climate change mitigation through a range of initiatives aimed at modernizing infrastructure and promoting sustainable practices. Key efforts include constructing an electric rail network and enhancing urban transport in Addis Ababa with light rail and rapid bus transit systems (FDRE CRGE, 2011). These measures aim to reduce individual car usage, thereby lowering emissions. Financial incentives, such as facilitating bank loans and offering tax reductions or exemptions for the taxi market, encourage the adoption of newer, more efficient vehicles, making the transition to greener transport options financially viable (Ministry of Finance, 2021).

The importation of electric vehicles (EVs) and hybrids (HEVs) is increasing, supporting the reduction of fossil fuel dependence and greenhouse gas emissions (FDRE Ministry of Planning and Development, 2020; Carrie H., 2024). Promoting EVs helps build a cleaner, more sustainable transport system. Most recently the GoE announced an import ban on combustion vehicles, which will further promote the role of EVs (Zachary S., 2024). Additionally, introducing fuel efficiency standards for cargo and passenger vehicles helps reduce the carbon footprint of the transport sector (Ministry of Transport, 2017).

The policy on non-motorized transport (NMT) further supports sustainable mobility by encouraging walking and cycling, thus reducing reliance on motorized transport (Ministry of Transport, 2020). Efforts to substitute imported fossil fuels with clean biofuels (ethanol and biodiesel) contribute to carbon emission reductions (FDRE CRGE, 2011).

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Ethiopia has substantial potential to replace traditional biomass fuels and fossil fuels with biomass resources derived from crop residues, which can play a crucial role in rural development, reducing energy poverty, and lowering greenhouse gas emissions. Although Ethiopia is rich in renewable energy resources, much of this potential remains untapped, and the country continues to grapple with energy poverty, inefficiency, and insecurity (Tolessa, 2023). Utilizing biomass generated during agricultural production, such as crop residues, can significantly contribute to bioenergy production. By adopting modern biomass conversion technologies like anaerobic digestion, fermentation, combustion, gasification, and pyrolysis, Ethiopia can generate gaseous and liquid transportation fuels, electricity, and heat (Tolessa, 2023). This modern and renewable biomass energy planning is particularly vital for Ethiopia, where the agricultural sector is the primary source of biomass resources. By harnessing these resources, Ethiopia can develop bioenergy programs that not only provide a sustainable energy source for households but also offer alternative fuels and electricity for the transportation sector, thereby reducing dependence on fossil fuels and enhancing energy security (Tolessa, 2023).

The government has also increased subsidies on imported petroleum fuels to discourage the use of old, inefficient vehicles and promote the importation of newer, more efficient models (Ministry of Trade & Regional Integration, 2022). However, this policy has begun to challenge economic welfare and contributed to a high inflation rate of about 34% in 2022 (Statista, 2024). Overall, these enablers highlight Ethiopia's comprehensive approach to climate change mitigation in the transport sector, integrating infrastructure development, financial incentives, and regulatory measures to foster sustainable transportation.

3.4.2.2 Barriers

The Ethiopian transport sector faces significant barriers to climate change mitigation, primarily due to a lack of vast oil reserves, leading to reliance on imported petroleum fuels. This dependence exacerbates the issues caused by an aging vehicle fleet that is highly fuel-inefficient and contributes substantially to greenhouse gas emissions (FDRE Planning and Development Ministry, 2020; FDRE CRGE, 2011). Additionally, the access to and availability of electricity is currently limited which poses a barrier for the transformation towards electric vehicles (Tolessa, 2023).

The underdeveloped transport infrastructure, characterized by insufficient road networks, heavy traffic congestion, lack of safe cycling lanes, and poor pedestrian networks, further increases fuel consumption and emissions (Ministry of Transport, 2020). Additionally, high import taxes on vehicles make newer, more efficient cars unaffordable for most, while a shortage of financial resources limits the ability to invest in necessary infrastructure improvements. These barriers collectively hinder efforts to create a sustainable and efficient transport system, posing significant challenges to Ethiopia's climate change mitigation goals.

3.9.1 (Quicklink to table on enablers and barriers)

3.4.3 Current status of national-sectoral climate policy

Ethiopia's transport sector is undergoing significant transformations with a range of policies aimed at promoting sustainability and mitigating climate change. The Non-motorized Transport Strategy (NMTS) is a cornerstone of these efforts, targeting clean, safe, and efficient transport systems. The strategy aims to enhance public transport in cities like Addis Ababa, alongside necessary infrastructure development. From 2020 to 2029, the NMTS is set to develop safe, efficient, and accessible walking and cycling networks, supporting a substantial modal shift where 80% of motorized trips are conducted via public transport and non-motorized means by 2029 (FDRE Ministry of Transport, 2020).

To support this, Ethiopia has implemented various initiatives to develop high-quality pedestrian and bicycle networks, greenways, street lighting, intersection improvements, and bicycle-sharing systems (Ministry of Transport, 2020). The strategy also includes trade policies, street design standards, and parking management to

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create a comprehensive non-motorized transport infrastructure. Additionally, the Ministry of Transport and Logistics has been tasked with assessing the existing landscape, evaluating each sub-sector, defining a national transport strategy, prioritizing investments, and outlining implementation needs (FDRE Ministry of Transport and Logistics, 2022). While these measures would increase livability through urban planning and improved mobility, they still lack integrated planning and coordination with other sectors (FDRE Ministry of Transport and Logistics, 2022). Furthermore, they would also require large infrastructure investments, which is still lacking.

One of the key components in reducing emissions from the transport sector is the implementation of vehicle emission standards and efficiency measures. The government aims to achieve a per capita GHG emission reduction of 64% by 2030 from 2010 levels. Enacting fuel efficiency standards is expected to result in a reduction of approximately 3.1 Mt CO2e by 2030 (CRGE, 2011; Ministry of Transport, 2017). To curb the import of old, inefficient vehicles, the government has imposed very high taxes on their importation, which can reach up to 500% of the normal vehicle price, depending on the vehicle's age, type, and engine capacity. This policy is designed to discourage the use of old vehicles and promote the importation of newer, more efficient models (Tadesse S., 2022).

In 2024, the government took a significant step by announcing an import ban on vehicles with combustion engines (Zachary S., 2024). This aligns with Ethiopia's broader goal of reducing reliance on fossil fuels. The government also promotes the use of biofuels such as bioethanol and biodiesel to replace fossil fuel imports, which are currently the predominant transport fuels (FDRE CRGE, 2011).

Ethiopia’s 10-year transport prospective plan includes a substantial investment of about 74 billion birr from various sources, including public-private partnerships (PPP), government funding, and foreign grants (Tewodros T., 2022). This investment will help mobilize funding from national and local sources to implement NMT projects (FDRE Ministry of Transport, 2020). To encourage the adoption of electric vehicles (EVs), the government has implemented tax reductions and exemptions for the importation of new vehicles and EVs, while imposing high import taxes on old vehicles (Tadesse S., 2022). Further initiatives include providing loans for the taxi market to purchase new fuel-efficient locally assembled vehicles (Ministry of Finance, 2021) and conducting awareness campaigns to promote e-mobility. For example, recently a one-month free transport ride in Addis Ababa by EVs was introduced to encourage public acceptance and use (Xinhua, 2022). Capacity building efforts are also underway to train local engineers and planners in implementing these new transport strategies. Overall, these policies highlight Ethiopia's commitment to transforming its transport sector into a sustainable, efficient, and environmentally friendly system. By focusing on non-motorized transport, enhancing public transport, implementing stringent vehicle standards, and promoting the use of clean fuels and electric vehicles, Ethiopia is making significant strides towards mitigating climate change and improving urban mobility.

Table 21: Analysed policies in Ethiopia’s transport sector

Type of instrument	Policy
Governance and planning instruments	Ethiopia Non-Motorized Transport Strategy/NMTS 2020-2029 Climate Resilient Transport Sector Strategy Ethiopian Transport Masterplan - Policy and Strategy 2022-2052
Regulatory instruments	Ethiopian National Transport Policy
Market-based instruments	
Information instruments	Capacity building and training Awareness campaigns

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3.4.4 How to strengthen national-sectoral climate policy?

The transport sector in Ethiopia undergoes significant transformations. As reviewed in the chapter above, positives of this strategy include improved livability, urban planning, and mobility. The focus on cleaner and efficient transport is set to enhance air quality and public health, while contributing to foreign currency savings by reducing fossil fuel imports. High import taxes and an import ban on old vehicles may stimulate domestic vehicle manufacturing and increase the importation of electric vehicles (EVs). Moreover, these policies modernize the transport sector, improving the quality and accessibility of public transport.

However, the strategy faces several challenges. There is a lack of integrated planning and coordination with other sectors, necessitating substantial infrastructure investments. Behavioural changes, such as shifting to non-motorized transport, are difficult to ensure. Implementing vehicle emission standards requires significant investment and technological upgrades, potentially making new vehicles and EVs unaffordable and inaccessible to many. Securing sufficient funding for these initiatives remains a challenge, as does the development of necessary infrastructure, such as EV charging stations. Moreover, the current limited access to and availability of electricity presents an obstacle to the transition to electric vehicles (Tolessa, 2023). Efforts to raise public awareness about e-mobility, including campaigns and initiatives like a one-month free EV ride, are positive steps towards behavioral change.

However, these initiatives often fall short in effectively reaching a diverse audience, limiting their impact.
Despite these challenges, Ethiopia's commitment to transforming its transport sector highlights significant strides toward mitigating climate change and improving urban mobility through comprehensive and multifaceted policies.

Transport-Land-Use-Environment Policies – develop integrated policies that consider the transport, land-use, and environmental factors achieving sustainable and climate-friendly transport services.

Infrastructure development and investment – expand and improve cycling and pedestrian networks by creating pedestrian-friendly infrastructure and establishing dedicated safe cycling lanes to promote environmentally friendly transportation options. Additionally, to also allocate sufficient investment on zero/low-Carbon transport infrastructure for enhancing public transport networks and encouraging safe and affordable ridesharing and carpooling.

Technology and efficient transport system – to promote and emphasize on the adoption of e-mobility as well as embracing digitalisation for efficient transport system by optimizing the transport operations and improving transport management. Use the largely untapped potential of biomass residues to replace fossil fuels, generate electricity for transport and decrease the use of traditional biomass.

Emission targets and sectoral regulations – this is mainly developing clear emission targets and implementing sectoral regulations by also establishing continuous and rigorous monitoring and control mechanisms for greenhouse gas (GHG) emissions in the sector. In addition, it is essential to develop strategies for mitigating the impacts of population growth and urbanisation, such as by promoting efficient and sustainable transport options.

3.5 Buildings

3.5.1 Current national-sectoral decarbonisation status and prospects

Global greenhouse gas emissions from buildings accounted for 21% of total global emissions. (Pathak, Slade, Pichs-Madruga, et al., 2022). These emissions are primarily from energy use for heating, cooling, and cooking, and from the production of building materials. Projections indicate that there is significant global mitigation potential in this sector (Cabeza et al., 2022). Buildings and their construction are therefore key to achieving the

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Paris Agreement. To date, however, energy demand in buildings has been steadily increasing, driven by the growth of the building stock combined with improved energy access and living standards (IEA, 2021). The global mitigation strategy for the building sector consists of five pillars: improved envelope performance, low-carbon heating, energy-efficient appliances and lighting, minimizing the embodied carbon of building materials, and developing sufficiency measures. Ethiopia is well aware of the challenges and strategies that are central to the sector and intends to limit GHG emissions from this sector to 5 MtCO2e, as stated in its NDC targets (Tsafos & Carey, 2020), while recent projections show an increase to 10 MtCO2e by 2030.

In 2020, 100% of Ethiopia's power generation was renewable with 96% from hydro power projects (IEA, n.d.). 51% of the country's population had access to electricity and 8% had access to clean cooling fuels (IRENA, 2022). Of the total final energy consumption, residential and commercial sectors consumed nearly 87.4% and 1.4%, respectively. Residents in informal settlements use a mix of hydroelectric (modern/ renewable energy) and 44% use Charcoal and firewood (traditional) energy for cooking (Berhe, 2019). Although per capita energy consumption in Ethiopia has been increasing, e.g., from 23 Kilo Watt hour (kWh) in 2000 to 70 kWh by 2014, this is significantly lower than the average per capita energy consumption across all African countries (500 kWh per capita) (Berhe, 2019). Households that use charcoal and firewood for cooking have higher primary energy intensity than households that use electricity (Ejigu, 2016). Incandescent lamps, fluorescent tubes and compact fluorescent lamps are often used. The share incandesce lamps is higher than the latter. Conventional storage type boilers and compact instant water heaters are used for water heating. However, their share is small. In some cold regions, charcoal stove is used for heating water (Ejigu, 2016). Typical construction materials such as cement, hollow concrete blocks (HCB), and reinforcement bars (rebars) contribute to about 94% of the embodied energy consumption and 98% of the CO2 emissions, besides generating significant construction waste (Taffese & Abegaz, 2019).

3.5.2 National-sectoral mitigation enablers and barriers

3.5.2.1 Enablers

Mitigation strategies to reduce embodied energy and CO2 emissions in Ethiopia's buildings sector are critical for addressing climate change. Energy-efficient cement production is essential, given the high energy intensity of conventional cement (Taffese & Abegaz, 2019). By adopting alternative materials and using prefabricated and recyclable materials, the sector can significantly lower its carbon footprint. Passive building design features, such as high thermal mass and low wall-to-window ratios, offer substantial energy consumption reductions across various Ethiopian climates, although there's a prevailing belief that space cooling and heating are often unnecessary (Zeleke et al., 2022; Baron & Donath, 2016).

Additionally, focusing on cooking, which has a high energy savings potential, followed by lighting, can further reduce energy demand. In rural areas without electricity, alternatives like candles, kerosene lamps, firewood, and solar energy are used for lighting (Ejigu, 2016). Promoting solar cookers, biogas, and liquid biofuels as substitutes for solid biomass in cooking can further enhance energy efficiency and reduce emissions (SE4All, 2013). Government housing programs and real estate developers can play a crucial role in scaling up the use of solar hot water systems (SE4All, 2013).

Additionally, the enforcement of building codes, coupled with training programs for adherence to these standards, are necessary steps to ensure sustainable construction practices (Taffese & Abegaz, 2019). Collectively, these strategies and enablers can significantly contribute to climate change mitigation in Ethiopia's buildings sector by reducing energy consumption and lowering CO2 emissions.

3.5.2.2 Barriers

The buildings sector in Ethiopia faces several barriers that hinder effective climate change mitigation efforts. One of the primary challenges is the shortage of skilled professionals and the unavailability of green building materials

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and technologies in the local market, which limits the implementation of sustainable construction practices and energy-efficient designs (Gelan, 2022). This deficiency is further complicated by a strong cultural preference for biomass in cooking, driven by the taste of the food, traditional practices, and entrenched consumption habits. This reliance on biomass contributes significantly to CO2 emissions and deforestation (Kebede et al., 2022). Unfortunately, buildings in Ethiopia still exhibit significant deficiencies in materials and implementation, such as fire suppression systems and earthquake protection. Additionally, issues like corruption and health and safety concerns persist. (GIZ, 2020).

Research by Taffese and Abegaz (2019) revealed that cement, HCBs, and rebars are the primary energy consumers and major contributors to CO2 emissions. Together, they accounted for 94% of the embodied energy and 98% of the CO2 emissions. Additionally, the waste generated by cement, HCBs, and rebars surpassed national limits by 148%, 159%, and 157%, respectively, which underlines the saving potential in this area. Therefore, Ethiopia needs to intensify its research on construction materials to explore ways to lower embodied energy and reduce CO2 emissions (Taffese & Abegaz, 2019).

There is also a pervasive lack of awareness about green buildings and their benefits. An example is the lack of national building energy codes which could promote energy efficiency (Taffese & Abegaz, 2019). This is compounded by a common perception that green buildings are prohibitively expensive, which discourages both developers and consumers from investing in sustainable construction (Gelan, 2022). The absence of institutions dedicated to evaluating and certifying sustainable buildings creates a significant gap in ensuring quality and recognition for green building initiatives (Anshebo et al., 2022).

Furthermore, the lack of a comprehensive policy and regulatory framework for green buildings, along with a limited understanding of their benefits among policymakers, hampers the adoption and promotion of sustainable building practices (Gelan, 2022). There are also no clear targets, milestones or dedicated action plans for the sector which makes long-term planning difficult (Climatescope, 2022). Collectively, these barriers create a challenging environment for advancing climate change mitigation in Ethiopia's buildings sector, necessitating targeted interventions to address these issues and promote sustainable development.
3.9.1 (Quicklink to table on enablers and barriers)

3.5.3 Current status of national-sectoral climate policy

Ethiopia has its fair share of regulatory, informative and market-based instruments addressing the building sector. However, the large number of actors involved in the development of the sector will also become a problem in Ethiopia. The capacity and knowledge for climate-friendly construction still needs to be developed largely in order to align all relevant actors towards decarbonisation (Cabeza et al., 2022).

In terms of **governance and planning instruments**, the National Adaptation Plan of Ethiopia outlines a comprehensive approach to enhance energy efficiency and mitigate climate change in the buildings sector through the National Energy Efficiency Action Plan (NEEAP). NEEAP promotes energy-efficient appliances, establishes energy efficiency standards, and implements energy management systems across various sectors, including industry, transportation, and buildings (EnergyPortal.eu, 2023). This plan is critical for reducing energy consumption and lowering greenhouse gas emissions in the buildings sector.

Additionally, three **regulatory instruments** were identified. The fourteen Ethiopian Building Code of Standards (EBCS) provide detailed construction guidelines covering all aspects of building, including structural elements, energy efficiency, and system design, ensuring uniform standards and promoting sustainable construction practices (GIZ, 2020). They cover the entire construction process of single, two and multi-family buildings, including structural elements, electrical systems, plumbing, heating, ventilation and air conditioning, energy efficiency requirements, as well as all other components of the construction sector (GIZ, 2020). As a part of the

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implementation of the building code, a construction council oversees the construction sector and ensures that players comply with uniform standards set by the code (GIZ, 2020). Although the EBCS send a positive signal to market actors the country still lacks standards for energy efficiency in buildings and low-carbon heating and cooling measures which could be formulated in the form of national building energy codes (Taffese & Abegaz, 2019).

Product-specific Minimum Energy Performance Standards (MEPS) introduced by the Ethiopian Standards Agency are another significant step towards climate change mitigation. MEPS have already been established for AC induction motors and CFL lighting, with plans to expand these standards to other household appliances, including cookstoves and injera baking appliances (Sigra Group AS, 2019; Eludoyin et al., 2021). The MEPS have also proven to be a cost-effective policy measure for boosting the efficiency of appliances. Finally, the 2019 Ethiopian standard for Clean Cook Stove and Clean Cooking Solution further supports this by setting performance requirements for electric cooking appliances, aligning with international standards (Sieff et al., 2022).

In terms of **market-based instruments**, financial incentives for renewable energy products, particularly solar rooftop systems play a crucial role. Since 2018, off-grid energy products have been exempted from certain taxes, although inconsistent tax policy interpretation has posed challenges. The updated 2022 tax code aims to provide clearer guidelines, ensuring solar products are more affordable and accessible (Clasp & UK Aid, 2022). This is complemented by initiatives like the Solar Lighting in Rural Ethiopia project, which establishes solar lighting centers to provide solar panels and lanterns to rural households, along with training and microloans to facilitate adoption (UNFCCC, n.d.; LWF, 2023). Additionally, Ethiopia's renewable energy auctions have successfully driven down solar PV project costs, making renewable energy more competitive and attractive. The country's procurement programs have achieved some of the lowest solar PV project prices in sub-Saharan Africa (US$c 2,53/kWh), demonstrating the potential for scaling renewable energy deployment (Kruger et al., 2019).

Finally, **information instruments** play a crucial role in decarbonizing the sector. National energy efficiency labelling schemes and energy audits in the industrial, commercial, and public sectors are part of Ethiopia’s strategy to enhance energy efficiency and promote sustainable energy use (Eucker et al., 2019). Training and education initiatives, such as the Solar Lighting in Rural Ethiopia program and the establishment of a solar competence center in Addis Ababa, are essential for building local capacity in solar energy. These programs train solar engineers and technicians, enabling them to start businesses and contribute to rural electrification efforts (UNFCCC, n.d.). By providing training, product development, testing, and assembly services, these initiatives ensure that knowledge and expertise in solar energy are developed and utilized effectively within the country (UNFCCC, n.d.).

Overall, these policies and initiatives collectively contribute to climate change mitigation in Ethiopia's buildings sector by promoting energy efficiency, renewable energy adoption, and sustainable construction practices, while also building local capacity and awareness.

Table 22: Analysed policies in Ethiopia’s buildings sector

Type of instrument	Policy
Governance and planning instruments	National Adaptation Plan of Ethiopia
Regulatory instruments	Ethiopian Building Code of Standards (EBCS) Product-specific minimum Energy Performance Standards (MEPSs) 2019 Ethiopian standard for Clean Cook Stove and Clean Cooking Solutions
Market-based instruments	Financial Incentives (Renewable energy/solar rooftop) Solar Lighting in Rural Ethiopia

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	Renewable Energy Auctions
Information instruments	Energy Labelling Schemes Training and Education (part of Solar lighting in Rural Ethiopia)

3.5.4 How to strengthen national-sectoral climate policy?

Decarbonizing the building sector in Ethiopia faces multiple barriers that cannot be resolved with a single policy instrument. Policymakers must develop a balanced policy package that combines a variety of mutually reinforcing measures to achieve effective decarbonisation (Hoefele & Thomas, 2011). Establishing roadmaps and coordination mechanisms is crucial, setting clear targets, milestones, and action plans for all decarbonisation strategies across ministries and between national, sub-national, and local governments, involving various stakeholder groups. Regulatory standards should be enforced, such as the Building Code of Standards, along with developing and enforcing building energy codes for both residential and national buildings, and implementing product-specific minimum energy performance standards (MEPS) to reduce construction waste and emissions while promoting energy efficiency.

Financial incentives, including tax breaks, can help offset the higher upfront costs of energy-efficient buildings, heating and cooling systems, appliances, on-site renewable energy, and the production of low-emission building products. Loans or grants could be provided for implementing energy efficiency measures, and carbon taxes could be collected to further reduce emissions (OECD, n.d.). Information instruments, such as increased research into construction materials, can help reduce waste and emissions. Currently, Ethiopia is not fully equipped to tackle these challenges. Despite rapid growth, the country lacks institutions to assess and certify sustainable buildings (Anshebo et al., 2022), and there is a deficit in policy and regulatory frameworks for green buildings, as well as a lack of understanding among policymakers about the benefits of green buildings. On the technical side, Ethiopia faces a shortage of skilled professionals, green building materials, and technologies in the local market (Gelan, 2022). Addressing these issues requires comprehensive policies and coordinated efforts to promote sustainable building practices and enhance the capacity for innovation in the building sector.

3.6 Land Use

3.6.1 Current national-sectoral decarbonisation status and prospects

The updated Ethiopian Nationally Determined Contribution (NDC) released in July 2021 highlights significant potential within the Land Use Change and Forestry (LULUCF) sector for mitigating greenhouse gas (GHG) emissions. According to the NDC, this sector holds substantial promise for emission reductions, with a conditional emission projection scenario indicating a potential decrease of -99.9 Mt CO2 eq by 2030, compared to a Business-as-Usual (BAU) scenario of 140.2 Mt CO2 eq and an unconditional projection of 91.8 Mt CO2 eq (NDC 2021). The document emphasizes two primary pillars for leveraging this potential: extensive reforestation efforts and improving the efficiency of household biomass energy use for cooking and baking.

In Ethiopia, methane emissions pose a significant challenge within the Agriculture, Forestry, and Other Land Use (AFOLU) sector, with the agricultural sector alone accounting for 79,311 Mt CO2 eq in 2020 (World Bank 2023). The livestock sector is identified as a major contributor to GHG emissions, with a BAU scenario projecting emissions to reach 194.8 Mt CO2 eq by 2030. However, under the conditional scenario, emissions could potentially decrease to 180 Mt CO2 eq, and under the unconditional scenario, they are projected at 192.9 Mt CO2 eq (NDC 2021). Moreover, the Managed Soils sector has been introduced to distinguish between emissions from livestock and crop production. By 2030, emissions from this sector are expected to amount to 10.6 Mt CO2 eq in the conditional scenario, with projections of 10.9 Mt CO2 eq in the unconditional scenario and 11.0 Mt CO2 eq in the BAU scenario (NDC 2021). This sector-specific differentiation underscores the complexity of emissions sources within the AFOLU sector and highlights the need for targeted mitigation strategies. Moreover, deforestation for

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agriculture and biomass use contributes significantly to higher emissions. The widespread use of traditional biomass for energy, particularly in rural areas, leads to deforestation and increased CO_2 emissions, exacerbating climate change (Tolessa 2023). Methane emissions, primarily from the agricultural sector, further compound the problem, as livestock production is a major source of this potent greenhouse gas (Holden, 2022).

The Ethiopian NDC underscores the critical role of the LUCF sector in achieving substantial emission reductions through reforestation and improved biomass energy utilisation. Addressing methane emissions from agriculture and enhancing management practices in both livestock and crop production are pivotal for achieving Ethiopia's emission reduction targets and advancing climate resilience in the AFOLU sector.

3.6.2 National-sectoral mitigation enablers and barriers

3.6.2.1 Enablers

The current state of the Ethiopian land use sector, which encompasses agriculture, livestock, and forestry, reveals a multifaceted approach towards emission reduction and climate change mitigation. The strategies outlined highlight the necessity of enhancing carbon storage, adopting sustainable management practices, and improving the efficiency of agricultural practices.
One of the key enablers is to improve the land use to enhance their role in carbon storage. This includes reforesting 3 million hectares of land by 2030 and restoring existing forests to improve their carbon sequestration capabilities (NDC 2021, 12). Moreover, carbon storage in grasslands can be improved through plant diversity, improved grazing management and biodiversity restoration (Bai and Cotrufo 2022). These measures are critical as they directly address the need to increase carbon sinks, thereby reducing atmospheric CO_2 levels. The share of agricultural land under sustainable management practices is another significant focus (NDC 2021, 12). Sustainable practices include reducing pre-harvest losses and minimizing the conversion of land for agricultural infrastructure, which can help maintain soil health and reduce emissions from land use changes. Mechanizing agriculture through the replacement of cattle and oxen with tractors is proposed to enhance efficiency (NDC 2021, 13). This mechanisation can potentially reduce methane emissions from livestock and improve the overall productivity of the agricultural sector.

In the livestock subsector, there are several enablers aimed at improving efficiency and reducing greenhouse gas (GHG) emissions. This includes the use of oilseeds in animal feed to enhance feeding efficiency and the promotion of improved breeds of cows, which are more productive and have a lower GHG intensity per unit of agricultural GDP (NDC 2021, 13). Additionally, a shift in the livestock composition is suggested, favoring poultry over cattle due to the lower emissions associated with poultry production. This shift also includes promoting a demand shift from beef to chicken (NDC 2021, 13).

Reducing the use of residential biomass through the adoption of electric stoves, improved cookstoves, and renewable biofuels is another enabler (NDC 2021, 12). This transition is aimed at lowering emissions from traditional biomass use, which is prevalent in rural areas and contributes significantly to deforestation and air pollution. Increasing access to finance for farmers is crucial for enabling adaptation to climate change. Financial support allows farmers to invest in long-term crops and trees, which can help prevent soil erosion and crop failures (Holden 2022). Moreover, reforming land management and providing land tenure security through land certificates can incentivize farmers to make long-term investments in sustainable practices, further contributing to climate change mitigation (Holden 2022).

In summary, Ethiopia's land use sector is actively pursuing a range of strategies aimed at reducing emissions and enhancing resilience to climate change. These include improving carbon storage in grasslands and forests, adopting sustainable agricultural practices, enhancing the efficiency of the livestock sector, transitioning to cleaner energy sources in households, and supporting farmers through financial access and secure land tenure. Each of these measures is crucial for achieving the country's climate goals and ensuring sustainable land use practices.

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3.6.2.2 Barriers

The Ethiopian land use sector also faces several significant barriers that hinder efforts toward emission reduction and climate change mitigation. These barriers include environmental, economic, and infrastructural challenges that complicate sustainable development and climate resilience.
One of the primary environmental barriers is the impact of higher average temperatures and greater variability in rainfall, which alter the environment for crops and exacerbate soil erosion (Holden 2022). These changes make it difficult for farmers to maintain productivity and adapt to shifting climate zones, which are increasingly affecting agricultural practices in Ethiopia (Zeleke et al. 2022).

Unsustainable land management practices, including the excessive use of chemical fertilizers and pesticides, lead to soil degradation and loss of fertility. These practices undermine the long-term productivity of the land, making it more difficult to sustain agricultural yields and contributing to environmental degradation. The lack of sustainable practices further exacerbates soil erosion and degradation, reducing the land's ability to function as a carbon sink (Zeleke et al., 2022). Low agricultural productivity is another barrier, driven by environmental degradation and limited mechanisation of agriculture. The sector remains predominantly reliant on traditional farming methods, with minimal use of modern equipment. This limited mechanisation hampers efficiency and productivity, making it challenging to improve agricultural outputs and reduce emissions (GIZ, 2018).

The lack of access to finance for farmers is a critical economic barrier. Without financial resources, farmers struggle to invest in sustainable practices, mechanisation, or long-term crops that could enhance productivity and resilience to climate change (Holden 2022). Additionally, low private investment in the agricultural sector further limits opportunities for growth and development, perpetuating cycles of low productivity and economic vulnerability. Food insecurity remains a pressing issue, directly impacting the development of the Agriculture, Forestry, and Other Land Use (AFOLU) sector (Bakala, 2016). Persistent food insecurity hinders efforts to implement sustainable practices and improve productivity, as immediate survival needs often take precedence over long-term sustainability goals. This, in turn, affects the overall development and resilience of the sector, making it more vulnerable to climate change impacts (Bakala, 2016; Holden, 2022).

In summary, the Ethiopian land use sector faces numerous barriers to emission reduction and climate change mitigation, including environmental challenges, unsustainable land management practices, low agricultural productivity, limited mechanisation, and significant economic constraints. Addressing these barriers is essential for enhancing the sector's sustainability and resilience, ultimately contributing to the country's climate goals and development objectives.

3.9.1 (Quicklink to table on enablers and barriers)

3.6.3 Current status of national-sectoral climate policy

The Ethiopian land use sector has a number of policies in place aimed at emission reduction, adaptation, and climate change mitigation. These policies reflect a comprehensive approach, although implementation and achieving specific goals remain challenging. In general, it has to be noted that it is difficult to assess the progress and effectiveness of land use policies as for now. The sector is characterized by a gap which exists between ambitious goals on the one hand and policies as well as international financial support on the other. Ethiopia has a vision for 2030, which is to be an African Beacon of prosperity. One of the six strategic pillars is to build a climate resilient green economy.

As stated in the NDCs, Ethiopia plans to transform large parts of the AFOLU sector into carbon sinks at least in the conditional scenario. This is in line with the findings in the global sectoral knowledge synthesis which states that medium confidence exists that the capacity of natural sinks may increase despite climate change (Naabuurs et al. 2022). A large part of the Ethiopian policy to create carbon sinks is based on tree planting projects which

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have yet to show if they can be an effective measure.

In terms of **governance and planning instruments**, the Ten-Year Development Plan (2021-2030) aims to significantly increase national forest coverage from 15.5% to 30% and the coverage of wildlife habitats from 8.6% to 14% (FDRE 2021). This plan also includes increasing land use efficiency from 33% to 100% in existing irrigation schemes and integrating industrial, infrastructural, and agricultural land use with nature protection (FDRE 2021). However, the plan lacks detailed direct policies on how these goals will be achieved, highlighting a potential gap between targets and actionable strategies.

Additionally, the Climate-Resilient Green Economy (CRGE) Strategy launched in 2011, targets reducing agricultural emissions, protecting and expanding forests, and adopting energy-efficient technologies across various sectors, including transport and industry (CAT, 2022). The CRGE strategy has identified 60 interventions to reduce GHG emissions to 150 mtCO2e by 2030, down from a business-as-usual projection of 400 mtCO2e (FDRE, 2020; CAT, 2022). The CRGE is currently under review, and the updated version is awaited to provide further direction.

The CRGE anticipates that agricultural crop production will rise significantly from 19 million tonnes to 71 million tonnes by 2030. This projected growth is mainly attributed to the expanded use of fertilizers and the increased acreage dedicated to agriculture. Consequently, this surge in production is expected to result in an increase in emissions from 12Mt CO2e to 60Mt CO2e. (FDRE 2011, p. 15). There is no indication that emissions have decreased in the period since the CRGE strategy came into effect. There is no method in place to attribute the potential decrease in emissions to the CRGE strategy or the initiatives driven specifically by the CRGE strategy. In other words, even if Ethiopia's national GHG emissions could have reliably been assessed as decreasing since 2010, there are no grounds for suggesting that this decrease would have been due to CRGE implementation. The CRGE has a stronger focus on agriculture than on forestry, but nevertheless includes key forestry-related strategic interventions that can contribute to adaptation, such as land use planning, forest monitoring, pest and disease control, payment for ecosystem services etc (FDRE 2020, p. 66).

Overall, there is still a lack of strategic planning regarding agroforestry systems. Those should be carefully managed to avoid food production impact compromising crop and livestock productivity when incorporating trees and shrubs. Moreover, agroforestry benefits take long periods to materialize, making it less attractive to farmers than other types of agriculture (Luedeling et al., 2016). Despite reforestation efforts, Ethiopia lost over 8kha of forest in 2021 and 2022. The number has decreased every year since 2019 (positive trend).

Additionally, three **regulatory instruments** have been examined. The Ethiopian Livestock Master Plan (LMP) (2015-2020) targeted improvements in genetics, feed, and health services to boost productivity in key livestock value chains (FAO 2015). While this plan set ambitious targets, its impact on emission reduction and climate adaptation remains to be fully assessed. The Lowlands Livelihoods Resilience Project (2019-2025) aims to improve the resilience of pastoral and agro-pastoral communities, addressing climate adaptation by enhancing livelihoods in vulnerable regions (World Bank 2024). The National Forest Sector Development Program (NFSDP) (2016-2025) serves as a master plan for sustainable forest management, informing policies and interventions to transform the forest sector (FDRE 2018a).

Green Legacy Campaigns have been successful in massive tree planting efforts, with billions of trees planted from 2019 to 2022 (CAT 2022). This initiative plays a crucial role in enhancing carbon sequestration and improving the ecosystem. National REDD+ Strategy (2018-2030) aims to reduce deforestation, forest degradation, and enhance forest carbon stock by promoting conservation and restoration of forest ecosystems. It contributes to the CRGE strategy and aims for the forest sector to achieve 50% of the total emission reduction (FDRE 2018b). REDD+ also focuses on sustainable financing for forest management, conservation, and restoration.

In terms of **market-based instruments**, the National Biogas Program (2007), with goals of constructing 14,000

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biogas plants, aims to reduce reliance on biomass and lower emissions from residential energy use. While the program has been renewed, its success in achieving targets is unclear (Kamp and Forn 2016).
The National REDD+ Strategy for Ethiopia (NRS), spanning from 2018 to 2030, is a pivotal policy framework aimed at bolstering the nation's role in global climate mitigation efforts through enhanced forest and land management practices. Aligned with Ethiopia's Climate Resilient Green Economy (CRGE) strategy and its 2030 greening targets, the NRS focuses on curbing deforestation and forest degradation, while concurrently boosting forest carbon stocks via conservation and restoration initiatives. Central to its objectives are strengthening governance structures, building local capacities for sustainable forest management, and fostering an enabling environment conducive to long-term forest preservation. By successfully implementing REDD+, the strategy envisions maximizing Ethiopia's forest sector's mitigation potential, targeting to contribute 50% of total emission reductions. This strategic approach not only aims to secure sustainable financing for forest management, conservation, and restoration efforts but also anticipates the forest sector to play a significant economic role, projected to contribute 11.2% to the national GDP (FDRE, 2018).

In terms of **information instruments**, the Program of Adaptation to Climate Change (EPACC) (2010) focused on adapting agriculture to climate change, identifying climate-sensitive infrastructure, and informing subsequent climate strategies like the CRGE and Growth and Transformation Plans (FAO 2016). Another promising approach is the Participatory and Integrated Land Use Planning (ILUP) project since it faces many challenges in the Ethiopian land use sector. It adopts a multi-level approach to enhance participatory and intersectoral land use planning. It strengthens the capacities of land management, civil society, and the private sector to develop, legally anchor, and pilot these plans, with a focus on peri-urban and rural areas with high land competition. The project also invests in training, increasing the number and quality of graduates and skilled workers. By bolstering the regulatory and institutional framework at national and regional levels, the ILUP project promotes sustainable resource use, holistic settlement planning, and prevents land use disputes, contributing to good governance and creating a favourable investment environment (GIZ, 2022).

In conclusion, the absence of integrated land use policy and land use plan not only contributes to forest loss but also reinforces unsustainable land use and land cover changes at large, which is detrimental sustainable economic development of Ethiopia. To this end, the preparation and effective implementation of a national framework for an integrated national land use plan, (currently under preparation and led by the Prime Minister’s Office), should be finalized to address Ethiopia’s persistent land management issues. There is also a clear gap in cross-sectoral coordination, joint planning and implementation of projects and programs. Finally, the sector is guided by numerous policies targeting emission reductions and climate adaptation. While these policies provide a robust framework, their success depends on effective implementation, addressing barriers such as financing, mechanisation, and sustainable practices. Enhancing policy clarity and execution will be crucial in meeting Ethiopia's climate goals and ensuring sustainable development in the AFOLU sector.

Table 23: Analysed policies in Ethiopia’s land use sector

Type of instrument	Policy
Governance and planning instruments	Ten-year development plan (2021-2030) Climate Resilient Green Economy (CRGE) Strategy Ethiopia 2011
Regulatory instruments	Livestock Master Plan Lowlands Livelihoods Resilience Project National Forest Sector Development Program (NFSDP) of Ethiopia
Market-based instruments	National Biogas Program 2007 National REDD+ Strategy 2018-2030
Information instruments	Program of Adaptation to Climate Change (EPACC) Ethiopia 2010 Integrated Land Use Planning in Ethiopia (ILUP)

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3.6.4 How to strengthen national-sectoral climate policy?

To strengthen Ethiopia's national climate policy in the land use sector, it is essential to develop comprehensive land use plans with clear targets and milestones, such as reforesting 3 million hectares by 2030. Ethiopia's NDC formulates the ambitious goal to transform the AFOLU sector into a carbon sink if international support is provided (conditional NDC). Land in Ethiopia was used in most areas in an uncontrolled and unplanned fashion without considering natural resource conservation and environmental sustainability (Haddis, 2017). Although the Ten-year development plan mentions targets for the land use sector, Ethiopia still requires detailed regional master plans accompanied by policy measure tailored to the specific regional needs. Those exist mostly in urban centres at the moment. Therefore, an overall effective land use strategy underpinned with policy measures is still missing. Without coordination the emission reduction targets will not be reached.

Enhancing regulatory frameworks to promote sustainable agricultural practices and enforcing minimum energy performance standards for agricultural machinery will help reduce emissions and improve efficiency. Providing financial incentives, such as tax breaks, grants, and low-interest loans, can encourage investments in sustainable practices and technologies. Strengthening institutional capacity through training programs and updating curricula on sustainable land use planning is vital. Increasing access to finance for farmers will enable investments in long-term crops and trees, while promoting research and innovation in sustainable practices and technologies.

Transitioning rural households to cleaner energy sources, like electric stoves and renewable biofuels, will help reduce deforestation and CO2 emissions. Enhancing monitoring and evaluation frameworks to regularly assess policy effectiveness and ensure compliance is crucial. Addressing food insecurity through integrated strategies, such as crop diversification and improved storage facilities, will support sustainable practices without compromising immediate food needs. By implementing these measures, Ethiopia can enhance its land use sector's sustainability and achieve its climate goals.

3.7 Conclusion

This section has examined the current enablers, barriers, and policy options in five key sectors: industry, energy, transport, buildings, and land use. Each sector was discussed in its own chapter, following a consistent structure: Introduction, enablers and barriers, the current status of national climate policy, and policy recommendations based on the analysis. For a more detailed analysis, sector-related tables outlining enablers, barriers, and policy options can be found in the annex.

Ethiopia's industrial sector has made significant progress in aligning with national Science, Technology, and Innovation (STI) policies and intellectual property rights frameworks, fostering innovation and adherence to high standards. Financial incentives and government support for laboratory and testing facilities attract investment and encourage compliance with environmental and operational benchmarks. However, the sector faces challenges, such as inadequate collaboration among stakeholders, an imbalance between imports and exports, and the use of outdated technologies. Strengthening coordination, enhancing technological adoption, and improving regulatory frameworks are essential to overcoming these obstacles. Addressing these challenges will further Ethiopia's efforts in climate change mitigation and the sustainable development of its industrial sector.

Overcoming barriers in Ethiopia's energy sector necessitates robust regulatory frameworks and effective policies to attract private investment in renewable energy. Enhancing R&D for innovation, fostering international collaboration for technology transfer, and improving institutional capacities are critical. Economic incentives such as feed-in tariffs and tax exemptions can stimulate sector growth. Establishing clear performance and technical standards for renewable energy technologies, coupled with professional training and capacity-building programs, will ensure sustainable energy development. Setting quantified renewable energy targets, promoting modern energy access, and expanding renewable energy capacity will significantly contribute to climate change mitigation

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and the overall resilience of Ethiopia's energy sector.

The Ethiopian transport sector faces several challenges, including limited access to electricity, inadequate infrastructure for EVs, high costs of implementing new technologies, and behavioural resistance to non-motorized transport. Additionally, there are funding constraints and a lack of integrated planning with other sectors. Despite these obstacles, there are promising enablers for this transition. Policy support, such as high import taxes and bans on old vehicles, can stimulate domestic vehicle manufacturing and EV imports. Public awareness campaigns and integrated transport-land-use-environment policies can promote sustainable transport practices. Investing in infrastructure for pedestrian and cycling networks, along with leveraging biomass residues for electricity generation, can enhance eco-friendly transport options. Setting clear emission targets and enforcing rigorous GHG monitoring will help regulate environmental impacts. Overall, these strategies underscore Ethiopia's commitment to a climate-resilient and efficient transport system.

The Ethiopian building sector faces several challenges including a lack of institutions to assess and certify sustainable buildings, an underdeveloped policy and regulatory framework for green buildings, and limited awareness among policymakers about their benefits. Additionally, there is a shortage of skilled professionals, green building materials, and technologies in the local market. Potential enablers to address these issues include developing clear roadmaps and coordination mechanisms, enforcing regulatory standards such as building energy codes and minimum energy performance standards, and providing financial incentives like tax breaks and grants to offset the higher costs of energy-efficient buildings and technologies. Moreover, investing in research and development for construction materials can further reduce waste and emissions, supporting the sector's transformation towards sustainability.

Strengthening Ethiopia's national climate policy in the land use sector requires the development of comprehensive land use plans with clear targets which are supported by implementing policies. Enhancing regulatory frameworks and providing financial incentives will promote sustainable agricultural practices and reduce emissions. Strengthening institutional capacity through training and updated curricula, increasing access to finance for farmers, and promoting research and innovation are vital steps. Transitioning rural households to cleaner energy sources and improving monitoring and evaluation frameworks will further support sustainability. Addressing food insecurity through integrated strategies will ensure that immediate needs are met without compromising long-term goals. By implementing these measures, Ethiopia can significantly enhance the sustainability of its land use sector and achieve its climate goals.

3.8 Bibliography

Introduction

Climate Action Tracker (2022). Ethiopia. [Online] Available at: https://climateactiontracker.org/countries/ethiopia/ (accessed 29 July 2024).

NDC (2021). Ethiopia - Updated Nationally Determined Contribution. [Online] Available at: https://unfccc.int/sites/default/files/NDC/2022-06/Ethiopia%27s%20updated%20NDC%20JULY%202021%20Submission_.pdf

Michal, N., Sam, F., Jana, D., Nick, K., Tucker, L., Hitomi, R., Philip, S., Joana, S., Amelia, S., Stolle, C.,Jayaraj, S. and Terry, T. (2015). Climate Change Legislation in Ethiopia, an Excerpt from the 2015 Global Climate Legislation Study. *A Review of Climate Change Legislation in 99 Countries*. [Online] Available

Funded by the European Union

at: https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/05/ETHIOPIA.pdf

World Bank (2024). The World Bank in Ethiopia: Overview. [Online] Available at: https://www.worldbank.org/en/country/ethiopia/overview (accessed 28 July 2024).

Industry

AFREC Energy (n.d.). Ethiopia. [Online] Available at: https://au-afrec.org/ethiopia (accessed 28 July 2024)

Altenburg, T. (2010). Industrial policy in Ethiopia. *Discussion Paper / Deutsches Institut für Entwicklungspolitik; 2/2010*. [Online] Available at: https://www.files.ethz.ch/isn/115489/2010-02e.pdf

Climate Governance (2020). CAT Climate governance series. [Online] Available at: https://climateactiontracker.org/documents/838/2020_12_CAT_Governance_Report_Ethiopia.pdf

CRGE (2011). Ethiopia's Climate Resilient Green Economy, Green Economy strategy. [Online] Available at: https://www.jica.go.jp/Resource/english/our_work/climate_change/pdf/policy_14.pdf

COMESA (n.d.). Climate-Resilient Green Economy Implementation and Best Practices on Climate Action in ETHIOPIA. [Online] Available at: https://www.comesa.int/wp-content/uploads/2020/06/Climate-Resilient-Economy-Ethiopia-Report-1.pdf

Damtie, M., Bayou, M. (2008). Overview of Environmental Impact Assessment in Ethiopia Gaps and Challenges. *MELCA Mahiber*. [Online] Available at: https://chilot.blog/wp-content/uploads/2011/01/overview-of-eia-book-html.pdf

DANAS Electrical Engineering (2015). Project document on Electric Injera Mitad Energy Efficiency Standards and Labeling. [Online] Available at: https://www.academia.edu/33020865/Project_document_on_Electric_Injera_Mitad_Energy_Efficiency_Standards_and_Labeling (accessed 29 July 2024).

Desalegn, A., Solomon, N. (2021). Effects of institutional capacity, infrastructure governance, and equity on state- and nation-building processes in Ethiopia. *Journal of Infrastructure, Policy and Development (5),* 2. ECPC (2024).

EEA (n.d). Energy Efficiency Program and activity plan Ethiopian Energy Authority. *European Environment Agency*. [Online] Available at: https://rise.esmap.org/data/files/library/ethiopia/Energy%20Efficiency/Ethiopia_Energy%20Efficiency%20Program%20Final%20A4.pdf

EIC (n.d.). Ethiopia Investment Policies and Incentives and opportunities. *Ethiopian Investment Commission*. [Online] Available at: http://www.unido.or.jp/files/Ethiopia-Investment-Policies-and-Incentives-and-Opportunities.pdf

EnergyPortal.eu. (2023). Energy Efficiency Initiatives in Ethiopia: A Path to a Greener Future. *EnergyPortal.Eu*. [Online] Available at: https://www.energyportal.eu/news/energy-efficiency-initiatives-in-ethiopia-a-path-to-a-greener-future/30748/ (accessed 29 July 2024).

ENA (2022). Fuel Subsidy Revision Pushes Down Monthly Gov't Loss from 10 to 4 Billion Birr. *Ethiopian News Agency*. [Online] Available at: https://www.ena.et/web/eng/w/en_40278 (accessed 29 July 2024).

Erena, O.T., Kalko, M.M., Debele, S.A. and Nsiah, C. (2021). Technical efficiency, technological progress and productivity growth of large and medium manufacturing industries in Ethiopia: A data envelopment analysis. *General & Applied Economics.* [Online] Available at: https://doi.org/10.1080/23322039.2021.1997160

Funded by the European Union

ESIC (2010). Ethiopian Standard Industrial Classification. *ESIC.* First Publication-January 2010. [Online] Available at: https://docplayer.net/22180046-Ethiopian-standard-industrial-classification-esic-first-publication-january-2010.html (accessed 28 July 2024).

ESIPC (n.d). Environmental Standards for Industrial Pollution Control in Ethiopia. [Online] Available at: https://plasticsdb.surrey.ac.uk/documents/Ethiopia/Republic%20of%20Ethiopia%20%282011%29%20Environmental%20standards%20for%20industrial%20pollution%20control%20in%20Ethiopia.pdf

Eucker, D., Ferdinand, N., Morales, C., & Telfser, K. (2019). Quality Infrastructure for Climate Change Mitigation and Adaptation to Climate Change: Potentials, opportunities and chances in Sub-Saharan Africa. *Physikalisch-Technische Bundesanstalt.* [Online] Available at: https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_9/9.3_internationale_zusammenarbeit/publikationen/PTB_Study_QI_Climate_Change_Africa_EN_.pdf

EVR (2022). Ethiopian Voluntary National Review. [Online] Available at: https://hlpf.un.org/sites/default/files/vnrs/2022/VNR%202022%20Ethiopia%20Report_1.pdf

Fanuel, S., Butler,M., Grinsted,P. (2022). On the Path to Industrialization : A Review of Industrial Parks in Ethiopia - Policy Report (English). *Washington, D.C. : World Bank Group.* . [Online] Available at: http://documents.worldbank.org/curated/en/099350011132228872/P1741950a12ef10560af5008750d1393b7c (accessed 28 July 2024).

Gebeyehu, W. (2022). What is New in Ethiopia's New Industrial Policy: Policy Direction and Sectoral Priorities. *Ministry of Industry of Ethiopia.* [Online] Available at: https://unctad.org/system/files/non-official-document/aldc_2022_pdsd_eth_pdw_3-4_mar_ppt_worku_gebeyehu_eng.pdf

Girum, A.T., Abreham, T.B., Yedilfana, S.M., Natei. E.B., , Ramato, A.T. (2021). Opportunities and Challenges of Renewable Energy Production in Ethiopia. *Sustainability, MPDI.*

Girma, K. (2023). Evaluation of the Status of the Ethiopian Nuclear Infrastructure Development. *Ethiopian Journal of Science and Technology*, 16 (Special), 23-34.

GMSE (2019). Green Manufacturing Strategy for Ethiopia: Growing Industry Sustainably. [Online] Available at: https://www.climatelinks.org/sites/default/files/asset/document/2021-06/190817_ETH_Green%20Manufacturing%20Strategy%20for%20Ethiopia%20-%20Final.pdf

IEA (2019.). Ethiopia—Countries & Regions. *IEA*. [Online] Available at: https://www.iea.org/articles/ethiopia-energy-outlook (accessed 26 July 2024).

Krueger, J., Gebru, A., Asnake, I. (2012). Environmental Permitting in Ethiopia: No Restraint on "Unstoppable Growth*. Environmental Science, Political Science*. [Online] Available at: https://hulr.haramayajournals.org/index.php/hulr/article/view/382/268 (accessed 29 July 2024).

Mahlet, E. M. (2022). Green Industrialisation in Ethiopia, Challenges and Potentials on the Road to a Net Zero Green economy Case Study. *Vienna Institute for International Dialogue and Cooperation (VIDC).* [Online] Available at: https://www.vidc.org/fileadmin/martina/studien/mahlet_eyassu_melkie_green_industrialisation_in_ethiopia_vidc_study_may2022.pdf

Mulualem, G.G. (2021). Development and manufacturing of solar and wind energy technologies in Ethiopia: Challenges and policy implications. *Renewable Energy,(168), 107-118.*

Negussie, R. (1999). Cleaner Industrial Production practice in Ethiopia: Problems and Prospects. *Journal of Cleaner Production, (7), 409-412.*

Oqubay, A. (2018). Industrial Policy and Late Industrialisation in Ethiopia*. Working Paper Series N° 303, African Development Bank, Abidjan, Côte d'Ivoire*. [Online] Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/WPS_No_303__Industrial_Policy

Funded by the European Union

_and_Late_Industrialization_in_Ethiopia_B.pdf

Reporter (2024). Most transport providers cut off from fuel subsidies three years ahead of schedule. [Online] Available at: https://www.thereporterethiopia.com/38360/ (accessed 26 July 2024).

Sigra Group AS (2019). Energy Efficiency Strategy for the Ethiopian Manufacturing Sector. [Online] Available at: https://www.climatelinks.org/sites/default/files/asset/document/2021-06/Energy%20Efficiency%20Strategy%20-%20FINAL.pdf

TYDP (n.d.). Ten Years Development Plan (TYDP), A Path Way to Prosperity, (2021 - 2030). [Online] Available at: https://www.ircwash.org/sites/default/files/ten_year_development_plan_a_pathway_to_prosperity.2021-2030_version.pdf

Tsafos, N., Carey L. (2020). Energy Transition Strategies: Ethiopia's Low-Carbon Development Pathway. [Online] Available at: https://www.csis.org/analysis/energy-transition-strategies-ethiopias-low-carbon-development-pathway (accessed 29 July 2024).

UNDP (2021a). Capacity Needs Assessment and Capacity Development Plans: For Updated Ethiopia's NDC Implementation of the Ethiopian Transport, Energy and Industry Sectors. *United Nations Development Programme*. [Online] Available at: https://www.epa.gov.et/images/PDF/NDC/Ethiopia_2021_Report_Final%20NDC%20Support_Transport%20Energy%20&%20Industry.pdf

UNDP (2021b). Financing strategy and Implementation Plan, for Update Ethiopia's Nationally Determined Contributors. *United Nations Development Programme.* [Online] Available at: https://www.epa.gov.et/images/PDF/NDC/Final_Financing%20strategy%20and%20implementation%20plan.pdf

UNIDO (2018). Industrial Park Development In Ethiopia Case Study Report. *Inclusive and Sustainable Industrial Development Working Paper Series WP 21 / 2018.* [Online] Available at: https://downloads.unido.org/ot/10/69/10694802/Industrial%20park%20development%20in%20Ethiopia%20Case%20study%20report.pdf

UNCTAD (2020a). Ethiopia Science, Technology & Innovation Policy Review. *United Nations Conference on Trade And Development.* [Online] Available at: https://unctad.org/system/files/official-document/dtlstict2020d3_en.pdf

World Bank (2023). World Bank and Ethiopia Sign $40 Million Agreement to Cut Carbon Emissions Through Sustainable Landscape Management. *World Bank*. Press Release February 9, 2023. [Online] Available at: https://www.worldbank.org/en/news/press-release/2023/02/09/world-bank-and-ethiopia-sign-40-million-agreement-to-cut-carbon-emissions-through-sustainable-landscape-management (accessed 26 July 2024).

World Bank (2024). The World Bank in Ethiopia – Overview. World Bank. [Online] Available at: https://www.worldbank.org/en/country/ethiopia/overview (accessed 26 July 2024).

Yalew, A. W. (2022). The Ethiopian energy sector and its implications for the SDGs and modeling. *Renewable and Sustainable Energy Transition, 2, 100018*. [Online] Available at: https://doi.org/10.1016/j.rset.2022.100018

Energy

Climate Action Tracker (2022). Ethiopia. [Online] Available at: https://climateactiontracker.org/countries/ethiopia/ (accessed 29 July 2024).

EEA (2018). Improved Electric Mitad Production and Training Module Preparation. *Ethiopian Energy Authority*

Funded by
the European Union

Project document.

EEA (2018). TARIFF GUIDELINEAND METHODOLOGY - For Grid power supply. Ethiopian Energy Authority. [Online] Available at: https://rise.esmap.org/data/files/library/ethiopia/Electricity%20Access/Ethiopia_Tariff%20guideline%20and%20methodology.pdf,

FDRE (2019). National Electrification Program 2.0: Integrated Planning for Universal Access (Lighting to All). *Ministry of Water Irrigation and Energy.*

FDRE (2011). Ethiopia's Climate-Resilient Green Economy. *Federal Democratic Republic of Ethiopia.* [Online] Available at: https://faolex.fao.org/docs/pdf/eth186137.pdf (accessed 5 July 2024).

FDRE (2016). Growth and Transformation Plan II (2015/16-2019/20), Volume I: Main Text. *Federal Democratic Republic of Ethiopia, National Planning Commission.* [Online] Available at: https://plasticsdb.surrey.ac.uk/documents/Ethiopia/National%20Planning%20Commission%20(2016)%20Growth%20and%20Transformation%20Plan%20II%20Vol%201,%20Ethiopia.pdf

Gebreslassie, M. G. (2020). Solar home systems in Ethiopia: Sustainability challenges and policy directions. *Sustainable Energy Technologies and Assessments, 42, 100880.* [Online] Available at: https://doi.org/10.1016/j.seta.2020.100880

GIZ (2022). Multi-actor Cooking Energy Strategy for Refugees and Host Communities in Ethipoia (2022-2030). German Society for International Cooperation. [Online] Available at: https://reliefweb.int/report/ethiopia/multi-actor-cooking-energy-strategy-refugees-and-host-communities-ethiopia-2022-2030-december-2022 (accessed 5 July 2024).

GoE (2020). Updated nationally determined contribution (uNDC). *Government of Ethiopia.* [Online] Available at: https://www.greenpolicyplatform.org/national-documents/ethiopia-nationally-determined-contribution-ndc; https://africandchub.org/country/ethiopia, (accessed 5 July 2024).

Mekonnen, T.W., Teferi, S.T., Kebede, F.S., Anandarajah, G. (2022). Assessment of Impacts of Climate Change on Hydropower-Dominated Power System—The Case of Ethiopia. *Appl. Sci. 2022, 12, 1954.* [Online] Available at: https://doi.org/10.3390/app12041954

MoWE (2013). Ethiopian National Energy Policy. ENEP, Ministry of Water and Energy.

Ritchie, H., Roser, M., Rosado, P. (2022). Energy. OurWorldInData. [Online] Available at: https://ourworldindata.org/energy (accessed 5 July 2024).

Sieff R., Troncoso, K., Tesfa M. (2022). Ethiopia eCooking Market Assessment. Modern Energy Cooking Service. [Online] Available at: https://mecs.org.uk/wp-content/uploads/2022/02/MECS-EnDev-Ethiopia-eCooking-Market-Assessment-presentation.pdf

Taka, G. N. (2020). Determinants of energy-based CO2 emissions in Ethiopia: A decomposition analysis from 1990 to 2017. Sustain., vol. 12, no. 10, pp. 1–17, 2020. [Online] Available at: doi: 10.3390/su12104175

Tesfamichael, M., Mulugetta, Y., Beyene, A. D., & Sebsibie, S. (2021). Counting the cost: Coping with tariff increases amidst power supply shortfalls in urban households in Ethiopia. *Energy Research & Social Science, 71, 101860.* [Online] Available at: https://doi.org/10.1016/j.erss.2020.101860

Viegand Maagøe A/S (2023). Review of Ethiopian Energy Efficiency Policy. *Ethiopian-Danish Energy Cooperation, Aug 2023.*

Yalew, A. W. (2022). The Ethiopian energy sector and its implications for the SDGs and modeling. *Renewable and Sustainable Energy Transition, 2, 100018.* [Online] Available at: https://doi.org/10.1016/j.rset.2022.100018

Funded by the European Union

Transport

Addis Standard (2024). Ethiopia surpasses 100,000 electric vehicles mark, ministry reports. *Ministry of Transport and Logistics*. [Online] Available at: https://twitter.com/addisstandard/status/1770736867807289444 (accessed 28 March 2024).

Hampel, C. (2024). Ethiopia exceeds import targets for electric vehicles. *Electrive*. [Online] Available at: https://www.electrive.com/2024/04/05/ethiopia-exceeds-import-targets-for-electric-vehicles/, (accessed 28 March 2024).

Kaleab E., Mengesha Y. (2023). A Path to Low Carbon and Climate Friendly Transport Sector in Addis Ababa: System Dynamics Approach. *Addis Ababa University.* [Online] Available at: https://etd.aau.edu.et/server/api/core/bitstreams/e4058568-a9dd-4a07-bfe8-136f5f307475/content (accessed 28 March 2024).

Tolessa, Amsalu (2023). Bioenergy potential from crop residue biomass resources in Ethiopia. *Heliyon 9(2).* [Online] Available at: https://www.sciencedirect.com/science/article/pii/S240584402300779X (accessed 28 June 2024).

FDRE Ministry of Planning and Development (2022). Third National Communication (NC3) to the UNFCCC. *Federal Democratic Republic of Ethiopia.*

FDRE Ministry of Transport and Logistics (2022). Ethiopian Transport Master Plan - Policy and Strategy 2022-2052. *Federal Democratic Republic of Ethiopia.*

FDRE Ministry of Transport (2020). Ethiopia non-motorised transport strategy 2020-2029. *Federal Democratic Republic of Ethiopia*. [Online] Available at: https://unhabitat.org/sites/default/files/2020/07/ethiopia_nmt_strategy_en_200629.pdf (accessed 28 June 2024).

FDRE Ministry of Transport (2020). National Transport Policy. *Federal Democratic Republic of Ethiopia*.

FDRE Planning and Development Ministry (2020). Ethiopia's long-term low emission and climate resilient development strategy (2020-2050). *Federal Democratic Republic of Ethiopia.*

Federal Democratic Republic of Ethiopia (2015). Intended Nationally Determined Contribution (INDC) of the Federal Democratic Republic of Ethiopia. [Online] Available at: http://www4.unfccc.int/submissions/INDC/Published Documents/Ethiopia/1/INDC-Ethiopia-100615.pdf

IEA (2019). Ethiopia Energy Outlook – Analysis. *IEA*. [Online] Available at: https://www.iea.org/articles/ethiopia-energy-outlook (accessed 21 November 2023).

Ministry of Finance (2021). Directive no. 773/2021 to provide for tax and Duty exemption for vehicles rendering taxi Transport services. *Federal Democratic Republic of Ethiopia.*

Ministry of Trade & Regional Integration (2022). Targeted fuel price subsidies benefit low-income segments of society. *Federal Democratic Republic of Ethiopia*. [Online] Available at: https://motri.gov.et/en/news/targeted-fuel-price-subsidies-benefit-low-income-segments-of-society-1, (accessed 28 June 2024).

Ministry of Transport (2017). Ethiopia's Climate Resilient Transport Sector Strategy. *Federal Democratic Republic of Ethiopia.* [Online] Available at: https://www.mofed.gov.et/media/filer_public/15/31/153174c3-b472-4339-b3bb-fb2c48cad629/transport_cr.pdf (accessed 29 July 2024).

Ministry of Transport (2020). Ethiopia Non-Motorised Transport Strategy 2020-2029. *Federal Democratic Republic of Ethiopia*. [Online] Available at:

Funded by
the European Union

https://unhabitat.org/sites/default/files/2020/07/ethiopia_nmt_strategy_en_200629.pdf (accessed 29 July 2024).

Statista (2024). Ethiopia: Inflation rate from 1989 to 2029. [Online] Available at: https://www.statista.com/statistics/455089/inflation-rate-in-ethiopia/ (accessed 28 April 2024).

Tadesse S. M. (2022). Costly taxes drive Ethiopia's illicit vehicle trade. *ISS Africa*. [Online] Available at: https://issafrica.org/iss-today/costly-taxes-drive-ethiopias-illicit-vehicle-trade (accessed 22 November 2023).

Tewodros T. (2022). Ethiopia Transport Sector. *International Trade Administration*. [Online] Available at: https://www.trade.gov/market-intelligence/ethiopia-transport-sector (accessed 21 November, 2023).

Xinhua (2022)."Feature: Ethiopia embarks on e-mobility transition amid rising fuel prices, quest for green dev't. [Online] Available at: https://english.news.cn/africa/20220730/2f84ef1df8a6470e803bd93d472010fd/c.html, (accessed 28 April 2024).

Yonas, A. (2023). Registered Vehicle In Ethiopia Reaches 1.2 Mln. *The Reporter.* [Online] Available at: https://www.thereporterethiopia.com/10186/ (accessed 21 November 2023).

Zachary, S. (2024). Ethiopia Banning Non-Electric Car Imports. *CleanTechnica.* [Online] Available at: https://cleantechnica.com/2024/02/07/ethiopia-banning-non-electric-car-imports/ (accessed 28 March 2024).

Buildings

Anshebo, M. A., Mengesha, W. J., & Sokido, D. L. (2022). Developing a Green Building Assessment Tool for Ethiopia. *Heliyon, 8(9), e10569*. [Online] Available at: https://doi.org/10.1016/j.heliyon.2022.e10569

Antimiani, A., Costantini, V., & Paglialunga, E. (2023). Fossil fuels subsidy removal and the EU carbon neutrality policy. *Energy Economics*, *119*, 106524. [Online] Available at: https://doi.org/10.1016/j.eneco.2023.106524

Baron, N., Donath, D. (2016). Learning from Ethiopia—A Discussion on Sustainable Building. *ResearchGate*. [Online] Available at: https://www.researchgate.net/publication/299223052_Learning_from_Ethiopia_-_A_Discussion_on_Sustainable_Building (accessed 28 April 2024).

Berhe, A. G. (2019). HOUSE HOLD ENERGY MANAGEMENT IN INFORMAL SETTLEMENTS OF ADDIS ABABA. *SES*. [Online] Available at: https://mdl.donau-uni.ac.at/ses/pluginfile.php/405/mod_page/content/18/HOUSE%20HOLD%20ENERGY%20MANAGEMENT%20IN%20INFORMAL%20SETTLEMENTS%20by%20Abnet%20Gezahegn%20Berh.pdf

Cabeza, L. F., Bai, Q., Bertoldi, P., Kihila, J., Lucena, A. F. P., Mata, É., Mirasgedis, S., Novikova, A., & Saheb, Y. (2022): Chapter 9: Buildings Supplementary Material. In: IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*

Clasp, UK Aid (2022). OFF- AND WEAK-GRID SOLAR APPLIANCE MARKET ETHIOPIA. *UkAid.* [Online] Available at: https://www.clasp.ngo/wp-content/uploads/2022/05/Ethiopia-country-profile.pdf

Climatescope (2022). Climatescope 2022 | Ethiopia. [Online] Available at: https://www.global-climatescope.org/markets/et/ (accessed 28 April 2024).

Ejigu, N. A. (2016). Energy Modelling in Residential Houses: A Case Study of Single Family Houses in Bahir Dar City, Ethiopia. *KTH*. [Online] Available at: https://kth.diva-portal.org/smash/get/diva2:900564/FULLTEXT01.pdf

Funded by the European Union

Eludoyin, E. O., Broad, O., Tomei, J., Anandarajah, G., Pappis, I., Sahlberg, A., & Milligan, B. (2021). Energy system development pathways for Ethiopia. *UCL, KTH Royal Institute of Technology.*

EnergyPortal.eu. (2023). Energy Efficiency Initiatives in Ethiopia: A Path to a Greener Future. *EnergyPortal.Eu*. [Online] Available at: https://www.energyportal.eu/news/energy-efficiency-initiatives-in-ethiopia-a-path-to-a-greener-future/30748/ (accessed 29 July 2024).

Eucker, D., Ferdinand, N., Morales, C., Telfser, K. (2019). Quality Infrastructure for Climate Change Mitigation and Adaptation to Climate Change: Potentials, opportunities and chances in Sub-Saharan Africa. *Physikalisch-Technische Bundesanstalt.* [Online] Available at: https://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_9/9.3_internationale_zusammenarbeit/publikationen/PTB_Study_QI_Climate_Change_Africa_EN_.pdf

Gelan, E. (2022). Green Building Concepts and Technologies in Ethiopia: The Case of Wegagen Bank Headquarters Building. *Technologies*, *11*(1), 2. [Online] Available at: https://doi.org/10.3390/technologies11010002

GIZ. (2020). Partnership Ready Ethiopia: Construction. German Society for International Cooperation. [Online] Available at: https://www.giz.de/en/downloads/GBN_SectorBrief_%C3%84thiopien_Construction_E_WEB.pdf

Hoefele, V., Thomas, S. (2011). Combining theoretical and empirical evidence. *ECEEE 2011 Summer Study.*

IEA (n.d.). Ethiopia—Countries & Regions. *IEA.* [Online] Available at: https://www.iea.org/countries/ethiopia

IEA (2021). Tracking Buildings 2021. *International Energy Agency*. [Online] Available at: https://www.iea.org/reports/tracking-buildings-2021 (accessed 29 August 2023).

IRENA. (2022). Energy profile—Ethiopia. [Online] Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Ethiopia_Africa_RE_SP.pdf

Kebede, N., Tolossa, D., & Tefera, T. (2022). Determinants of Energy Choice for Domestic Use in Informal Settlements of Addis Ababa. *Journal of Science and Sustainable Development*, *8*(1), 33–44. [Online] Available at: https://doi.org/10.4314/jssd.v8i1.3 (accessed 29 August 2023).

Kruger, W., Stuurman, F., & Alao, O. (2019). Ethiopia Country Report. *Power Futures Lab*. [Online] Available at: https://www.gsb.uct.ac.za/files/Ethiopia_Country_Report.pdf

LWF (2023). Ethiopia: Solar lights for rural communities. *The Lutheran World Federation*. [Online] Available at: https://www.lutheranworld.org/news/ethiopia-solar-lights-rural-communities (accessed 29 July 2024).

OECD (n.d.). Carbon pricing background notes. *OECD*. [Online] Available at: https://www.oecd.org/tax/tax-policy/carbon-pricing-background-notes.pdf

OECD (2022). Pricing Greenhouse Gas Emissions: Key Findings for Ethiopia. *OECD*. [Online] Available at: https://www.oecd.org/tax/tax-policy/carbon-pricing-ethiopia.pdf

Pathak, M., Slade, R., Pichs-Madruga, R., Ürge-Vorsatz, D., Shukla, P. R., Skea, J., Abdulla, A., Khourdajie, A., Babiker, M., Bai, Q., Bashmakov, I., Bataille, C., Berndes, G., Blanco, G., Cabeza, L. F., Carraro, C., Clarke, L., de Coninck, H., Creutzig, F., … Winkler, H. (2022): Working Group III contribution to the IPCC Sixth Assessment Report (AR6). Technical Summary.

SE4All (2013). *Updated Rapid Assessment and Gap Analysis on Sustainable Energy for All (SE4All): The UN Secretary General Initiative*. [Online] Available at: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/MWH_-_Updated-Rapid_Gap_Analysis.pdf

Funded by
the European Union

Sieff, R., Troncsoso, K., & Tesfamichale, M. (2022). *Ethiopia—eCooking Market Assessment*. [Online] Available at: https://mecs.org.uk/wp-content/uploads/2022/02/MECS-EnDev-Ethiopia-eCooking-Market-Assessment.pdf

Sigra Group AS (2019). Energy Efficiency Strategy for the Ethiopian Manufacturing Sector. [Online] Available at: https://www.climatelinks.org/sites/default/files/asset/document/2021-06/Energy%20Efficiency%20Strategy%20-%20FINAL.pdf

Taffese, W. Z., & Abegaz, K. A. (2019). Embodied Energy and CO2 Emissions of Widely Used Building Materials: The Ethiopian Context. *Buildings* 9(6), Article 6. [Online] Available at: https://doi.org/10.3390/buildings9060136 (accessed 29 August 2023).

Tsafos, N. and Carey L. (2020). Energy Transition Strategies: Ethiopia's Low-Carbon Development Pathway. [Online] Available at: https://www.csis.org/analysis/energy-transition-strategies-ethiopias-low-carbon-development-pathway

UNFCCC (n.d.). Solar Lighting in Rural Ethiopia. *United Nations Climate Change*. [Online] Available at: https://unfccc.int/climate-action/momentum-for-change/activity-database/momentum-for-change-solar-lighting-in-rural-ethiopia

Zeleke, B., Kumar, M., & Rajasekar, E. (2022). A Novel Building Performance Based Climate Zoning for Ethiopia. *Frontiers in Sustainable Cities*, *4*. [Online] Available at: https://www.frontiersin.org/articles/10.3389/frsc.2022.684148

Land Use

Bakala, F. (2016). Food Insecurity in Ethiopia. [Online] Available at: https://core.ac.uk/reader/234684260 (accessed 5 July 2024).

Bai, Y. and Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding, challenges, and solutions. *Science* 377(6606). DOI: 10.1126/science.abo2380.

CAT (2022). Climateactiontracker – Ethiopia. [Online] Available at: https://climateactiontracker.org/countries/ethiopia/policies-action/ (accessed 5 July 2024).

FAO (2015). Ethiopia Livestock Master Plan. *Food and Agriculture Organization of the United Nations*. [Online] Available at: https://www.fao.org/faolex/results/details/es/c/LEX-FAOC191493/ (accessed 5 July 2024).

FAO (2016). Voicing Pastoralism through Integrative Advocacy: Experiences and lessons learned from Ethiopia. *Food and Agriculture Organization of the United Nations*. [Online] Available at: https://www.fao.org/family-farming/detail/fr/c/433933/ (accessed 5 July 2024).

FDRE (2011). Ethiopia's Climate-Resilient Green Economy. *Federal Democratic Republic of Ethiopia*. [Online] Available at: https://faolex.fao.org/docs/pdf/eth186137.pdf (accessed 02.07.2024)

FDRE (2018a). National Forest Sector Development Program, Ethiopia. *Federal Democratic Republic of Ethiopia.* [Online] Available at: https://www.undp.org/ethiopia/publications/ten-year-national-forest-sector-development-programme (accessed 5 July 2024).

FDRE (2018b). National REDD+ Strategy (2016-2030). *Federal Democratic Republic of Ethiopia.* [Online] Available at: https://faolex.fao.org/docs/pdf/eth178847.pdf (accessed 27 June 2024).

FDRE (2020). Ethiopia's Climate Resilient Green Economy (CRGE) Strategy (2011-2019) – Implementation Progress Assessment Report. *Federal Democratic Republic of Ethiopia*. [Online] Available at:

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https://documents1.worldbank.org/curated/en/099431306152210191/pdf/P17111608a30af0b00ab1705840c391dc04.pdf

FDRE (2021). Ten Years Development Plan - a Pathway to Prosperity 2021-2030. *Federal Democratic Republic of Ethiopia*. [Online] Available at: https://www.ircwash.org/sites/default/files/ten_year_development_plan_a_pathway_to_prosperity.2021-2030_version.pdf

GIZ (2018). Agricultural Mechanisation & Rural Employment. *German Society for International Cooperation.* [Online] Available at: https://www.giz.de/en/downloads/giz2019-EN-Agricultural-Mechanisation-Rural-Employment.pdf (accessed 5 July 2024).

GIZ (2022). Integrated Land Use Planning in Ethiopia. *German Society for International Cooperation.* [Online] Available at: https://www.giz.de/de/downloads/giz2023-en-ethiopia-integrated-land-use.pdf (accessed 28 June 2024).

Haddis, Zeden (2017). ETHIOPIA'S MOVE TO A NATIONAL INTEGRATED LAND USE POLICY AND LAND USE PLAN*. Paper prepared for the World Bank*. [Online] Available at: https://www.land-links.org/wp-content/uploads/2017/03/USAID_Land_Tenure_WB17_Ethiopia_Move_Land_Use_Plan.pdf

Holden, Joseph (2022). Land and Climate: Lessons from Ethiopia. Available at: https://dai-global-developments.com/articles/land-and-climate-lessons-from-ethiopia/ (accessed 5 July 2024).

IPCC (2019). Summary for Policymakers. In: C*limate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [Online] Available at: https://doi.org/10.1017/9781009157988.001

Kamp, Linda Manon; Forn, Esteban Bermúdez (2016). Ethiopia's emerging domestic biogas sector: *Current status, bottlenecks and drivers, Renewable and Sustainable Energy Reviews, Volume 60, 2016, Pages 475-488, ISSN 1364-0321.* [Online] Available at: https://doi.org/10.1016/j.rser.2016.01.068.

Luedeling, E., Smethurst, P. J., Baudron, F., Bayala, J., Huth, N. I., van Noordwijk, M., Ong, C. K., Mulia, R., Lusiana, B., Muthuri, C., & Sinclair, F. L. (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs. *Agricultural Systems*, *142*, 51–69. [Online] Available at: https://doi.org/10.1016/j.agsy.2015.11.005

Nabuurs, G-J., R. Mrabet, A. Abu Hatab, M. Bustamante, H. Clark, P. Havl.k, J. House, C. Mbow, K.N. Ninan, A. Popp, S. Roe, B. Sohngen, S. Towprayoon (2022). Agriculture, Forestry and Other Land Uses (AFOLU). *In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA. [Online] Available at: doi: 10.1017/9781009157926.009

NDC (2021). Updated Nationally Determined Contribution. [Online] Available at: https://unfccc.int/sites/default/files/NDC/2022-06/Ethiopia%27s%20updated%20NDC%20JULY%202021%20Submission_.pdf

Tolessa, Amsalu (2023). Bioenergy potential from crop residue biomass resources in Ethiopia. *Heliyon 9(2*). [Online] Available at: https://www.sciencedirect.com/science/article/pii/S240584402300779X (accessed 28 June 2024).

World Agroforestry (2020). Beyond the Green Legacy Initiative in Ethiopia. [Online] Available at: https://www.worldagroforestry.org/blog/2022/09/15/beyond-green-legacy-initiative-ethiopia (accessed 5 July 2024).

World Bank (2023). Agricultural methane emissions (thousand metric tons of CO2 equivalent). *World Bank.* [Online] Available at: https://data.worldbank.org/indicator/EN.ATM.METH.AG.KT.CE (accessed 5 July 2024).

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World Bank (2024). Lowlands Livelihood Resilience Project. [Online] Available at: https://projects.worldbank.org/en/projects-operations/project-detail/P164336 (accessed 5 July 2024).

Zeleke, Belay, Manoj Kumar and E. Rajasekar (2022). A novel building performance-based climate zoning for Ethiopia. *Frontiers in Sustainable Cities 4*. [Online] Available at: https://doi.org/10.3389/frsc.2022.684148 (accessed 5 July 2024).

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3.9 Annex

3.9.1 Enablers and Barriers

3.9.1.1 Industry

Table 24: Industry - National-sectoral mitigation enablers and barriers

Dimension	Enablers	Barriers
Geophysical feasibility	The development of industrial parks, in different geographical location of the country encourages manufacturing and export-oriented industries (UNIDO, 2018).	
Environmental-ecological feasibility	Development of energy efficiency standards and labeling for some products like Electric Injera Mitad manufacturing (Danas, E.E.,2012).	At present, the largest share of energy consumption 87% is dominated by traditional fuels (charcoal, fuel wood, dung cakes, and agricultural residues) which still pose various health and environmental risks. In the country, 55.2% of population is living without access to electricity in 2019 (Girum, A.T. et al, 2021).
Technological feasibility	Advancements with regard to technology and increases in productivity in large- and medium-sized manufacturing sectors.	Lack of skilled manpower and lack of maintenance (Girum, A.T. et al, 2021).
Economic feasibility	Grants, loans, subsidies, tax exemptions, carbon credits, and green bonds are examples of financial incentives and mechanisms that decrease the upfront costs and risks of investing in low-carbon solutions (World Bank, 2023), (UNDP, 2021).	Lack of investment capital is the top challenge for the development οφ renewable energy technologies (Mulualem G.G., 2021).
Sociocultural feasibility	Energy audits, training, awareness campaigns, demonstration projects, and technology transfer are examples of technical support and capacity growth that develop the skills and knowledge of industrial actors and stakeholders (EEA, n.d.).	The lack of institutional capacity has hindered the utilisation of renewable energy technologies Ethiopia (Negussie R., 1999).
Institutional feasibility	Policy and regulatory frameworks that support the implementation of energy efficiency and renewable energy measures, such as the Climate-Resilient Green Economy (CRGE) strategy (Yalew, 2022), the National Electrification Program (NEP), and the Feed-in Tariff (FiT) program to promote the growth of renewable energy sources.	Lack of motivation and lack of effective planning and monitoring. Challenges to create coordination and cooperation among industrial actors and stakeholders (Desalegn A. and Solomon N., 2021).

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3.9.1.2 Energy

Table 25: Energy - National-sectoral mitigation enablers and barriers

Dimension	Enablers	Barriers
Geophysical feasibility	Indigenous energy resources, of which there is huge exploitable potential of the renewable resources, fig 2. (NEP v2.0).	
Environmental-ecological feasibility		Negative impacts of climate change on hydro-dominated power sector [ENEP, 2013].
Technological feasibility	An already renewable electricity supply (hydropower, about 92%); replacement of incandescent lamps by LEDs, a measure by the EEP.	Less efficient and wasteful T&D; poor energy generation portfolio/mix; unsustainable traditional biomass use [ENEP, 2013].
Economic feasibility	Scaling Solar - World Bank financial and risk management support program for Sub-Saharan Africa; double-edged electricity *tariff reform*, for cost recovery in contrast to unaffordability and economic challenge for consumers (pushing to switch to other non-renewable sources).	Tariff increment leading to unaffordability and consumers tend to switch to other alternatives (often to non-renewables); lack of financing in general [ENEP, 2013].
Sociocultural feasibility	National improved cook-stove program, to reduce traditional biomass fuel use (NICSP); promoting energy saving, such as turning of lights, an initiative by the EPEA.	
Institutional feasibility	Legal framework to unbundle the government owned electric power and utilities [NEP 2.0]; regulatory framework for private sector participation in the sector via IPPs; energy efficient electric mitads, initiative of energy efficiency labelling by the Ethiopian Petroleum and Energy Authority (EPEA); national biogas program (NBPE) – rural communities mainly, initiative by SNV; Solar Home Systems (SHS) for rural community applications, institutions such as health centres/posts, schools, street lighting, etc..	Sub-standard solar PV systems/components importation due to lack of mandatory national standards and laws; lack of human and institutional capacity; lack of reliable and updated data [ENEP, 2013].

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3.9.1.3 Transport

Table 26: Transport - National-sectoral mitigation enablers and barriers

Dimension	Enablers	Barriers
Geophysical feasibility		Lack of vast oil reserves leads to sole dependence on imported petroleum fuels.
Environmental-ecological feasibility		
Technological feasibility	Roads infrastructure development – construct electric rail network, improve urban transport in Addis Ababa (light rail and rabid bus transit), mass transport enhanced by implementing the public transport fleet. Using large untapped biomass residue potential and replace fossil fuels and traditional biomass (Tolessa, 2023).	An already existing old fleet which is highly contributing to fuel inefficiency and GHG emissions; still underdeveloped transport infrastructure, such as lack of sufficient road networks, heavy traffic congestions leading to increased fuel consumption and emission, there are no sufficient/safe/efficient cycling lanes despite some trails, insufficient and unsafe pedestrian networks, etc.; insufficient and poor parking infrastructure.
Economic feasibility	Facilitate bank loans and tax reduction/exemptions privileges for taxi market.	High import tax on vehicles and leading to unaffordability for the majority; shortage of finance.
Sociocultural feasibility	Increasing importation of electric vehicles (EVs) and hybrids (HEVs).	
Institutional feasibility	Introducing fuel efficiency standards for the cargo and passenger vehicles; the policy on non-motorized transport, i.e., the NMT strategy; substitute imported fossil fuels with clean fuels from biofuels (ethanol and biodiesel); lifting government subsidy on imported petroleum fuels (gasoline, diesel, etc.) to inhibit the use of old inefficient vehicles and promote new vehicles importation, despite it started to challenge the economic welfare, and fuelled the already high inflation rate of about 34% in 2022.	

3.9.1.4 Buildings

Table 27: Buildings - National-sectoral mitigation enablers and barriers

Dimension	Enablers	Barriers
Geophysical feasibility		
Environmental-ecological feasibility	Mitigation strategies to reduce embodied energy and CO2 emissions from buildings include (Taffese & Abegaz, 2019): Energy-efficient cement production, adoption of alternative materials, use of prefabricated and recyclable materials.	

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Technological feasibility	Passive building design features such as high thermal mass and low wall to window ratio have a significant potential to reduce energy consumption in various climates of Ethiopia (Zeleke et al., 2022), although there is a perception among stakeholders that space cooling and heating are not necessary in most areas of Ethiopia (Baron & Donath, 2016). Cooking has a high potential for energy savings followed by lighting. In rural areas without access to electricity, candles, kerosene lamps, firewood and solar energy are used for lighting (Ejigu, 2016).	Lack of skilled professionals, green building materials and technologies on the local market (Gelan, 2022).
Economic feasibility		
Sociocultural feasibility	Solar cookers, biogas and liquid biofuels could be used as substitutes for solid biomass for cooking (SE4All, 2013).	There is still a high preference to use biomass for cooking owing to the taste of the cooked food, cultural practices and consumption habits (Kebede et al., 2022). Lack of awareness for green buildings and a perception that green buildings are expensive (Gelan, 2022).
Institutional feasibility	The market for solar hot water systems could be enhanced by government housing programmes and real-estate developers (SE4All, 2013). Introduce building code and create training programmes for building codes and standards (Taffese & Abegaz, 2019).	There are no institutions to evaluate and certify sustainable buildings in Ethiopia (Anshebo et al., 2022). Lack of policy and regulatory framework for green buildings and lack of understanding of the benefits of green buildings by policy makers (Gelan, 2022).

3.9.1.5 Land Use

Table 28: Land Use - National-sectoral mitigation enablers and barriers

Dimension	Enablers	Barriers
Geophysical feasibility	Grasslands could be improved in order to function as carbon storage. Reforest land in order to function as carbon storage (3 million ha of land by 2030) (NDC 2021, 12). Restore forests in order to improve their function as carbon storage (NDC 2021, 12).	Higher average temperatures and greater variability in rainfall leads to a changing environment for crops and soil erosion (Holden 2022).
Environmental-ecological feasibility	The share of agricultural land under sustainable management practices should be increased (NDC 2021, 12). Pre-harvest losses and land converted for agricultural infrastructure could be reduced (NDC 2021, 12).	Deforestation for agriculture and biomass use leads to higher emissions. Methane emissions are highest in the agricultural sector. Unsustainable land management including the use of chemical fertilizers and pesticides can lead to soil degradation. Climate zones are changing in Ethiopia (Zeleke et al. 2022).

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		Low agricultural productivity due to environmental degradation.
Technological feasibility	Reduce the use of residential biomass through electric stoves, improved cookstoves and renewable biofuels (NDC 2021, 12). The agriculture could be mechanized through the replacement of cattle/oxen by tractors (NDC 2021, 13). Feeding could be improved through the use of oilseeds (NDC 2021, 13). Efficiency and productivity in the livestock subsectors could be enhanced measures by number of improved cows and the GHG intensity of agricultural GDP (NDC 2021, 13).	Limited mechanisation of the agriculture.
Economic feasibility	Through increased access to finance, farmers are able to adapt to climate change, plant longer-term crops and trees and prevent soil erosion and crop failures (Holden 2022).	Lack of access to finance for farmers. Low agricultural productivity due to limited private investment.
Sociocultural feasibility		Unsustainable land management and land use. Food insecurity harms development in the AFOLU sector.
Institutional feasibility	Reform land management and provide land tenure security through land certificates for rural landholders is an incentive for long-term investments against climate change among farmers (Holden 2022). The share of poultry compared to cattle could be improved and a demand shift from beef to chicken could be promoted (NDC 2021, 13).	

3.9.2 Policy Options

Table 29: Industry - Status of instruments and policies

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	Climate Governance: Monitoring, Reporting and Verification (MRV) systems have been established for industry and agriculture, to be operationalised through adequate investments and staffing (Climate Governance, 2020). Energy Efficiency Program and activity plan: energy efficiency plants are developed by Ethiopia Energy Authority (EEA, n.d). Voluntary based energy audits for industry	Positives: Improvement of the Industrial Policy's alignment with the national Science, Technology, and Innovation (STI) policy and intellectual property rights (IPR) policies. Develop the ability to methodically create action plans that include Monitoring and Evaluation (M & E) for policies and Implementation Capability to enhance the performance of implementation. Challenges: Innovation efforts and

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		challenges; Effective collaboration across these diverse bodies is by nature a major challenge; The imbalance between fast-growing imports and slow-growing exports creates a structural, systemic challenge with no simple solution. (UNCTAD, 2020)
Regulatory instruments	Formation of the Environmental Policy of Ethiopia: Environmental protection is a top priority for the Federal Democratic Republic of Ethiopia's government. With the proclamation no. 9/1995, it created the Environmental Protection Authority (EPA) and gave it legal authority to oversee environmental protection in its entirety. Ethiopia's Environmental Policy was developed and authorized by the government in April 1997 (ESIPC, n.d.). For emission limits from stationary sources , the maximum allowable level of pollutants from a site, process, stack, vent, etc. are presented within this document . Industrial Policy in Ethiopia: Since the early 2000s, Ethiopia has actively pursued an industrial policy using a wide range of policy instruments (Altenburg A, 2010), (Oquba, 2018) . Green Economy Strategy: the nation has developed the Climate Resilient Green Economy (CRGE) Strategy to avoid lock-in in old technology (CRGE, 2011) Gradual phase-out of fossil fuels and fossil fuel boilers: One of the most important steps in lowering greenhouse gas emissions and addressing climate change is the gradual phase-out of fossil fuels and fossil fuel boilers in Ethiopian industry. Thought the International Energy Agency (IEA) predicted that Ethiopia's final energy consumption from fossil fuels to increase in the next years (IEA, 2019), the Ethiopian government has taken a number of steps to promote renewable energy sources and minimize dependence on fossil fuels. For example, the government has been revising subsidies for petroleum products since July 2022 as part of a plan to phase out subsidies at gas pumps (Reporter, 2024).	Positives: The Standards are presented for four different parts: Part 1-Guidance on Interpretation of this Document on Standards Part; 2-Standards for Specified Industrial Sectors; Part 3-General Standards for all other Industrial Effluents; Part 4-Standards for all other Industrial Gaseous Emissions and Part 5-Standards for Noise Limits. Challenges: Weak technological development and adoption practices, as well as the usage of outdated import technologies. This is brought about by lack of coordination among ecosystem actors, limited regulatory coverage and limited incentives to control technology transfer and R&D (Gebeyehu, 2022).
Market-based instruments	Green Manufacturing Strategy: (2019): Government offered no-tax for purchase of select testing equipment (GMSE, 2019).	Positives: The financial incentives encourages investors to be involved in to the

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	Environmental Permits and Fees: Environmental Protection Authority ("EPA") a straightforward permitting power, such that potentially polluting businesses cannot open or continue to operate without a permit directly from the EPA. For emission limits from stationary sources, the government may evaluate potential pollution and raise the permission fee based on probable environmental harm and economic damage to locals when enterprises request for licenses (Krueger K, et al, 2012). Financial incentives: Ethiopia offers a wide range of incentives to investments in growing sectors like manufacturing, agriculture, and agro-processing. These incentives include an exemption from customs charges on capital goods and building supplies, a nine-year income tax exemption for agricultural investment, and a six-year income tax exemption for manufacturing and agro-processing (EIC, n.d.).	manufacturing sectors positively respecting rules and regulation (EIC, n.d.). Strengthen institutional capability by providing skilled personnel and providing sufficient instruments (such as laboratory testing equipment, kits and reagents). Government offered no-tax for purchase of select testing equipment (GMSE, 2019) Challenges: lack regular monitoring and inspections for employee health and safety that would guide organisations toward effective environmental and social planning Inadequate public awareness—environmental planning is not adequately promoted by NGOs and activists (GMSE, 2019).
Information instruments	Ethiopian Cleaner Production Centre (ECPC): The project promoting Resource Efficiency in Small and Medium-Sized Enterprises It was developed by UNEP and was implemented under the framework of the Joint UNIDO-UNEP Program on Resource Efficient and Cleaner Production (RECP) in Developing and Transition Economies (ECPC, 2024). Environment Impact Assessment (EIA) Process: For emission limits from stationary sources , mandates that firms complete an Environmental Impact Assessment (EIA) before to starting specific projects in order to guarantee that environmental factors are incorporated into their planning (Damtie M. and Bayou M., 2008). Ethiopian Standard Industrial Classification (ESIC): Industry codes are not available. However, there is "Ethiopian Standard Industrial Classification (ESIC)". ESIC is used by government to collect and analyse data on the country's industrial sector (ESIS, 2010). Industries are divided into 10 major groups by the ESIC. The ESIC categorize s industries into ten main groups.	Positives: The project aims to develop an integrated toolkit that will be used to develop the capacities of National Cleaner Production Centers. Challenges: Lack of Awarenes; capacity problem; Absence of Effective Mechanisms for the EIA Process; Industry codes are not available

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Table 30: Energy - Status of instruments and policies

Type of instrument	Status / Is this policy in place?	What are the challenges for issue this policy or enforce this policy?
Governance and Planning instruments	Draft revised National Energy Policy: recognizes the national energy issues such as energy poverty, energy security, inefficient value chain and lack of data. It also outlines the status of limited technological capacity and lack of standards/regulations, as well as financing constraints and climate change impact. (MoWE, 2013). Increasing installed capacity from renewable energy resources, the GoE targeted a 25 GW generation capacity increase by 2030, mainly from hydro, geothermal, and wind [IEA, 2019]. National Electrification Program 2.0: outlines the target of achieving universal electricity (of 100%) by 2025 [*NEP 2.0*]. The electrification target was projected to have 65% grid access and 35% from off-grid solutions, mainly solar PV mini-grids (MoWIE, 2019) National Biogas Program Ethiopia – financing and construction of 14,000 biogas digesters within 5 years; job creation and economic development; contribute to mitigate deforestation and GHG emissions; etc. (NBPE, 2007). Committed NDC: Reduce by 220.59 Mt CO2e (53.5%) by 2030 from the 2010 BAU scenario in the conditional target Reduction of 12.4% (51.24 Mt CO2e) in the unconditional target.	Positives: (EP) *It identifies specific sub-sectors of (consumption, sources, etc. sub-sectors), challenges and policy issues, and highlight the need to address those through tailored policy objectives and instruments.* Challenges: *It lacks focus on RE, mentioning the need for the development of all RE sources. As the various infrastructure development is eminent, financing scheme and source is overlooked and had shallow relevant key stakeholder engagements.* Positives: (IIC) It has a vision for energy security and improved energy access. Challenges: No clear and materialized investment and financing scheme. Positives: (NEP) Aspires to ensure equitable energy access. Challenges: Very ambitious target without strict and quantified disaggregate RE targets; institutional capacity remains as a main problem. Positives: (NBP) Promotes access to clean cooking, economic and environmental benefits for users. Challenges: Access to finance for rural community (affordability) and lack of technical expertise. Positives: (NDC) *Promote sustainable energy transition, land use, and other sectors.* Challenges: *Weak accurate monitoring and evaluation, and financing (especially for the conditional NDC).*
Regulatory Instruments	Energy efficiency standards and labelling for home appliances Started initiative for buildings energy efficiency standards and labelling. Mandatory power factor (of 0.9) for industrial consumers. The CRGE strategy outlined RE targets from various resources. Home appliances' energy efficiency labelling schemes (electric stoves and mitads)	Positives: Some existing international partnerships and cooperation help in institutional capacity development. Challenges: Lack of adequate technical and institutional capacity, finance. No clear and reliable legal/regulatory framework, schemes and policies that promote, attract, and create enabling environment for private investment in renewable energy in Ethiopia.

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	Building energy efficiency labelling initiative.	
Market-based instruments	Financial incentives and tax subsidies for renewable energy technologies. Energy auditing and labelling for the building sector (recent initiatives). Promote IPP such as for utility scale solar PV power generation (bulk electricity sells to the utility company). Initiatives and campaigns for replacement of incandescent lamps with CFLs/LED.	Positives: favours the national energy supply mix; the energy efficiency helps in in energy consumption reduction. Challenges: Weak supportive regulatory framework for private investment and lack of transparency.
Information instruments	For the market promotion and dissemination, the EPEA conducted trainings and capacity building activities for electric mitad/stove manufacturers in selected cities for energy efficiency improvement and foreseen efficiency labelling.	Positives: It contribute to a significant energy efficiency improvement as it's the main sub-sector having huge consumption in the residential sector. Challenges: There still exist lack of technical capacity of manufacturers, put a challenge in its sustainable implementation and their compliance.

Table 31: Transportation - Status of instruments and policies

Type of instrument	Status / Is this policy in place?	What are the challenges for issue this policy or enforce this policy?
Governance and Planning instruments	Non-motorized Transport Strategy (NMTS): Clean, safe, and efficient transport targets- Promote public transport in cities like the capital - Addis Ababa, and required infrastructure development. The NMTS 2020-2029 stated the development of Safe, efficient, and accessible walking and cycling networks [FDRE Ministry of Transport, 2020]. Non-motorized transport initiative and policy (cycling, walking) outlined by modal shift targets by 2029 such as 80% of motorized trips by public transport and NMT [FDRE Ministry of Transport, 2020]. Enhance public transport service Implementation of initiatives to develop high-quality pedestrian networks, bicycle networks, greenways, street lighting, intersection improvements, bicycle sharing, rental systems, trade policies, street design standards, parking management, etc. Assess the existing landscape, evaluate each sub-sector, define the national transport	Positives: It support liveability and good urban planning, and improved mobility. Challenges: Lacks integrated planning and coordination with other sectors, it also requires large infrastructure investment, and difficult to ensure behavioural change such as for 'shifting'.

	strategy, prioritize investments, and outline implementation needs [FDRE Ministry of Transport and Logistics, 2022].	
Regulatory instruments	Vehicle emission standards and efficiency (per capita GHG transport sector emission reduction of 64% by 2030 from the 2010 level). Enacting fuel efficiency standards is also envisioned to achieve emission reduction of about 3.1 Mt CO2e by 2030 [CRGE, 2011; Ministry of Transport, 2017]. The GoE imposed very high tax system for importing old vehicles, planning to completely ban in the future. Import taxes (VAT, excise, surtax, withholding, etc. taxes) could reach as high as 500% depending on vehicle age, type and engine capacity), particularly highly discouraging importation of old vehicles [Tadesse S., 2022]. In 2024, the government announced an import ban on vehicles with combustion engines (Zachary S., 2024) Use of biofuels (bioethanol, biodiesel) to highly replace the fossil fuels import which is the predominant transport fuel.	Positives: Cleaner and efficient transport sector and improving air quality (hence health); contributes to foreign currency saving due to import reduction. High import taxes and an import ban could result in 1) Domestic manufacturing of vehicles and 2) Boosting imports of electric vehicles Challenges: Implementation of emission standards will pose difficulty; it requires investment and technology upgrade which then create unaffordability and accessibility.
Market-based instruments	The GoE, in its 10-year transport prospective plan, has planned to invest about 74 bln in the sector from various sources including PPP, government funding, foreign grants, etc. [Tewodros T., 2022]. Mobilize funding from national and local sources to implement NMT projects [FDRE Ministry of Transport, 2020]. Ethiopia implements tax reductions/exemptions for new vehicle and EVs importation. Imposed high import taxes for old vehicles [Tadesse S., 2022]. Initiatives to provide loans for the taxi market for new fuel-efficient vehicles.	Positives: Modernisation of the transport sector, enhance the sector including better quality and accessibility, esp. of the public transport system. Challenges: Getting sufficient funding would still be a challenge; affordability for new vehicles and EVs even with the tax laws; the need for infrastructure development including charging stations for EVs.
Information instrumens	Awareness creation campaign for the use of e-mobility, such as a 1-month free transport ride by EVs. Capacity building of local engineers, planners, etc. Promote the use of non-motorized mobility, cycling, walking; facilitate the use of public and mass transport.	Positives: Create public awareness about e-mobility in big cities. Challenges: Weak in terms of effectiveness in reaching the diverse community or audience for the intended behavioural change and awareness.

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Table 32: Buildings - Status of instruments and policies

Type of instrument	Status / Is this policy in place?	What are the challenges for issue this policy or enforce this policy?
Governance and Planning instruments	National Adaptation Plan of Ethiopia: The NEEAP proposes a variety of energy efficiency measures for various sectors, such as industry, transportation, and buildings (EnergyPortal.eu, 2023). Under NEEAP, major initiatives include promoting energy efficient appliances, establishing energy efficiency standards, and labelling as well as implementing energy management systems in industries (EnergyPortal.eu, 2023).	Positives: Government promotes the development of efficient renewable-based energy networks and standards Challenges: There is no net-zero emissions target or long-term carbon reduction strategy (Climatescope, 2022). There are still significant deficiencies in the materials and implementation of buildings in Ethiopia (GIZ, 2020). Dedicated funds by the government or by energy companies could provide stable funding sources to financing the upfront costs of decarbonisation options. Ethiopia has not yet implemented this. Clear targets, milestones and a dedicated action plan is missing to this point.
Regulatory instruments	Ethiopian Building Code of Standards (EBCS): The fourteen Ethiopian Building Code standards provide detailed instructions for construction standards regarding the operational requirements, system design, handover, inspection and maintenance of construction (GIZ, 2020). They cover the entire construction process of single, two and multi-family buildings, including structural elements, electrical systems, plumbing, heating, ventilation and air conditioning, energy efficiency requirements, as well as all other components of the construction sector (GIZ, 2020). As a part of the implementation of the building code, a construction council oversees the construction sector and ensures that players comply with uniform standards set by the code (GIZ, 2020). Product-specific minimum Energy Performance Standards (MEPSs): MEPS for AC induction motors and CFL lighting have already been introduced by the Ethiopian Standards Agency, following a request from Ethiopia's Energy Authority (Sigra Group AS, 2019). MEPS are also planned for electrical appliances for household appliances, including	Positives: Building energy codes make building energy efficiency and low carbon heating/cooling for buildings the standard sending a clear signal to market actors. MEPSs have proven to be most cost-effective policy measure for boosting the efficiency of appliances. Challenges: Ethiopia does not have national building energy codes (Taffese & Abegaz, 2019). Ethiopia does not have an energy sales cap system that could incentivize suppliers to help their customers reduce electricity consumption. Phasing out fossil fuel boilers would send a signal to the market on the exclusion of fossil fuel alternatives in the near- and medium-future.

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	appliances used for injera baking, cooking, refrigeration, washing, air conditioning and water heating (Eludoyin et al., 2021). Implementation plans are also in place. Implementation plans have been put in place for the full adoption of MEPS for lighting, cookstoves and injera baking by 2020, 2025 and 2026 respectively. 2019 Ethiopian standard for Clean Cook Stove and Clean Cooking Solution: Locally produced electric injera baking stoves, Mitads, are covered under a voluntary MEPS scheme and a further MEPS for electric cookstoves is foreseen. The 2019 Ethiopian standard for Clean Cook Stove and Clean Cooking Solution, Performance Requirements and Test Methods (ES 6085: 2019) conforms to the international clean cooking standard ISO19867-1 (Sieff et al., 2022). The standard covers electric cooking appliances with a volume of less than 150l and a capacity of less than 20kW, intended for domestic use, small-scale enterprise, and institutional settings.	
Market-based instruments	Financial incentives (Renewable energy/solar rooftop): A standard economic policy has been developed and implemented by the government to address inconsistent tax interpretations and application of taxes and duties on solar products (Clasp & UK Aid, 2022). Since 2018, aside from duty tax, excise tax, and surtax, off-grid energy products were also exempt from 15% VAT and 2% withholding tax if they were not used commercially (Clasp & UK Aid, 2022). However, due to inconsistent tax policy interpretation, additional customs duties were applied to appliances used in off-grid and weak-grid areas as their use is difficult to categorize (Clasp & UK Aid, 2022). The new updated tax code for 2022 set in place tariffs to be applied to imported solar products and some PURE (Clasp & UK Aid, 2022). According to the tax code, all solar products and SWPs are subject to a 5% duty tax and a 15% VAT, and solar system components are exempt from duty tax (Clasp & UK Aid, 2022). Solar Lighting in Rural Ethiopia: As part of this project, solar lighting centers are established across Ethiopia to provide solar lighting to rural Ethiopian households (UNFCCC, n.d.). In	Positives: In Ethiopia, the explicit carbon price is not levied. An implicit price on carbon emissions through fuel excise taxes accounted for 6.1% of emissions in 2021 and remained unchanged from 2018 (OECD, 2022). Tax incentives can help overcome the higher up-front costs of highly energy-efficient buildings, heating and cooling systems and appliances, on-site renewable energy, and the manufacture of low-embodied emissions building products. Challenges: There are no loans or grants provided to implement energy efficiency measures (e.g., wall or loft insulation or double glazing) in buildings (Climatescope, 2022). Neither carbon taxes nor other GHG emissions taxes are collected in Ethiopia (OECD, n.d.).

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	addition to selling, installing, and maintaining solar systems, solar centers also offer training and microloans to households who are unable to cannot afford to purchase solar systems themselves (UNFCCC, n.d.). The project makes available solar panels and lanterns to the disadvantaged families in Ethiopia (LWF, 2023). Renewable Energy Auctions: Renewable energy auctions of Ethiopia have the potential to become a model for other countries in the region (Kruger et al., 2019). With its procurement programs, the country has twice achieved the lowest solar PV project prices in sub-Saharan Africa (Kruger et al., 2019). In 2016, the tender was awarded for the 100 MW Metehara solar PV project to ENEL Green Power at US$c 5,85/kWh and in 2019, ACWA Power awarded two 125 MW (total Capacity 250 MW) solar projects at one of the cheapest tariff rates of US$c 2,53/kWh over 25 years (Kruger et al., 2019).	
Information instruments	Energy labelling schemes: A national energy efficiency labelling scheme and energy audits to be conducted in the industrial, commercial and public sectors are among the energy efficiency strategies intended to be implemented by the Ethiopian Energy Authority (EEA) and the Green Economy strategy (Eucker et al., 2019). Training and Education: As a part of the Solar Lighting in Rural Ethiopia program, an international solar energy school has established to train solar engineers especially for rural electrification (UNFCCC, n.d.). After graduation, it is possible for solar technicians to start their own businesses in villages (UNFCCC, n.d.). As part of this initiative, a solar competence center has been established in Addis Ababa to ensure that the knowledge and know-how associated with solar energy are developed and utilized in the country (UNFCCC, n.d.). Training, product development, testing, and assembly are the services provided by the solar competence center (UNFCCC, n.d.).	Positives: General information provision raises awareness about decarbonisation options and their cost-effectiveness among key stakeholders. Training and education to provide the workforce with the necessary knowledge and skills will enhance the confidence of investors. Challenges: Ethiopia should provide general information that raises awareness about decarbonisation options and their cost-effectiveness among key stakeholders. Certification of qualified actors to ensure accurate, optimal, and safe services and to enhancing confidence of investors/users on the services delivered.

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Table 33: Land Use - Status of instruments and policies

Type of instrument	Status / Is this policy in place?	What are the challenges for issue this policy or enforce this policy?
Governance and Planning instruments	Ten-year Development Plan: Active 2021-2030. Includes many goals on the AFOLU sector but it remains unclear how those goals will be achieved through direct policies. The main focus area of the environment and climate change plan is ensuring sustainable development by developing, enriching, maintaining and protecting the country's natural environment, forests, wild life and other biodiversity resources. Targets Land Use: • Increase national forest coverage from 15.5% to 30%, and increase the coverage of wild life habitats from the present area of 8.6% to 14% (p. 73) • Increase land use efficiency from 33% to 100% in 20 existing irrigation schemes • Link industrial, infrastructural and agricultural land use with the protection of nature (FDRE 2021) Climate-Resilient Green Economy (CRGE) Strategy Ethiopia 2011: According to CAT, the strategy aims to reduce agricultural emissions, protect and expand forests, expand renewable electricity generation, and adopt energy efficient technologies in transport, industry and the built environment (CAT 2022) New developments: The Ethiopian government is reviewing the existing CRGE Strategy. The current version published back in 2011 with visions for 2025. The release of the updated CRGE was planned for Q1 2020 but has been postponed. There is no further information available on content. Main pillar regarding land use: Protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks, adoption of agricultural and land use efficiency measures The CRGE strategy identified 60 potential interventions to reduce GHGs below the BAU of 400mtCO2e by 2030, possibly even keeping it on par with a 2010 emission level of 150 mtCO2e.	Positives: National roadmaps regarding agriculture and FOLU exist. Target setting for different areas in the sector. Challenges: The current plans still lack clearly defined policy measures for achieving the emission reduction targets. Land in Ethiopia was used in the past in an uncontrolled and unplanned fashion. This is likely to continue without cross-sectoral coordination and joint planning.

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	(FDRE 2020, CAT 2022)	
Regulatory instruments	Livestock Master Plan: The Ethiopia Livestock Master Plan (LMP) is a sectoral policy document at the national level covering the period of 2015–2020. The LMP is a five-year development implementation plan or 'roadmap', to be used to implement the Growth and Transformation Plan II (GTP II). The LMP sets out investment interventions—better genetics, feed and health services, which, together with complementary policy support—could help meet the GTP II targets by improving productivity and total production in the key livestock value chains for poultry, red meat-milk, and crossbred dairy cows (FAO 2015) Lowlands Livelihoods Resilience Project: Improve livelihood resilience of pastoral and agro-pastoral communities in Ethiopia. World Bank funded project, implemented by Ministry of Irrigation and Lowlands Development (MILLS). Closing Date will be 2025 and start was in 2019 (World Bank 2024) National Forest Sector Development Program (NFSDP) of Ethiopia: The National Forest Sector Development Program (NFSDP) is expected to serve as a master plan for the enhancement of sustainable forest management in Ethiopia from 2016-2025. The three volumes of the NFSDP publication inform forest-related policies, interventions and activities to transform the forest sector in Ethiopia. Green Legacy Campaigns: • First: Plant 4 billion trees in 2019. • Second: Plant 5 billion seedlings in 2020, achieved in August 2020 (reportedly). • Third: Plant 20 billion trees until 2022 including agroforestry trees (CAT 2022)	Positives: A forest sector master plan exists. Project-level actions in the forest sector such as tree-plantings. Challenges: Land tenure security is not sufficient which prevents farmers and other landholders from making long-term investments. The LMP focused mainly on economic productivity and neglected emission targets.
Market-based instruments	National Biogas Program 2007: This policy aims to develop the biogas sector in Ethiopia. The Specific objectives are to: • attract and strengthen institutions and organisations for the development of a national biogas sector; • construct 14,000 biogas plants in the four selected regions over a period of 5 years;	Positives: While designing the REDD+ Strategy Ethiopia reached a level of 80% attention to the strategies design components which is a good number in comparison to other countries. https://www.mdpi.com/2071-1050/10/12/4781 Challenges:

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	• ensure continued operation of the biogas plants installed under the NBP; • maximize the benefits of all biogas plants installed. The policy was renewed several times and it is unclear if the goals where achieved. An analysis on barriers and drivers can be found in (Kamp and Forn 2016). National REDD+ Strategy 2018-2030: Implementation in cooperation with UNFCC. The National REDD+ Strategy (NRS) contributes effectively to a large part to the Climate Resilient Green Economy (CRGE) strategy and Ethiopia's greening targets in 2030, while maximizing national co-benefits thereby adding to the global climate change mitigation efforts through improving forest resource and land management. The strategy focuses on reducing deforestation, forest degradation and enhancing forest carbon stock by promoting conservation and restoration of forest ecosystems; strengthening governance and development of local capacities and putting in place enabling environment for sustainable forest management. The Vision: To see that the successful implementation of REDD+ guarantee that the forest sector achieves its mitigation potential. The forestry sector, with REDD+ as its major mitigation lever, will contribute 50% of the total emission reduction. Sustainable financing through REDD+ will support investment in forest management, forest conservation, and forest restoration. The forest sector contributes 11.2% to the national GDP https://faolex.fao.org/docs/pdf/eth178847.pdf (p.38)	Ethiopia lost over 8 kha of forest in 2021-2022. Although, the number has decreased every year since 2019 forest losses remain a challenge (SOURCE).
Information instruments	Program of Adaptation to Climate Change (EPACC) Ethiopia 2010: Adapt agriculture to climate change. Identify climate sensitive infrastructure and community level vulnerability. The program informed the Ethiopian Climate Resilient Green Economy Strategy and the Growth and Transformation plans. The program concluded presumably in 2010 (FAO 2016).	Challenges: Information scarcity about AFOLU sector in general. Lack of monitoring methods hinder the development of coordinated and cross-sectoral plans for decarbonisation.

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	Integrated Land Use Planning in Ethiopia (ILUP): The Participatory and Integrated Land Use Planning (ILUP) project adopts a multi-level approach to enhance participatory and intersectoral land use planning. It strengthens the capacities of land management, civil society, and the private sector to develop, legally anchor, and pilot these plans, with a focus on peri-urban and rural areas with high land competition. The project also invests in training, increasing the number and quality of graduates and skilled workers. By bolstering the regulatory and institutional framework at national and regional levels, the ILUP project promotes sustainable resource use, holistic settlement planning, and prevents land use disputes, contributing to good governance and creating a favorable investment environment (GIZ, 2022).	

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4 Kenya - Case Study

4.1 Big picture: Current national-sectoral decarbonisation status and prospects

Kenya is located on the East African coast of the Indian Ocean. With a population of approximately 51.5 million people (Kenya National Bureau of Statistics, 2024), it spans an area of around 580,370 sq.km. Over the past decade, Kenya's economy has outperformed that of low- and middle-income countries (LMICs). Recently, however, the slowdown in the pace of poverty reduction in conjunction with COVID-19 pandemic have emphasised the vulnerability of many households. Although the Kenyan economy is recovering from the pandemic and is forecast to grow by an average of 5.4% in 2022-24, the ongoing drought and imported global inflation have been especially challenging (World Bank Group, 2022).

Kenya has made significant progress in establishing a well-diversified energy mix and more than doubled its electrification rate between 2014 and 2018. The government has increased the connectivity to urban and rural areas through a combination of off-grid and grid-tied systems. Renewable energy resources such as geothermal, wind, and hydropower have played a significant role in the progress toward clean energy and energy access goals (Kleinman Center for Energy Policy, 2023). The next figure shows the cumulative installed capacity as of December 2023.

Technology	Interconnected Capacity (MW)		Captive Capacity (MW)	Off-grid Capacity	Total Installed Capacity	% Total Installed
	Installed	**Effective**				
Hydro	839.3	810.4	33.0	0.1	872.4	25.00%
Geothermal	940.0	841.1	3.7	-	943.7	27.04%
Thermal	572.8	562.4	21.3	35.6	629.7	18.05%
Wind	435.5	525.5	-	0.6	436.1	12.50%
Solar	210.3	210.3	196.2	3.9	410.4	11.76%
Bioenergy	2.0	2.0	111.8	-	113.8	3.26%
Imports	200.0	200.0	-	-	200.0	-
WHRC	-	-	83.5	-	83.5	2.39%
Total	**3,199.9**	**3,051.7**	**449.5**	**40.1**	**3,689.5**	**100.00%**

Figure 12: Installed, Effective and Captive Power Capacity as of December 2023
Source: (Energy & Petroleum Regulatory Authority, 2024)

Kenya has one of the lowest carbon-intensive power systems in East Africa (Kahlen et al., 2021). Although due to population growth and increasing economic activity, Kenya’s emissions have risen in recent years (see Figure 13), according to the World Bank, emissions are currently not a concern for Kenya’s economy, accounting for only 0.1% of global emissions annually (World Bank Group, 2023a).

Climate change poses a significant threat to the growth trajectory of Kenya, which is why global initiatives to

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combat this phenomenon, particularly by reducing GHG emissions, if successful, also present beneficial prospects for the Kenyan economy. It is estimated that the Kenyan economy suffered between 2010-2020 socio-economic losses of 3-5 percent of its gross domestic product due to the impacts of climate change (International Food Policy Research Institute, 2023, NDC). This underscores the urgent need for investments to strengthen adaptation and resilience to these impacts and identify strategies to mitigate vulnerability.

Overall, as a small contributor to GHG emissions, Kenya has the potential to make a positive contribution to the global climate change mitigation effort, by maintaining its current low carbon emissions policies in power production and introducing similar policies for all sectors (World Bank Group, 2023b).

Figure 13 shows the greenhouse gas emissions by sector from 1990 to 2020.'[9]

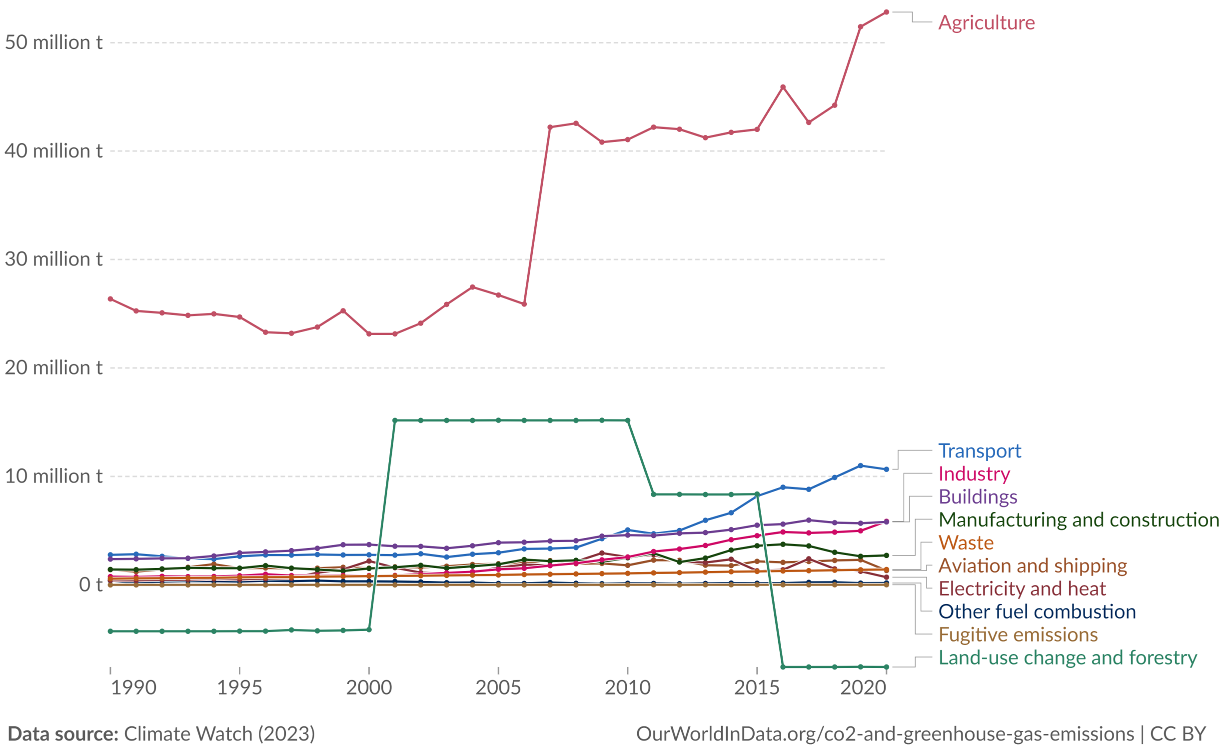

Figure 13: Greenhouse gas emissions by sector, Kenya
Source: (ClimateWatch, 2023)

Without further action, Kenya's emissions from the energy sector could rise from around 20 Mt CO_2e in 2021 to around 130 Mt in 2050. Under 'Business As Usual' (BAU), most of the increase in emissions will come from transport and industries, driven by population growth, and economic growth (Ministry of Energy & Petroleum, 2023a).

Kenya has set itself targets for reducing its GHG emissions: The country submitted an updated NDC under the Paris Agreement in December 2020 that includes mitigation and adaptation contributions and an emission reduction of 32% below BAU by 2030 (including LULUCF) (Climate Action Tracker, 2022a), compared to 30% in the initial one (Updated NDC). It addresses the severe socio-economic losses resulting from extreme weather events and climate change impacts on the country's economy. Recognising its dependence on climate-sensitive natural resources, Kenya aims to pursue a low-carbon, climate-resilient development pathway through this contribution. While the first NDC foresaw a conditional target, with the updated NDC the country commits to

[9] Note: Greenhouse gas emissions are measured in tonnes of carbon(ii) oxide equivalents over a 100 year timescale

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mobilise 13% of the needed budget no longer by international resources but by itself (Ministry of Environment and Forestry, 2020). However, the updated NDC does not contain sectoral mitigation targets. On the sectoral initiatives: Kenya has not signed the Global Methane (https://www.globalmethanepledge.org/) and the Coal Exit Pledges. Figure 14 illustrates the progress of climate action as of May 2022 (Climate Action Tracker, 2022a).

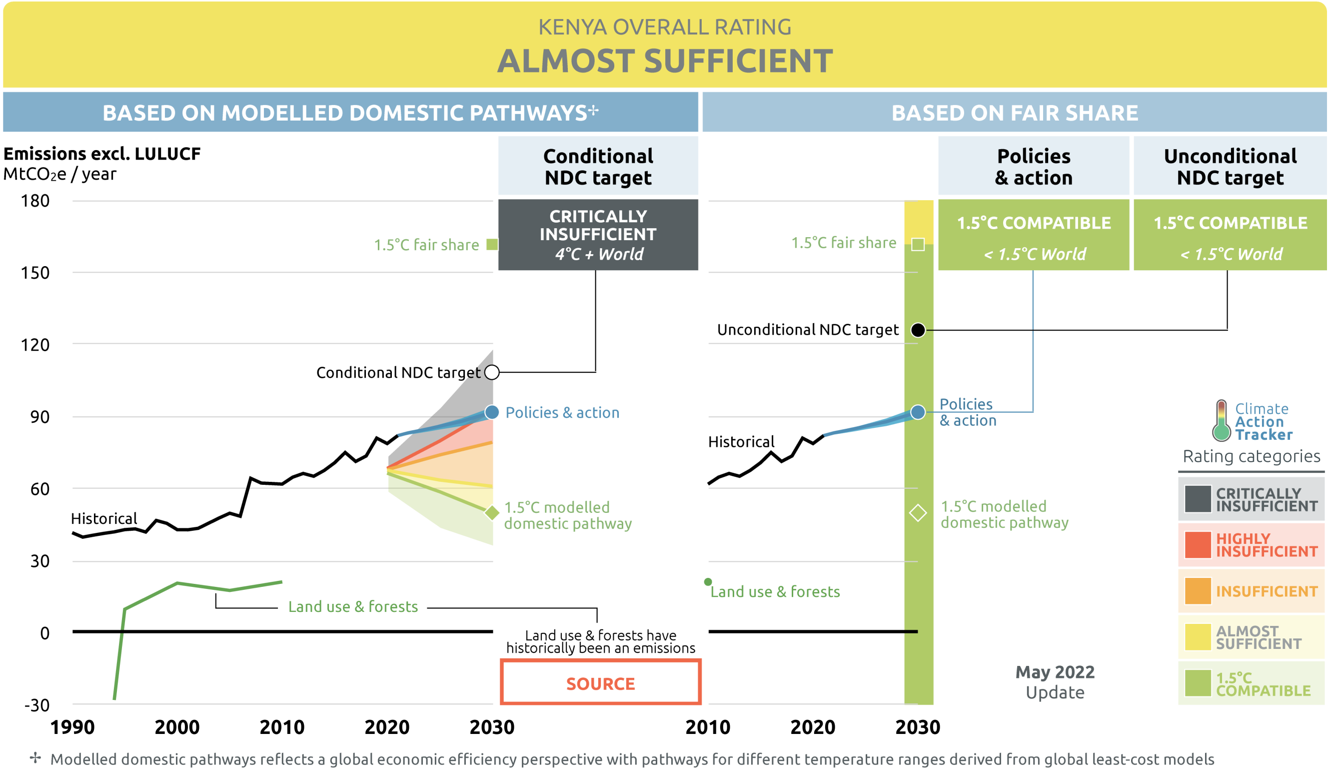

Figure 14: Kenya's climate action progress as at May 2022
Source: (Climate Action Tracker, 2022a)

4.2 Industry

4.2.1 Current decarbonisation status and prospects

Kenya's industry is the largest in the Eastern African region, highlighting its crucial role in Kenya's economy and those of its neighbours (Ho, 2019). As of 2020, this sector was responsible for 17% of Kenya's GDP, ranking third after agriculture and services (Statista, 2022). According to the original NDC baseline, emissions from the industrial processes sector are expected to increase from 3.3 MtCO2e in 2015 to 5.9 MtCO2e by 2030. Despite this rise, the sector's share of total national emissions is anticipated to remain steady at approximately 6% (excluding LULUCF) (Ministry of Environment and Natural Resources, 2017). Emissions in the industry sector mainly stem from cement and charcoal manufacturing industries (Ministry of Environment and Natural Resources, 2017). Cement production is considered a key industry, experiencing a rising demand both within Kenya and from neighbouring nations. Meanwhile, charcoal production predominantly relies on traditional, less efficient methods, and largely operates within an informal sector (Ministry of Environment and Natural Resources, 2017).

The top priority action for the industrial sector in the National Climate Change Action Plan (NCCAP) 2018-2022 is on the implementation of the Nationally Appropriate Mitigation Action (NAMA) for the charcoal sector targeting an abatement of approximately 1.2 $MtCO_2e$ by 2030 (Government of Kenya, 2018). Cement manufacturers (estimated at 0.23 $MtCO_2e$) have been shifting from fuel oil to coal to reduce costs, making the sector a significant potential consumer of coal. This development eliminates the potential usefulness of any climate action

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improvements as a means of reducing emissions in the cement sector.

According to the original NDC baseline, absolute emissions from the industrial sector are projected to grow from 3.3 $MtCO_2e$ (2015) to 5.9 $MtCO_2e$ (2030) while the contribution of industrial process emissions to total national emissions is expected to roughly remain at 6% (excl. LULUCF). Under the current lower bound policy projections, absolute emissions are projected to increase to 6.7 $MtCO_2e$ in 2030. The sector's target is to reduce emissions by 0.8 $MtCO_2e$ by 2030, corresponding to 2% of the original overall emissions reduction target of 30% by 2030 (Ministry of Environment and Natural Resources, 2017).

4.2.2 National-sectoral mitigation enablers and barriers

The industrial sector faces numerous barriers that hinder climate mitigation options, but there are also enablers that support climate action. The enablers and barriers are categorized and explained in more detail in Table 6 (annex) and summarized below:

Geophysical feasibility: With a domestic market of over 50 million people, Kenya is a leading economy in sub-Saharan Africa, serving as an economic, commercial, financial, and logistics hub of East Africa (International Trade Administration, 2022). Kenya possesses significant underground wealth, with around 970 minerals nationwide, including base metals, precious metals, rare earth and radioactive minerals. Mrima Hill, in the coastal county of Kwale, has one of the top five rare earth deposits in the world, and the region also contains niobium deposits projected to have a value of $35 billion (CA Global, n.d.).

Environmental and ecological feasibility: However, there are huge environmental risks associated with mining activities, such as when toxic chemicals are used in heavy mineral separation processes in vulnerable ecological systems, like the Wasini channel (Abuodha, 2002). This coastal area, with its fragile coral reefs and wildlife, is a crucial part of the economy, supplying a living for many people on the coastline. Besides mining activities, deforestation, soil erosion, flooding, poaching, and pollution can also be consequences of industrial activities.

Technological feasibility: Kenya is a leading African state in information and communication technologies (ICT), showcasing significant advancements in this sector. The country's robust digital economy is poised for substantial growth, with projections indicating it will contribute 9.24% to Kenya's GDP by 2025. Kenya stands out among African countries for its advanced ICT skills development; these skills encompass a wide range, from basic digital literacy, including the use of mobile phones, mobile banking, the internet, and social media, to more advanced competencies in data analytics, app development, and network management. There are a number of government and private initiatives that have addressed ICT skills. However, these focus on literacy and basic skills, which is not enough for a rapidly growing society with high youth unemployment (Domingo, 2023). The *Kenya Energy Transition and Investment Plan (ETIP)* identifies several challenges, including cost premium for hydrogen direct reduced iron (DRI), high costs of Carbon Capture and Sequestration (CCS) implementation (cement sector) and immature market and high capital cost of heat pumps for low-temperature heat processes (Ministry of Energy & Petroleum, 2023a).

Economic feasibility: Kenya experiences a strong flow of foreign direct investment, particularly in finance and insurance, renewable energy, trade, manufacturing, communication, and education sectors. Numerous private-equity entities operate in Kenya, including multilateral institutions like the International Finance Corporation (IFC) and the African Development Bank, as well as bilateral bodies such as the U.S. International Development Finance Corporation (DFC) (World Bank Group, 2023b).

Sociocultural feasibility: Kenya boasts a young, growing, and educated English-speaking population with high technological fluency. As part of Kenya Vision 2030, the Kenya Industrial Research and Development Institute (KIRDI) is being transformed into a world-class research institution through capacity-building initiatives and equipment upgrades. However, to ensure long-term and widespread benefits from economic growth, Kenya must address the participation gap of poor and rural households, who have largely been left out of the GDP growth, with a poverty rate of 38.6% in 2021 (World Bank Group, 2023b). The country also faces challenges such as

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inequality in educational and other opportunities, weak job creation, and persistently low productivity growth. Additionally, a smaller share of women is employed in the industry sector, highlighting the need for more inclusive development strategies.

Institutional feasibility: Kenya, a member of the British Commonwealth, also enjoys strong bilateral and multilateral trade relationships as a member of the East African Community (EAC), Common Market for Eastern and Southern Africa (COMESA), and the Africa Continental Free Trade Area (AfCFTA). The government has implemented pro-business reforms, including regulations on starting businesses, obtaining access to electricity, registering property, protecting minority investors, and streamlining the business insolvency process (International Trade Administration, 2022). As part of Kenya Vision 2030, Special Economic Zones have been established as key enablers for the manufacturing sector, aiming to drive industrialisation and social transformation to attract investment (SEZ Authority, n.d.).

4.2.3 Current status of national-sectoral policy

4.2.3.1 Industry

The Kenyan Government, recognising that the industry sector has stagnated at around 10% of GDP for the last two decades, concluded that a coherent National Industrialisation Policy was essential for advancing industrial development. The *Kenya Vision 2030* aims to make Kenya a middle-income, newly industrialising country with a high quality of life. In line with this, the *National Industrialisation Policy Framework* was established, with the vision "to be the leading industrialised nation in Africa with a robust, diversified and globally competitive manufacturing sector", aiming for 15% annual industrial growth rate, to make Kenya Africa's top industrial investment destination and boost employment and wealth creation (Republic of Kenya, 2012).
Additionally, the *Constitution of Kenya* (2010) prioritises sustainable development and the protection of natural resources. The *Mining Act of 2016 and the Mining Bill of 2015* designate the government the trustee of mineral resources.
Kenya's National Industrialisation Policy Framework, developed through extensive consultation with public sector, private sector, civil society, development partners, and non-governmental stakeholders, reflects a comprehensive approach and it includes robust mechanisms for monitoring and evaluation. However, Kenya's industrial sector confronts formidable challenges such as low value addition, inadequate market information leading to restricted market access and a narrow export base, high costs of infrastructural services affecting competitiveness, scarcity of skilled industrial human resources, limited access to affordable long-term finance, high industrial land costs, and inadequate attraction of local and foreign direct investment (Republic of Kenya, 2012). Addressing these challenges is crucial for advancing Kenya's industrialisation goals and enhancing economic growth.

The *Kenya Energy Transition and Investment Plan (ETIP)* identifies several challenges in the different sectors and outlines required policy actions. The policy measures envisaged in the ETIP are included in the respective policy categories.

In the area of **governance and planning instruments**, many areas of the policy package (Quicklink to synthesis of existing knowledge - industry: 2.2) have been considered, such as long-term planning and strategy. The Kenya ETIP foresees midterm infrastructure plans – especially for new value chains – to enable the private sector to anticipate decarbonisation options available.
Kenya's adoption of the *Energy (Appliances' Energy Labelling and Performance) Regulations* in 2016, enforced by the Energy and Petroleum Regulatory Authority (EPRA), mandates a register of appliances meeting Minimum Energy Performance Standards (MEPS) (Karanja, 2021). This encompasses refrigerators, air conditioners, motors, and fluorescent lamps, ensuring that only energy-efficient products can be legally sold. This initiative incentivizes manufacturers and retailers to produce and distribute energy-efficient appliances, promoting sustainability and reducing energy consumption. However, the country faces challenges from multiple regulatory frameworks at both county and national levels, alongside diverse levies and fees imposed by county governments. These complexities hinder the wholesale and retail trade sectors from fully capitalising on opportunities across different counties, thereby limiting growth and investment potential.

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Regarding **regulatory instruments**, Kenya has a labelling regulation in force, while ETIP envisions stricter energy efficiency standards, especially for new construction and major renovations and the required use of heat pumps where possible.

Regarding **market-based instruments**, ETIP lists possible public procurement to achieve a critical mass for decarbonised products. Furthermore, it mentions the development of incentive schemes which mitigate unprofitable shares of investments in new clean technologies (for example CCS applications).

Kenya has developed domestic legislation and institutional frameworks to regulate carbon market engagement in line with Kenya's intention to utilise voluntary cooperation under Article 6 of the Paris Agreement (Ministry of Environment and Forestry, 2020). In 2023, Kenya introduced the *Climate Change (Amendment) Act, 2023*. It will regulate carbon projects and trading in Kenya; coupled with the possible introduction of a carbon tax and environmental excise taxes to combat emissions (Nduba-Banja et al., 2023). Prior to the amendment of the Climate Change (Amendment) Act, carbon finance and carbon markets in Kenya were not legally protected. In the past there have been complaints and allegations of exploitation of Kenyan farmers and local communities by carbon project proponents, distorted benefit-sharing agreements, misreporting or measurement of carbon emission reductions and forced evictions. The amended Climate Change Act now provides for the establishment of a national carbon registry in Kenya and regulates the trading of carbon credits. Carbon trading projects must now undergo a mandatory environmental and social impact assessment in accordance with Kenyan environmental laws (Murungi-Omondi, 2024). The National Assembly Budget and Appropriations Committee has approved the draft *Carbon Credit Trading and Benefit Sharing Bill ('Carbon Trading Bill')*, 2023, for formal introduction to parliament. The bill aims to establish a regulatory framework for carbon credit trading and benefit sharing, create a Carbon Trading and Benefit Sharing Authority, regulate carbon trading businesses, and set up a Carbon Credit Trading Tribunal (ENSight, 2023).

Other possible instruments that are currently missing in the policy package are e.g. subsidies and grants to address the lack of capital and to invest in cleaner technologies, tax incentives and investments in clean energy supply chains (Quicklink to synthesis of existing knowledge - industry: 2.2)

Regarding **information instruments**, Kenya has established the *Kenya National Cleaner Production Centre (KNCPC)* as part of the global UNEP/UNIDO National Cleaner Production Centre program with a mission to build national capacity for Resource Efficient and Cleaner Production application in enterprises through awareness creation, training, project implementation, and policy advice for increased enterprise productivity and sound environmental management. Other policies and measures with regard to information, education and capacity building measures are missing like training programs, guidance and toolkits or measuring the carbon footprint in the industry sector.

The next table lists the individual policies and measures in the industrial sector. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex (Quicklink: 4.9.1.)

Table 34: Kenya's policy package (industry sector)

Type of instrument	Status
Governance and planning instruments	• Kenya Vision 2030 (2008) • National Industrialisation Policy Framework (2012) • Constitution of Kenya (2010) • Mining Act of 2016; Mining Bill (2015) • Kenya Energy Transition & Investment Plan 2023-2050
Regulatory instruments	• Energy (Appliances' Energy Labelling and Performance) Regulations (2016)
Market-based instruments	• Climate Change (Amendment) Act (2023) • Carbon Credit Trading and Benefit Sharing Bill (2023) (the "Carbon Trading Bill")

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Information instruments	• Kenya National Cleaner Production Centre (KNCPC) (2000)

4.2.4 How to strengthen national-sectoral policy

Kenya has introduced several key policy instruments regarding the industrial sector[10]. These include the long-term Kenya Vision 2030 and the National Industrialisation Policy Framework. The recently introduced market-based instruments (Climate Change Amendment Act and the Carbon Trading Bill) also address significant existing problems with carbon projects.

Regarding the barriers described under sociocultural feasibility, capacity building and training need to get more attention from the government. This could mean for example investing in training programs to equip the industrial workforce with skills needed for green technologies and sustainable practices or financial assistance to industries transitioning to lower emissions operations.

Given the country's rich mineral resources and fragile ecosystems, clear guidelines are needed to regulate the trade-off between potential economic gains and environmental risks. The Mining Act of 2016 aims to position Kenya as the most attractive location for mining investments in Africa and to improve the country's global competitiveness. Environmental protection was not neglected in the law; but how well these aspects are addressed depends on the relationship between the regulations on environmental management and their interactions with the related legislation on environmental issues, i.e. EMCA, Water Act, etc. (KPMG, 2016).

To strengthen Kenyan climate policy in the industry sector, establishing a National Climate Change Fund that will oversee the mobilisation and disbursement of climate finance is important. However, the source of funds remains a challenge. Additionally, the government should enable greater access to finance and funding for energy audits and advisory services aimed at increasing the energy efficiency of business processes (Ministry of Energy, 2020b).

4.3 Energy

4.3.1 Current decarbonisation status and prospects

Over 94% of Kenya's electricity is generated from renewable energy sources, making emissions from electricity and heat relatively low. This is particularly impressive, as 20 years ago fossil fuels accounted for the majority of electricity generation (EMBER, 2024). Geothermal energy is the most significant source, with an estimated potential of 10,000MW, but current installed capacity is under 863MW (International Trade Administration, 2024). Over 30% (2020) of Kenya's electricity comes from hydropower (Energy & Petroleum Regulatory Authority, 2023), which poses challenges during periods of low water levels, necessitating fossil-fuel thermal generation. Reliance on costly energy imports, including crude petroleum which accounts for 25% of the national import bill, significantly slows economic growth in the country (Ministry of Foreign Affairs, 2018).

The total electrical energy generated grew by 5.03% from 12,652.74GWh in 2022 to 13,289.63 GWh in 2023 *(Energy & Petroleum Regulatory Authority, 2023)*.

Table 35: Energy generated between 2022 and 2023

Technology	2021/2022	2022/2023	% Change

[10] With regard to specific instruments, only overarching recommendations can be provided here. Given the industry-specific differences in requirements, barriers, and enablers, it is essential to develop tailored solutions for each industry branch.

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Hydro	3,348.71	2,569.18	-23.28%
Thermal	1,647.75	1,395.49	-15.31%
Wind	2,052.26	2,201.72	7.28%
Geothermal	4,953.15	6,035.00	21.84%
Bagasse/Biogas	0.38	0.21	-44.83%
Imports	337.5	644.07	90.83%
Solar	312.99	443.95	41.84%
Total	**12,652.74**	**13,289.63**	**5.03%**

Source: (Energy & Petroleum Regulatory Authority, 2023)

Geothermal energy generation increased by 21.84% due to new capacity from Olkaria 1 Unit 6 and the Sossian Geothermal plants. While hydro generation declined due to extended drought periods (Ambani, 2023), the gap was filled by increased energy imports from the Ethiopia-Kenya HVDC link and expanded wind and solar resources. Electricity imports surged by 90.83%, with wind and solar generation increasing by 7.28% and 41.84%, respectively (Business Today, 2023).

A comparison of the energy generated between the financial year 2021/2022 and the financial year 2022/2023 is provided in the table above.

Kenya aims for 100% renewable energy by 2030 as mentioned in the Kenya Energy Transition & Investment Plan 2023 (Ministry of Energy & Petroleum, 2023b) and plans to supply green hydrogen to future green industries by 2040 (IRENA, 2023). With regard to green hydrogen, Kenya is part of the Africa Green Hydrogen Alliance (AGHA) (www.gh2.de/agha). However, the (outdated in some areas) Kenya Vision 2030 (vision2030.go.ke) envisaged that around 12% coal-generated capacity by 2040, including the currently in the "announced" state 960MW coal-fired power plant expected to start commercial operation in 2034.

Rising economic activities and population growth have increased domestic energy demand, primarily met by foreign energy imports. Kenya's updated NDC predicts energy will be the leading contributor to emissions by 2030 due to increased fossil fuel consumption for electricity, heating, and transportation (Ministry of Environment and Forestry, 2020). In view of Kenya's target of 100% renewable energies in the electricity supply, it may come as a surprise that the electricity sector is listed here. However, this can be explained by the fact that plans for the Lamu Coal Power Station are already at an advanced stage.

Figure 15 illustrates the evolution of CO_2 emissions from coal and oil since 2000.

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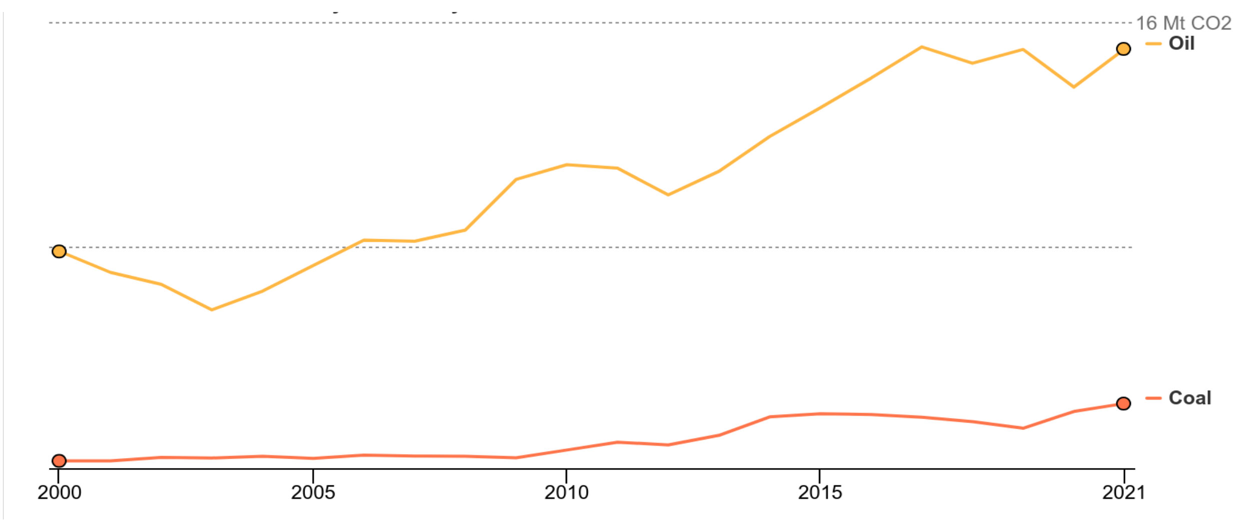

Figure 15: Evolution of CO2 emissions by fuel in Kenya since 2000
Source: (International Energy Agency, n.d.)

The Ministry of Energy's 20-year least-cost power development (2010 to 2030) proposes the inclusion of nuclear power in the energy mix, citing its favourable cost efficiency compared to geothermal and coal. Nuclear energy is proposed here as an integral part of the power generation portfolio to make the power generation mix "robust" with a low carbon footprint. The target confirmed in 2016 of bringing 1000 MWe of nuclear power plant capacity online by 2025 and 4000 MWe by 2033 underlines the commitment to nuclear energy as an important part of the energy infrastructure (Ministry of Energy & Petroleum, 2023c; Nuclear Power & Energy Agency, n.d.). In view of the long planning and implementation period for the construction of a nuclear power plant, however, it is not clear how the plans can be put into practice. Additionally, there is strong public reaction to both planned power options. It should be noted that an earlier attempt at constructing a coal plant in Lamu failed because of strong public opposition (Kimeu, 2024; Obura, 2019).

4.3.2 National-sectoral mitigation enablers and barriers

The energy sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorised and explained in more detail in the annex (Quicklink 4.9.2) and summarised below:

Geophysical feasibility: Kenya possesses significant renewable energy potential, including geothermal, wind, offshore wind, solar, biomass, and biofuels. Regarding hydropower, as already indicated above, reductions in reservoir levels, caused by climate change induced droughts, decrease hydroelectric generation, leading to greater use of fossil fuels, which increase greenhouse gas emissions and the cost of living (Ministry of Environment and Natural Resources, 2016c). Furthermore, while Kenya has abundant renewable energy resources, more than half of Kenyan households still rely on wood fuel and dirty fuels (animal dung) for cooking.

Environmental and ecological feasibility: With a significant renewable energy potential, there is a critical need to ensure the resilience of the energy infrastructure. Balancing environmental concerns with economic growth presents a challenge, forcing the country to make decisions and trade-offs in its pursuit of sustainable development. This challenge is evident in the sharp rise in energy demand and the controversial plans to generate electricity from coal and even nuclear.

Technological feasibility: In 2020, losses in electricity transmission increased from 18% to 23%, highlighting significant inefficiencies in the system (Government of Kenya, 2018; Ministry of Environment and Forestry, 2021). Additionally, the national grid struggles with inadequate capacity to integrate new intermittent power generation sources, such as solar and wind, while aging and lack of maintenance lead to frequent grid stability issues (Ministry of Environment and Forestry, 2018, p. 3). To address these issues and reduce dependence on biomass fuels like

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charcoal and wood, there is a pressing need to improve access to modern energy sources and services.

Economic feasibility: The high initial costs of renewable energy technologies are a major barrier. It is imperative that Kenya achieves energy security and accessibility to meet the increasing energy demand. If there are foreseeable supply gaps with regard to renewable energy, there could be a decision to continue using fossil fuels. But if fossil fuel projects go ahead, they will lock Kenya into a high-carbon, high-cost, and high-pollution energy system that will wreak havoc on communities, natural systems (the long known 'resource curse'), and the climate (Rapid Transition Alliance, 2022). Given the low renewable costs, financing and climate funding should be made available to Kenya and other Sub-Saharan countries to address the issue. A new and rapidly expanding solution is the "Productive Renewables Energy Uses", which in essence facilitates income and this in turn enables paying off the renewables production unit (World Resources Institute, 2024).

Sociocultural feasibility: In 2021, the share of the population with access to electricity in Kenya increased from 36% in 2014 to 76.54% (Statista, 2024). This is due in particular to the massive expansion of renewable energies; Kenya has successfully increased energy generation across all scales, from large-scale wind and solar farms to microgrids serving rural areas, while lately the increase in Commercial and Industrial applications is significant with captive power increasing almost monthly (GET.invest, n.d.). The diversity of technologies and business models ensures there is an energy solution available for every requirement (Rapid Transition Alliance, 2022). Barriers include the inability of population to meet the cost of electrification and inability of the government to meet the cost of extending its power grid.

Institutional feasibility: The government, supported by various development partners, is actively promoting energy efficiency through regulatory enactments and institutional programs. Simultaneously, it has implemented policies facilitating easier access to financing for renewable energy initiatives. However, the predominant focus among local stakeholders remains on enhancing household energy access rather than on energy efficiency initiatives. While Kenya has introduced net metering and feed-in tariffs, implementation allowing businesses and individual customers to sell surplus electricity back to the grid is still limited (EPRA, n.d.-a).

Counties in Kenya often have different interests than the Ministry of Energy, particularly regarding resource management and grid expansion responsibilities. The policy landscape is influenced by stakeholders representing various energy technologies and socio-technical setups. Smaller entities like the Kenyan Renewable Energy Association (KEREA) advocate for their perspectives, distinct from larger bodies such as the Kenya Private Sector Alliance (KEPSA) and the Kenyan Association of Manufacturers (KAM), which prioritise least-cost energy solutions, often favouring fossil fuels despite alternatives. In parallel Kenya as member of international institutions and organisations is obliged to implement globally approved energy policies. This dynamic will shape the way the national visions of development prevail in energy policy decisions (Newell & Phillips, 2016).

4.3.3 Current status of national-sectoral policy

Kenya has liberalised its energy sector and has recently made significant progress in formulating a renewable energy policy (Kiplagat et al., 2011). With a very high proportion of renewable energy, Kenya's electricity mix is one of the most sustainable in the world. However, the political commitment to a sustainable electricity supply must be consistently pursued - in particular the plans for coal-fired power generation must be reconsidered for this reason and the plans to close all coal-fired power plants by 2040 must be consistently implemented (World Resources Institute, 2023).

Kenya takes a holistic approach: even though the main strategies in the **governance and planning instruments** are assigned to the energy sector, the strategies include other sectors as well:

The Bioenergy Strategy 2020-2027 (Ministry of Energy, 2020a) launched by the Ministry of Energy aims to promote bioenergy as a key sector for Kenya's economic development. It aligns with national and county renewable energy priorities to deliver modern energy solutions through innovation and consultation. As the inaugural strategy, it provides guidelines and identifies interventions to develop and sustainably utilise bioenergy resources from 2020-2027. Key features include a coordination mechanism at the Department of Renewable

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Energy, adaptive planning with multi-stakeholder consultations, and a focus on learning and feedback. The strategy does not set hard quantitative targets but offers guidance on achievable outcomes for the short-term (2020-2022) and medium-term (2023-2027). *The Kenya Energy Transition & Investment Plan (ETIP)* provides a harmonised roadmap for the energy sector with a holistic approach that includes the investment requirement for its implementation. It sets the stage for the development of energy sector targets to be incorporated into future National Blueprints. *The Kenya National Energy Efficiency and Conservation Strategy (NEECS) (Ministry of Energy, 2020b)* is the roadmap towards achieving energy efficiency goals that will have an overall positive impact on Kenya's economy. Improving energy efficiency will help reduce the demand for fossil fuels and related greenhouse gas emissions as well as improve energy security – but beyond this, it is considered as one of the priority areas to enhance the quality of life of the Kenyan citizens. *The Kenya National Adaptation Plan 2015-2030* (NAP) (Ministry of Environment and Natural Resources, 2016a) builds on the foundation laid by the *National Climate Change Response Strategy (NCCRS).* This NAP aims to consolidate the country's vision on adaptation supported by macro-level adaptation actions that relate to the economic sectors and county-level vulnerabilities to enhance long-term resilience and adaptive capacity. The NAP includes various proposed actions in land use, energy, and transport sectors. The *National Climate Change Action Plan (NCCAP) 2018-2022* sets out the path towards low-carbon climate-resilient development in a manner that prioritizes adaptation. It encourages the mainstreaming of adaptation and mitigation actions across sectors and levels of government and the engagement and participation of key stakeholders, including the private sector, development partners, and the public in climate change processes and interventions.

A central **regulatory instrument** is *Kenya's Energy Act, 2019* which consolidates and updates laws in the energy sector, repealing the previous Energy Act, the Geothermal Resources Act, and the Kenya Nuclear Electricity Board Order No. 131 of 2012. This new Act aims to unify energy-related laws, define national and devolved government functions, exploit renewable energy sources, regulate petroleum and coal activities, and manage electricity supply and usage. With its enactment, responsibility now shifts to the executive branch to further develop the sector.

In terms of **market-based instruments**, the *Renewable Energy Feed-in Tariff (FiT) System* is now established in the new Energy Act, providing additional legislative support for the 'Feed-In Tariffs Policy on Wind, Biomass, Small-Hydro, Geothermal, Biogas, and Solar Resource Generated Electricity' (FiT Policy) initiated by the Ministry of Energy in 2008. This policy aims to promote renewable energy generation and its distribution through local networks, encourage the adoption and innovation of renewable energy technologies, and reduce greenhouse gas emissions and Kenya's reliance on non-renewable energy sources. The current FiT Policy and its tariff structures will remain in effect under the new Act until new subsidiary legislation is developed, which may adopt or update the existing policy. Furthermore, financial policy permits the full or partial deduction of tax obligations on renewable energy investments. Evidence mostly supports this instrument as it enhances the return on investment. According to *Kenya's VAT Act (2013) and the amended VAT Act (2014)*, renewable energy investors are exempt from value-added tax and import duties on both temporary and permanent materials and equipment needed for constructing renewable energy projects. In Kenya, for example, the government has implemented several energy taxes to promote sustainable energy consumption and raise revenue for public expenditure. The main energy tax in Kenya is the excise duty on petroleum products, applied to petrol, diesel, and kerosene at a rate of KES 18.05 per litre (about 0,14 US$), KES 12.12 per litre (about 0,09 US$), and KES 7.89 per litre (about 0,06 US$), respectively. The revenue generated from the tax is used to fund various public expenditures, such as infrastructure, health, and education (Akinyi Addero, 2023).

With regard to **informational instruments** the *Climate Change Act* establishes frameworks for reporting and monitoring climate-relevant information, promoting transparency, and setting targets for reducing GHG emissions. The *Energy Act* and the National *Climate Change Action Plan* also include provisions for the dissemination of information related to energy production, consumption, and efficiency. In addition, to increase public understanding of renewable energy benefits and climate change impacts a *Public Awareness Campaign and Education Program* was implemented (media, workshops, etc.). By improving access to relevant information and fostering greater public and stakeholder engagement, these measures support more informed decision-making, promote the benefits of renewable energy, and drive the effective implementation of climate mitigation strategies

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in the energy sector. However, despite efforts to disseminate data and best practices, there are barriers such as limited reach to remote or underserved areas, lack of updated information, and insufficient resources for effective communication (for more information on poverty levels and unserved remote communities: Statista (2024): Demographics of Kenya. URL: https://www.statista.com/study/87991/demographics-of-kenya/).

The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex (Quicklink 4.9.2).

Table 36: Kenya's policy package (energy sector)

Type of instrument	Status
Governance and planning instruments	• Kenya Energy Transition & Investment Plan (ETIP) 2023-2050 • Bioenergy Strategy 2020-2027 • Kenya National Adaptation Plan 2015-2030 • Kenya National Energy Efficiency and Conservation Strategy (NEECS)
Regulatory instruments	• Kenya Energy Act (2019)
Market-based instruments	• Feed-in tariff (FiT) on electricity generated from wind, biomass, and small hydropower (2008); extended to geothermal, biogas, and solar energy (2010) • Kenya VAT Act (Tax relief on renewable energy investments)
Information instruments	• Climate Change Act (2016) • Energy Act (2019) • Renewable Energy Feed-in Tariff Act • National Climate Change Action Plan • Public Awareness Campaign and Educational Programs

4.3.4 How to strengthen national-sectoral climate policy

The Kenyan government formulated several plans and strategies with ambitious targets for the energy sector, such as the plan to close all coal-fired power plants by 2040. It is particularly noticeable that the strategies are not limited to just one sector, but always take other sectors such as transportation or buildings into account; the ETIP for example covers important aspects like renewable energies, green hydrogen, e-mobility, energy storage and clean cooking.

But the implementation and reporting of climate change actions face several challenges: weak or non-existent coordinating units and technical capacity, especially at the county level; poor coordination among actors, leading to duplication and risk of double counting; and an unclear NCCAP implementation and reporting process due to ambiguous roles and responsibilities. Additionally, inadequate financial resources hinder progress, as many institutions fail to allocate or mobilize sufficient funds. The private sector and CSOs show low response rates in reporting, despite training efforts, indicating a lack of appreciation for reporting importance. Furthermore, reduced support from development partners in 2019-2020 contributed to low achievements in some areas during this period.

The ambitious net zero target contrasts with the growing hunger for energy and the growing population. And to promote renewable energy, fiscal incentives outlined in law but not yet practiced should be implemented. The FiT policy needs restructuring for greater revenue certainty, involving stakeholders like the World Economic Forum and conducting research to refine the policy and its benefits. Efficiency improvements should include establishing a one-stop shop and clear guidelines for government discussions, enhancing energy efficiency regulations with a standards and labelling program, compiling an inventory of current regulations and compliance, and identifying Kenyan-made goods that could benefit from energy efficiency labelling, along with the support needed to promote these goods.

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4.4 Transport

4.4.1 Current decarbonisation status and prospects

Kenya's transport sector accounts for 8.3% of its total GDP. As the largest consumer of petroleum products in Kenya, the sector significantly contributes to the GHG emissions. The rail sub-sector was responsible for 0.13 MtCO2 emissions in the year 2015. This is the highest recorded value in the rail subsector in the country's historical emission profile and is an indication of the growing activities within the sub-sector. It is assumed that the spike in 2015 was driven by increased activity during construction of the Standard Gauge Railway as fuel data recorded may have included values of all fuel used during the transportation of materials and equipment, used in construction of the Standard Gauge Railway (SGR). The aviation sub-sector was responsible for roughly 0.2 MtCO2e emissions in 2015. On the other hand, road transport contributed to about 6,9 MtCO2e as summarised below in Table 37.

Road Transport	Fuel type	2015 (tonnes of fuel)	2015 (tCO2e)	% of fuel type
Passenger Cars	Diesel	44,694	144,741	3.6
	Petrol	667,358	2,099,024	73.7
Light commercial vehicles	Diesel	218,879	708,833	17.5
	Petrol	23,899	75,170	2.6
Heavy goods vehicles	Diesel	871,117	2,821,081	69.6
Buses	Diesel	116,847	378,404	9.3
Motorcycles	Petrol	214,338	674,151	23.7
All categories	Diesel	1,251,537	4,053,059	100
	Petrol	905,595	2,848,345	100
Total		2,157,132	6,901,404	

Table 18: Fuel consumption and emissions by vehicle category and fuel *Source: (Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works, 2020)*

Kenya has put measures in place to promote the shift from road to rail and the country is developing legal and policy frameworks to promote the use of electric vehicles; it adopted the electric vehicle pledge at COP26. The country agreed that it will accelerate the transition to zero emissions vehicles in their market. Greater electrification of the transport sector can therefore make a major contribution to achieving Kenya's transport sector goal of reducing emissions by 3.46 MtCO2e against the baseline in 2030 (EPRA, n.d.-a). The Ministry of Roads and Transport launched Kenya's first Electric Mobility (e-mobility) Draft Policy, which aims to guide the development of electric mobility in all modes of transportation – road, rail, air and maritime – by providing a framework for the transition from the use of conventional internal combustion engine (ICE) vehicles (Ministry of Roads and Transport, 2024a).

4.4.2 National-sectoral mitigation enablers and barriers

The transport sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorised and explained in more detail in the annex (Quicklink 4.9.3) and summarised below:

Geophysical feasibility: Kenya has significant renewable energy potential, including geothermal, wind, solar, biomass, and biofuels, (a Bioenergy Strategy was published in 2021 to provide a pathway to a sustainable bioenergy future), which can enhance the capacity to decarbonise its transport sector. However, a challenge to the sector's electrification may be that at the same time as the country has an ambition to increase the sector's electrification, it also needs to invest in modernising access to energy in households and electrifying the remaining 20-30% of the population. That is why large investments not only in electricity supply, but importantly in

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transmission and distribution infrastructure will be needed. There needs for integrated planning, or the objectives of one sector can compete with the ones in another sector. Furthermore, there are several geophysical barriers such as uneven terrain, underdeveloped infrastructure, and susceptibility to climate impacts like flooding and droughts. These challenges complicate the development and implementation of sustainable transport solutions.

Environmental and ecological feasibility: The increased demand for fossil fuels in transportation leads to high greenhouse gas emissions as the sector consumes at least 70% imported petroleum products. In addition, public transportation is dominated by low-capacity minibuses, and traffic congestion in cities like Nairobi exacerbates fossil fuel consumption and local air pollution, impacting public health (Ministry of Environment and Natural Resources, 2016c) ((Ministry of Environment and Natural Resources, 2016). Even though the number of electric vehicles in Kenya is increasing (Ambani, Brian (2024): Kenya electric vehicles uptake goes up five-fold. 14th April 2024. In: The East African. URL: https://www.theeastafrican.co.ke/tea/business/kenya-electric-vehicles-uptake-goes-up-five-fold-4589332#), their share is still relatively low and cannot yet contribute to reducing emissions in the transport sector. However, there are programs to ease traffic congestion and improve intersections, such as the construction of pedestrian bridges, the improvement of crosswalks in Nairobi, a smart traffic system on Nairobi's western ring roads and initiatives such as tree planting, landscaping and the construction of sidewalks.

Technological feasibility: In Kenya, there is a comprehensive engagement of the private sector to promote shifting cargo from road to rail, and government involvement in an e-mobility pilot with UN-Environment, deploying 50 electric motorcycles in Kisumu. Additionally, support from The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) helps identify barriers in the EV business. Significant barriers exist, such as the lack of climate-proof infrastructure, poorly developed energy infrastructure limiting alternative energy adoption, limited charging and fuelling infrastructure, and the high cost of technology, including efficient vehicles, charging stations, and other e-mobility infrastructure (Wiesmann et al., 2014).

Economic feasibility: A significant enabler is the reduction of excise duty on electric vehicles, as proposed in the Finance Bill of 2019, which lowers the duty from 20% to 10%, making electric vehicles more affordable. However, a major barrier is the high cost associated with replacing existing vehicles with more fuel-efficient ones. This financial burden limits the widespread adoption of cleaner, more efficient vehicles, hindering progress toward a sustainable transport sector (Ministry of Finance and Economic planning, 2016).

Sociocultural feasibility: Enablers include increased public awareness campaigns and potential job creation in the green transport sector (Ministry of Energy & Petroleum, 2023a). However, barriers such as public resistance to change (e.g. to electric vehicles), economic inequality making sustainable transport options unaffordable for many, a lack of a skilled workforce to support and maintain green technologies.

Institutional feasibility: Kenya's institutional feasibility for a climate-friendly transport sector includes support from international institutions and NGOs as key enablers. If this support can provide essential funding, expertise, and advocacy to drive sustainable transport initiatives then it will serve Kenya well. However, significant barriers exist, such as a lack of coordination between various government agencies and resource limitations. These barriers hinder the effective planning, implementation, and management of sustainable transport projects.

4.4.3 Current status of national-sectoral policy

Kenya's public transport system is privately operated, with the road transport network served by matatus (minibuses), taxis (traditional and ride-hailing services), bodabodas (motorcycles), and tuk-tuks (three-wheelers). The transport sector consumes about 72% of all petroleum products imports. Among the outlined objectives in Kenya's Nationally Determined Contribution (NDC) are to increase the adoption of electric vehicles, improve fuel economy performance, and reduce CO_2 emissions in the transport sector (Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works, 2021). The National Energy Efficiency and Conservation Strategy (2020) envisions that by 2025, 5% of all registered vehicles in Kenya will be electric powered, compared to nearly zero currently. Similarly, the Long-Term Strategy for GHG emissions reduction aims at net zero by 2050 targeting transition to e-mobility (EnergyCapital&Power, 2024; ESI Africa, 2023; Ministry of Roads and Transport, 2024b).

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The electricity used now for electric vehicles comes from the national grid, but a strategic plan is underway to enhance more abundant and reliable electricity supply, including constructing the controversial nuclear plant by NuPEA at the coast region.

A *Transport Sector Climate Change Annual Report* (Republic of Kenya, 2023b) is regularly published, highlighting key strategies for the coming years and listing measures and programs to promote sustainable transport. Challenges and recommendations for additional measures are also included. This Annual Report is the basis for this chapter.

The *Ministry of Roads & Transport* is dedicated to enhancing transport services and infrastructure to boost trade, improve connectivity, and enhance service delivery. The *Climate Change Coordination Unit* (CCCU) within the State Department for Transport continues to implement, monitor, and report mitigation and adaptation measures in accordance with the *Climate Change Act* (2016) and global reporting requirements under the Paris Agreement.

The transport sector is characterised by **governance and planning instruments**. Many goals and strategies have been implemented to reduce GHG emissions. The Ministry of Roads and Transport published an updated *Integrated National Transport Policy* (Ministry of Roads and Transport, 2024c) in March 2024, which includes climate protection aspects. This policy is currently being revised to further integrate climate change and other sustainability elements. To achieve energy transition for a Net Zero Economy, the *Kenya Energy Transition and Investment Plan (ETIP)* (Ministry of Energy & Petroleum, 2023a) mentions some key technology interventions for the transport sector. These are for cars and motorcycles: 1) Improve new cars efficiency standards and encourage public transport usage, 2) Shift the market of new cars and 2 wheelers to electric with ca. 30% compound annual growth rate, 3) Shift the whole fleet to electric as old cars and motorcycles retire; for freight trucks and buses 1) Improve new efficiency standards on freight trucks and buses, 2) Shift trucks and buses to electric and hydrogen; for aviation and shipping: 1) Implement new efficiency improvements and biofuels when available.

To strengthen public transport, especially from road to rail, the *East African Rail Masterplan* completed the standard gauge railway (SGR) from Nairobi to Naivasha in 2019, shifting 30% of freight from road to rail. Additionally, 4,678,000 tons of freight were shifted from road to rail from Mombasa to Nairobi. However, it must be mentioned that the rail system is currently diesel powered. The *Nairobi Railway Masterplan* was implemented to upgrade the Nairobi commuter rail system, transporting 2.3 million people in 2022. Regarding bus transportation, 70 km of the *Bus Rapid Transport* system for Nairobi were constructed. For climate change adaptation, 3,098 km of roads have been climate-proofed — 1,570.4 km by the Kenya National Highways Authority (KeNHA) and 1,539.23 km by county governments. Efficiency improvements for heavy-duty trucks are also being addressed. To promote electromobility, *pilot projects* for buses and 3 & 2 wheelers vehicles were tested in Nairobi. With regard to the expansion of the transportation network in Kenya, the Chinese Belt&Road Initiative should also be mentioned: In 2017, the first section of Kenya's Chinese-built railroad opened. Two years later, work on the tracks in the middle of the country was halted and the master plan to connect the country with other landlocked countries in East Africa appears to have been abandoned (Soy, Anne (2023): China's Belt and Road Initiative: Kenya and a railway to nowhere. In: BBC. 14th October 2023. URL: https://www.bbc.com/news/world-africa-67101736).

Electric vehicles are also addressed by **regulatory and non-economic instruments**. *Standards* were introduced for the sale of electric vehicles. *Euro4 regulations* were implemented for trucks to reduce emissions. There is a vehicle age limit for importation to 8 years and also inspections exist, although there is a lack of capacities and resources (Mbandi et al., 2023). A *draft regulation on the prevention of pollution from shipping* is in progress, in accordance with the international convention on the prevention of pollution from ships. For aviation, regulations have been published under the *Carbon Offsetting and Reduction Scheme for International Aviation* (CORSIA).

Market-based instruments are completely lacking in Kenya's transport sector policy package, representing a significant gap that needs to be addressed to overcome barriers related to financing and incentives for switching to climate-friendly alternatives.

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In the area of **information instruments**, campaigns, projects and research activities have been and are being conducted. This includes e.g. a study on the electrification of 2 and 3-wheelers (https://unhabitat.org/join-us/calls/conducting-market-research-on-2-and-3-wheelers-in-kenya-with-a-focus-on-electric) was conducted and recommendations were implemented to enable the switch to electricity. Further *feasibility studies* are ongoing regarding alternative marine power sources, sustainable aviation fuels, and the installation of shore power infrastructure for four berths. Additionally, educational and capacity-building programs have been implemented to overcome the lack of information and awareness. *Fifteen climate change focal points* from transport agencies were trained on climate change planning, budgeting, and advancing transport and climate strategies. Moreover, 300 people participated in *webinars* on fuel economy and electric mobility options, and driver sensitisation in eco-driving was implemented.
The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex (Quicklink 4.9.3).

Table 19: Kenya`s policy package (transport sector)

Type of instrument	Status
Governance and planning instruments	• Climate Change Coordinating Unit (CCCU) • Integrated National Transport Policy reviewed • Climate Change Act • Construction of 70km of the Bus Rapid Transport for Nairobi. Construction of a total of 33 km of non-motorized transport facilities. • East African Rail Masterplan • 4,678,000 tons of freight from Mombasa to Nairobi shifted from road to rail. • Road vehicle inspection standards adopted. • Implementation of functional traffic light systems at key junctions and intelligent transportation systems. • Nairobi Railway Masterplan to upgrade Nairobi commuter rail system • 3,098 km of roads climate-proofed • Improving heavy-duty truck efficiency • Electric public buses /3 & 2 wheelers vehicles are being piloted in Nairobi
Regulatory instruments	• Draft regulation on the prevention of air pollution from shipping • Euro-4 compliance for all new truck (2023) • Draft CORSIA regulation • Standards for electric vehicles • Vehicle age limit for importation (8 years)
Market-based instruments	
Information instruments	• A study on the electrification of 2 and 3-wheelers was conducted • Fifteen climate change focal points from the transport agencies trained on climate change planning, budgeting, and advancing transport and climate strategies. Three hundred people participated in webinars on fuel economy and electric mobility options. • Driver sensitisation in eco-driving • Feasibility study ongoing alternative source of marine power / sustainable aviation fuels /on the installation of shore power infrastructure for four berths

4.4.4 How to strengthen national-sectoral climate policy

Already, the number of passenger cars is increasing steadily with rising incomes. This growth is accompanied by expanded roads and highways and the associated impacts on climate and local air pollution. Therefore, the transportation sector is highly relevant in Kenya, and the country has set goals to reduce greenhouse gas emissions in this sector, including passenger cars, freight trucks, buses, aviation, and shipping.

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Enhanced vehicle emission and fuel efficiency standards, a transition to alternative fuels, and investment in public transportation have proven to be effective strategies for achieving Kenya's climate protection goals. These measures also offer the added benefits of improved air quality and better health outcomes (Mbandi et al., 2023). However, significant gaps remain in implementation that need to be addressed promptly.

A key pillar is public transportation, which is still underdeveloped and dominated by minibuses (matatus). There are already initial efforts to expand public transportation, which need to be strengthened and expanded. Additionally, transferring freight transportation from road to rail holds great potential.

The Kenya Energy Transition and Investment Plan (ETIP) identifies targets, such as the National Energy Efficiency and Conservation Strategy's goal for 5% of new cars to be electric by 2025 and measures to achieve an average fuel consumption of 6.5 litres per 100 kilometres for light-duty vehicles by 2025. However, both targets have yet to be adequately addressed by policy and are currently under development.

To promote climate-friendly transportation, financial incentives are necessary, which are currently lacking in the policy package but could make electric and fuel cell vehicles cost-competitive and affordable. Possible measures from the ETIP include purchasing tax credits, low-emission zones, vehicle trade-in programs, free parking, and lower vehicle registration costs. Efficiency improvements and the development of suitable infrastructure for electromobility are also needed. Lastly, consumers need to be educated and trained. Regulatory measures such as those included in the NDC can also make a decisive contribution to reducing emissions.

Overall, it is essential to implement the measures consistently and ensure effective monitoring. Adequate capacities and resources must be available to carry out these measures (Mbandi et al., 2023).

4.5 Buildings

4.5.1 Current decarbonisation status and prospects

The Building, Mining and Construction Sector represents a broad, diverse but closely linked sector. Under the Kenya Association of Manufacturers (KAM), Building, the Mining & Construction Sector is represented by four subsectors namely Building and Construction Accessories, Cement Manufacturing, Precast & Ready-Mix Concrete, and Quarry and Mining sub-sectors. In 2019, the construction and the mining & quarry industry contributed 5.6% and 0.7% of Kenya's Gross Domestic Product (GDP) respectively (Bomett et al., 2021). Since then, the sector's contribution has been following an upward trend. In 2020, the construction industry added 7.1% to Kenya's GDP. It is worth noting that the sector's contribution to the Kenyan economy has followed an upward trend since 2016 (Statista, 2021).

4.5.2 National-sectoral mitigation enablers and barriers

The building sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorised and explained in more detail in the annex (Quicklink 4.9.4) and summarised below:

Geophysical feasibility: Kenya's different climatic zones can support the adaptation of various building designs and technologies, promoting climate-friendly building policies. However, extreme weather events like intense rainfalls have affected various regions in Kenya, including the Coastal area, Central areas including Nairobi, the Western Highlands, Rift Valley, Lake Victoria Basin, South-eastern lowlands and North-eastern regions. The associated flooding and impact on buildings is often due to a combination of factors, including poor urban planning, development in riparian areas and outdated drainage systems in urban areas (Trium Limited Consultancy., 2024).

Environmental and ecological feasibility: Eco-friendly construction materials and technologies are gaining popularity in Kenya. The country is leading in sustainable construction practices by using recycled materials,

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renewable energy solutions, green building certifications, water and energy-efficient technologies, and sustainable waste management systems, making construction more environmentally conscious. On the other hand, the local climate context is not considered sufficiently during the design and construction phases of the most modern buildings (Ministry of Energy, 2020c). One reason for this is that national building regulations have not been updated to include provisions for heating or cooling systems in buildings. As a result, emissions are rising, albeit not at the level of the global North.

Technological feasibility: In terms of technological feasibility, Kenya is well positioned in the building sector: Since 2006, the Kenya Association of Manufacturers (KAM) has hosted the national Centre for Energy Efficiency and Conservation (CEEC) and is involved in program administration on behalf of the Ministry of Energy. From 2011 to 2015, UN-Habitat and UN Environment implemented the "Promoting Energy Efficiency in Buildings in East Africa" program. Additionally, the International Finance Corporation (IFC) entered into an agreement with the Kenya Green Building Society (KGBS) to promote a greener construction sector in Kenya. This partnership involves KGBS marketing IFC's EDGE green building software and certification program to the Kenyan property industry and collaborating on future technical trainings. However, challenges persist in the clean cooking sector – which mostly uses firewood and charcoal, including insufficient research, development, and innovation, lack of modern fuels, the use of inefficient cookstoves due to high upfront costs, and an inadequate number of testing labs for appliances, cookers, and fuels (Ministry of Energy, 2020b).

Economic feasibility: The promotion of green buildings and energy efficiency technologies faces several economic challenges. There is a lack of public sector like subsidies and a general market support for green buildings (IEA, 2019a) and insufficient financial support for developing local testing labs needed for energy efficiency research and development activities (Munene et al., 2019a). Additionally, homeowners are reluctant to replace inefficient devices with more efficient ones due to the high costs associated with these upgrades. Furthermore, households lack motivation to purchase energy efficiency technologies because of their low purchasing power (Munene et al., 2019a).

Sociocultural feasibility: In collaboration with the Ministry of Industrialisation and Enterprise Development and leveraging Global Environment Facility funding, UNDP has helped Kenya to introduce minimum energy performance standards and administered comprehensive campaigns aimed at informing retailers and consumers of the need to improve energy efficiency in residential, commercial, and industrial sectors; the Minimum Energy Performance Regulations make it mandatory for selected electrical appliances to achieve MEPS (Ministry of Energy 2020). Despite these efforts, the rapid growth of building stock, primarily due to the increase in the number of hotel and institutional buildings (Ministry of Energy, 2020b), poses additional challenges. Many households continue to use low-efficiency cookstoves due to a preference for and lack of knowledge about improved cookstoves and fuels (Ministry of Energy, 2020b). Furthermore, there is a significant lack of awareness and inadequate knowledge among distributors and customers regarding energy efficiency and energy labels (Munene et al., 2019a).

Institutional feasibility: The Kenya Green Building Society (KGBS) is an independent, non-profit membership-based society registered with the World Green Building Council as its Kenya Chapter. Recognised by the Ministry, KGBS is mandated to run certification schemes for the built environment, advocate for green buildings, and train green building professionals. Several bilateral agencies have either direct energy efficiency programs in Kenya or broader energy sector programs with strong energy efficiency components, such as USAID's Power Africa flagship program, GIZ's Program for Energy Efficiency in Buildings (PEEB), the multi-donor Energising Development (EnDev) Kenya project, and direct support for energy efficiency activities. Despite these initiatives, challenges persist in the nascent market for green buildings (EDGE, 2023), including the lack of support for mandatory energy audits, particularly for large residential projects, no phasing-out of inefficient energy technologies, lack of enforcement of minimum energy performance standards (MEPs) (Ministry of Energy, 2020), and the insufficient capacity of enforcement agencies to promote compliance with MEPs (Munene et al., 2019a).

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4.5.3 Current status of national-sectoral policy

Kenya's Climate Change Act, 2016 provides a framework within the state Department for Public Works for action that promotes low carbon, climate resilient development practices within the construction industry. It further aims to reduce greenhouse gas emissions that are projected to increase because of population and economic development such as building and construction. Actions to decrease climate change threats are expected to reduce GHG emissions by 30% by 2030. The building and construction sectors have a large potential in reducing GHG emissions because building material, technologies and processes have substantial carbon footprint (Kenya Building Research Centre, n.d.).

In terms of **governance and planning instruments**, Kenya has not set net zero targets (Climate Action Tracker, 2022).

Regarding **regulatory instruments** since the mid-1960s, Kenyan construction codes have been based on British standards, but they are now transitioning to European construction guidelines (Eurocodes) (Copenhagen Centre & Building Efficiency Accelerator, 2018a). Although a *draft energy efficiency building code for Kenya* has been published (Kenya, State Department for Public Works, 2022, as cited in UN Environment Programme, 2022), it has not yet taken effect (UN Environment Programme, 2022a). To comply with the code, buildings must conserve energy, utilise passive and natural cooling methods, and use natural daylight (Climate Action Tracker, 2022a). The code also considers the use of PV and wind energy in new housing developments, along with solar hot water for bathrooms. Kenya adopted the *Energy Labelling and Performance regulations* in 2016, with the EPRA responsible for registering appliances that meet the *Minimum Energy Performance Standards (MEPS)* (Okadia, 2023a). MEPS are set for six electrical appliances, including motors, air conditioners, fridges, CFLs, magnetic ballasts, and fluorescent lamps, with plans to include more product categories such as LEDs, computers, TVs, and cookstoves by 2025. However, high initial investment costs are considered a barrier to the use of efficient lighting products (Ministry of Energy, 2020b).

There are several **economic instruments** that can be listed for Kenya: The CFC Stanbic and Cooperative Bank offer $33 million in *green credit lines for energy efficiency projects*, and HF Group has launched a credit facility for green mortgages supported by IFC (Copenhagen Centre & Building Efficiency Accelerator, 2018b). The government has announced the establishment of a Super *ESCO* operated by the Kenya Power and Lighting Company to develop and implement energy efficiency projects (UN Environment Programme, 2021). The *Kenya Green Bond Program*, initiated in 2017, supports financial sector innovation, and the first green bond was issued in 2019 to raise KSh 4.3 billion for eco-friendly housing for university students (Green Finance Platform, 2019). Despite these initiatives, challenges include a lack of incentives for green building financing (EDGE, n.d.), limited financial incentives for energy efficiency in buildings (Copenhagen Centre & Building Efficiency Accelerator, 2018b), an underdeveloped ESCO market (SEFA, 2021), and no explicit carbon pricing, though fuel excise taxes indirectly address emissions (OECD, 2022).

A number of **information instruments** are in place in Kenya, including several international *green building rating systems* like Green Star Kenya, EDGE or LEED (EDGE, n.d.). The first *energy label* was introduced in 2019 (Okadia, 2023b), with the EPRA implementing a five-star rating scheme for appliances like refrigerators, air conditioners, and motors, and plans to include more appliances (EPRA, n.d.-b). A digital campaign called #KenyaEnergyLabel was initiated by CLASP and EPRA to educate consumers (Blair & Wekongo, 2020). Pilot studies on *feedback measures*, such as the installation of smart energy meters in Mombasa's Kongowea Market, are underway, with more planned for public buildings (Covenant of Mayors, 2023). The Technical University of Kenya (TUK) offers a Green Building course, and various colleges provide craft certificates in solar installation. Projects like "Solar Learning For Women" provide *training* in solar technology and entrepreneurship (Solarafrica, n.d.). However, Kenya's Green Building Market is still developing, and both distributors and consumers lack awareness of energy efficiency. Price is the primary consideration for consumers due to unfamiliarity with energy ratings (Munene et al., 2019b). The clean cooking sector needs more innovation, research, and financial support for local testing labs and academic institutions to enhance energy efficiency research and development (Ministry of Energy, 2020; Munene et al., 2019).

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The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex (Quicklink 4.9.4).

Table 20: Kenya's policy package (building sector)

Type of instrument	Status
Governance and planning instruments	
Regulatory instruments	• Energy efficiency building code for Kenya (draft) • Energy Labelling and Performance regulations (2016) • Minimum Energy Performance Standards (MEPS)
Market-based instruments	• Green credit lines for energy efficiency projects • Kenya Green Bond Program (2017)
Information instruments	• Green Building Systems in Kenya • Energy label (2019) • Feedback measures • Training programs

4.5.4 How to strengthen national-sectoral climate policy

For Kenya to improve the governance and planning frameworks, it is crucial: With a growing population, to establish standardised guidelines for the construction and maintenance of green buildings, as well as regulations specifying the standards that new buildings must meet to be energy-efficient and environmentally friendly need to be implemented. For now, the country lacks standardised guidelines for the construction and maintenance of green buildings, and there are no legislations or regulations specifying the standards that new buildings must meet to be energy-efficient and environmentally friendly. Consequently, environmentally friendly design, the reduction of carbon footprints, and green construction practices are rarely considered by the Kenyan construction industry (The National Treasury and Economic Planning, 2023).

One problem that has not yet been adequately addressed in policy measures is the high proportion of biomass in Kenyan homes: Buildings accounted for around 67% of total final energy consumption in the country in 2019 and this high figure is mainly due to the use of biomass for cooking in private households, where biomass accounted for 64% of the total energy supply. Around 75% of Kenyan households use wood (firewood and charcoal) as their primary cooking fuel. Although there are programs in place aiming at clean cooking (Ministry of Energy, 2022), residential cooking fuels caused an estimated 24.8 $MtCO_2e$ of GHG emissions, or about a quarter of Kenya's total emissions, and led to 21,500 premature deaths from illnesses caused by cooking-related air pollution (NewClimate Institute & EED Advisory, 2021). Although clean cooking is not explicitly prioritised as a mitigation measure in the NCCAP, the plan recognises that improving the efficiency of cooking with biomass is an important measure to achieve the recommended emissions reduction target for the energy demand sector (Government of Kenya, 2018). While the building sector as a whole is not addressed in the NCCAP, it is an important component of achieving Kenya's energy demand and energy efficiency reduction targets (Climate Action Tracker, 2022b).

4.6 AFOLU

4.6.1 Current decarbonisation status and prospects

Land-use

The main land use in Kenya is agricultural land (48.5%). Outside of agricultural land, forest land covers only 6.3% of total land area, of which 96% of naturally regenerating forest. A detailed description of land use is

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provided in Table 3.

Table 21: Area by land-use in 2010 and 2020 in Kenya

Land use (1000ha)	2010	2020
Land area	56,914	56,914
Agricultural land	27,320	27,630
Cropland	6,020	6,330
Arable land	5,500	5,800
Permanent crops	520	530
Permanent meadows and pastures	21,300	21,300
Forest land	3,616	3,611
Naturally regenerating forest	3,464	3,458
Planted Forest	153	153
Other land	25,978	25,673

Source: (Food and Agriculture Organisation of the United Nations, 2024)

The biggest share in Kenya's current emissions comes from land-use, land-use change and forestry; it has contributed almost one third of the country's total emissions on average over the last 20 years (Climate Action Tracker, 2022a). With view to the country's economy, the agricultural sector is crucial: 28% of the GDP is generated here, 80% of Kenya's rural workforce are employed in the sector (World Bank & CIAT, 2015). According to the NDC baseline, until 2030 absolute agricultural emissions are projected to grow from 34 $MtCO_2e$ in 2015 to 41.6 $MtCO_2e$ in 2030 (Ministry of Environment and Natural Resources, 2017). To reduce methane emissions, improving livestock-keeping practices, feeding regimes and agroforestry systems are options (World Bank & CIAT, 2015).

Kenya´s food system emissions remained stable in absolute level over the past decade (2010-2020) at around 63 MtCO2 eq (Martius et al., 2023). Building a large forest-related carbon sink has contributed to curbing emissions significantly between 2010 and 2020. So far, the largest sources of emission in Kenya's food system are enteric fermentation (56% of total emissions), manure left on pasture (24%), and food waste disposal (11%). Altogether, these three categories account for 91% of all food system emissions (Martius et al., 2023).

Kenya is prioritising Carbon Credits (Nduba-Banja et al., 2023) and has launched a nationwide afforestation plan led by President Ruto, targeting the planting of 15 billion trees by 2032. This initiative aims to reduce greenhouse emissions, halt and reverse deforestation, and restore 5.1 million hectares of deforested and degraded landscapes, aligning with the African Landscape Restoration Initiative inaugurated on December 22, 2022. By focusing on afforestation and restoration efforts, Kenya aims to enhance its carbon sequestration capacity and leverage Carbon Credits to mitigate climate change impacts effectively (Republic of Kenya, 2023a).

4.6.2 National-sectoral mitigation enablers and barriers

Kenya's economy is highly dependent on climate-sensitive sectors such as agriculture, water, fisheries, forestry, and energy. The most vulnerable sectors happen to be the agricultural and water sectors, where land degradation remains a threat to the provision of environmental services and the ability of smallholder farmers to meet the growing demand for food and income (Ministry of Environment and Natural Resources, 2016b). Over 84% of Kenya's land area is arid and semi-arid, with poor infrastructure and other developmental challenges, leaving less than 16% of the land area to support over 80% of the population (Ministry of Environment and Forestry, 2020). The enablers and barriers are categorized and explained in more detail in Table 14 (annex) and summarized below:

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Geophysical feasibility: Enablers include reforestation programs aimed at achieving a tree cover of at least 10%, addressing the current forest cover of 7.4%. Additionally, effective land use planning and zoning help segregate and identify forest areas for conservation. However, due to economic aspects, the protection of the forest in Kenya is at risk and the protective measures are in danger of being lifted. Other barriers are soil erosion and water scarcity (National Environment Management Authority, n.d.).

Environmental and ecological feasibility: The promotion of climate-smart agriculture with efficient livestock management systems, the focus on Sustainable Land Management (SLM) to minimize degradation, rehabilitate degraded lands, and increase food production, and the mainstreaming of climate change considerations into environmental audits, impact assessments, and strategic assessments are enables. However, barriers include ongoing land conversion of forests, wetlands, and other natural habitats into urban or agricultural areas, contributing to deforestation, habitat loss, carbon release, and reduced biodiversity. Effective land use planning and zoning for conservation are also needed.

Technological feasibility: Effective technological solutions require robust infrastructure, advanced methodologies for sustainable land management, and innovative approaches to combat climate change - the necessary financial resources are not available in Kenya. The absence of detailed technological advancements, insufficient implementation of modern agricultural practices, and the need for better integration of technology into land-use policies hinder progress. Collaboration with international organisations and adherence to global standards could facilitate the adoption of advanced technologies and enhance Kenya's capacity for sustainable land management in the face of climate challenges.

Economic feasibility: Enablers are income and employment opportunities for the agriculture and food sector. Barriers include the lack of clear sources of climate finance for conservation and sustainable forest management over the medium and long term. Additionally, arid and semi-arid lands are particularly vulnerable to climate change impacts, especially without sufficient investments in resilience-building mechanisms. These economic challenges hinder the adoption and implementation of climate-friendly practices and sustainable land management in Kenya.

Sociocultural feasibility: Positive effects are the community involvement and educational programs that promote sustainable land management practices. Cultural norms that emphasize environmental protection and conservation also support these efforts. In addition, collaboration with local communities can integrate traditional knowledge into modern conservation strategies. However, barriers also exist like inadequate standards and training, limited knowledge, limited access to resources, high cost of inputs, and the need for broader education and awareness of the impacts of climate change on land use practices (Phiri et al., n.d.).

Institutional feasibility: Enablers include collaboration with international and national organisations to address land degradation, such as the Kenya Strategic Investment Framework (KSIF) with the World Bank and TerrAfrica, and significant commitments to sustaining natural resources through agreements like UNCCD, UNFCCC, CBD. Additionally, guidelines and standards for establishing green zones, as required by the Forest Act 2016, have been developed, linking with county physical planning and development control functions. However, barriers include inadequate or weak land use regulations and policies that may fail to address climate change concerns and promote unsustainable practices, leading to ongoing land degradation in watersheds, agricultural areas, rangelands, and settled areas.

4.6.3 Current status of national-sectoral policy

Kenya's land-use policy package is characterized by governance and planning instruments and by economic instruments. A number of policy measures have been implemented here, aimed in particular at creating awareness, strengthening capacity building and addressing financial barriers. However, there is an explicit lack of instruments that provide information or that educate relevant actors. Regulatory instruments have also been insufficiently implemented in the AFOLU sector in Kenya and should therefore be given greater consideration in the future policy design.

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To address the barriers of limited awareness, capacity building and financing, **some governance and planning instruments** were implemented in Kenya. A key player in the implementation of measures is the *Kenya Forest Service*, a State Corporation in the Ministry of Environment, Climate Change and Forestry. In addition, many planning and strategic measures have been implemented, such as the *Forest Conversation and Management Act*, the *Community Land Act* or the *National Forest Program*. The *2023-2027 Strategic Plan* aims to expand forest and tree cover for climate mitigation and adaptation, conservation and protection of forests for climate change resilience, economic development and livelihood improvement, organisational capacity building and collaboration. With regard to forests, two key measures can be mentioned here. This is the *National Plan for achieving 30% tree cover by 2032* and a campaign launched in 2022 to plant 15 billion trees by 2032. Furthermore, to overcome the lack of financing and for capacity building, the *Lake Victoria Environment Management Program (LVEMP)* is in place that was financed together with the United Republic of Tanzania and the Republic of Uganda. The aim is to enhance collaborative management of trans-boundary natural resources in the Lake Victoria Basin among EAC Partner States, to improve environmental management of targeted pollution hotspots and rehabilitate selected degraded sub-catchments, benefiting the communities reliant on the Lake Victoria Basin's natural resources. The objective of the *Kenya Climate Smart Agriculture Strategy 2017-2026* is to adapt to climate change, build resilience of agricultural systems while minimizing emissions for enhanced food and nutritional security and improved livelihoods. The *Agricultural Sector Development Strategy* and the *Agricultural Productivity and Agribusiness project* aim to transform the sector into an innovative commercially oriented and modern industry against the backdrop of constantly changing conditions due to climate change.

The policy package in AFOLU has a particular focus on governance and planning instruments with goals and strategies for the coming years. However, bioenergy and food system reform have not yet been comprehensively implemented. This is particularly critical in view of the droughts in Africa caused by climate change: according to a UN report, droughts have caused losses of more than 70 billion dollars over the last 50 years and have made 23 million people food insecure, mainly in Ethiopia, Kenya and Somalia (UNCCD 2023).

Regulatory instruments, such as the *Forest Conservation and Management Act* and the *National Climate Change Action Plan*, set standards and provide guidelines for sustainable land management and forest conservation. These regulations create a structured environment for implementing climate-smart agricultural practices and integrating renewable energy solutions, ensuring that projects align with national climate goals. By providing legal and regulatory support, these instruments facilitate compliance, attract investment, and drive effective implementation of mitigation strategies. However, challenges are the inconsistent enforcement of regulations and gaps in the regulatory framework. Instruments such as water efficiency requirements, land-use zoning or standard and certification programs are still lacking.

Economic instruments have also only been implemented by a *Project to strengthen climate resilience in the Lake Victoria Basin*. The project, which will benefit the people of Siaya and Busia in the west of the country, is funded with $5 million from the United Nations Framework Convention on Climate Change (UNFCCC). Other instruments, such as agri-environmental payments / payments for ecosystem services, access to financial resources and technology for sustainable forest management or taxes on food waste still form a gap in the policy package.

Only a few measures have been implemented in the area of **information instruments**. Knowledge and expertise development, education programs and awareness raising campaigns could help to make the sector more climate friendly. The *Socio-Economic Atlas of Kenya* to visualize the present, envisioning a sustainable future and the *ClimDev-Africa program*, which stands for Climate for Development in Africa, and which is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (ECA) and the African Development Bank (AfDB), were implemented here.

The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex (Quicklink 4.9.5).

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Table 22: Kenya`s policy package (AFOLU sector)

Type of instrument	Status
Governance and planning instruments	• Kenya Forest Service, a state Corporation in the Ministry of Environment, Climate Change and Forestry (2007) • Forest Conversation and Management Act (2016) • Comprehensive Africa Agriculture Development Program (CAADP) • The National Forest Program (2016-2030) • The National Plan for achieving 30% tree cover by 2032 • 2023-2027 Strategic Plan • Campaign launched in 2022 to plant 15 billion trees by 2032 • National Spatial Plan 2015-2045 • Community Land Act • Lake Victoria Environmental Management Project (LVEMP) • The Climate for Development in Africa (ClimDev-Africa) Program • Kenya Climate Smart Agriculture Strategy 2017-2026 • Agricultural Sector Development Strategy • Agricultural Productivity and Agribusiness Project • Kenya's National Wildlife Strategy 2030
Regulatory instruments	• National Climate Change Action Plan • Forest Conversation and Management Act • Agriculture Sector Transformation and Growth Strategy • Geothermal Development Policy • Land Use Planning and Management Frameworks
Market-based instruments	• Project to strengthen climate resilience in the Lake Victoria Basin.
Information instruments	• Socio-Economic Atlas of Kenya visualizing the present, envisioning a sustainable future • The Climate for Development in Africa (ClimDev-Africa) Program

4.6.4 How to strengthen national-sectoral climate policy

The policy package for the AFOLU sector is not yet very advanced and has a clear focus on planning and governance instruments. There are also challenges in the policy package due to weak policies, poor coordination and collaboration between institutions and weak enforcement. The financing of measures is also still inadequate and should be expanded. The country needs to transform its agricultural systems to make it more resilient while minimising greenhouse gas emissions.

The Kenya Climate-Smart Agriculture Program (2015–2030) will be crucial in this context to implement measures to reduce greenhouse gas emissions: Agriculture is the primary industry in Kenya So anything positive or negative happening in this space is crucial to the national economy.

To strengthen the existing policies, increasing financial and technical support is imperative. Many of the challenges in the AFOLU sector stem from insufficient funding and lack of access to advanced technologies. A large part of the funding is conditional on international support (NDC Partnerships, https://ndcpartnership.org/country/ken) (Climateworks Foundation, 2021). The government should work towards securing more climate finance. Additionally, creating incentives for private sector investments in sustainable land management practices would help bridge the funding gap. Providing farmers and land managers with access to modern technologies and training programs would improve productivity and sustainability while ensuring that input on the National Climate Change Fund addresses the unique needs of the agricultural sector. These initiatives could include climate-smart agriculture techniques, efficient water management systems, and renewable energy solutions tailored for

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agricultural use.

4.7 Conclusion

Kenya has significantly increased its electrification rate in recent years while investing heavily in renewable resources such as solar, geothermal, hydropower and wind. Despite its low emissions (0.1% globally), climate change poses a significant threat to the country's economy, costing between 3 to 5% of GDP each year. Kenya has adopted an Energy Transition and Investment Plan focused on decarbonisation. The plan requires significant investment and is underpinned by strong governance and supportive policies.

Kenya is facing the challenge of rising GHG emissions amidst a growing population and increasing economic activities. The country is targeting a 32% GHG emission reduction compared to BAU by 2030, in line with its Nationally Determined Contribution (NDC) under the Paris Agreement, aiming for a low-carbon, climate-resilient development pathway. Although the country is rated "almost sufficient" by the Climate Action Tracker, plans to introduce coal power by 2040 could impede its green energy goals, even as it aims for 100% renewable energy by 2030 and explores green hydrogen by 2040.

Kenya has established policy options for climate risk management to enhance mitigation mechanisms and adaptation capacities. The country has ratified the Paris Agreement and developed a Climate Change Act and a National Adaptation Plan (NAP). The 2010 Constitution of Kenya and the National Climate Change Response Strategy are some of the fundamental legal and institutional documents that address climate change management. However, there are several enablers and barriers that need to be considered. This report highlights sector-specific enablers and barriers in Kenya's industry, energy, building, transport, land-use sectors and how they affect current mitigation efforts. Some enablers include the existence of significant renewable energy potential, the introduction of a reforestation program to enhance efforts toward increasing tree cover, and increased collaboration with national and international organisations. On the other hand, land and environmental degradation, lack of climate proof infrastructure and the increase in fossil fuel demand, particularly in the transport sector, are some of the barriers identified.

The following are some of the sectoral policies and initiatives that are relevant to climate change mitigation and adaption: The Least Cost Power Development Plan (2021-2030), Kenya Climate Smart Agriculture Strategy, Forest Conservation and Management Act of 2016 and the National Forest Programme (2016–2030), Vision 2030, Wildlife Conservation and Management Act, 2013, The National Drought Management Authority Act, 2016, The Kenya Water Act, 2016, Draft Energy and Petroleum Policy, 2015, the Renewable Energy and Energy Efficiency Regulations 2012, Integrated National Transport Policy, National Solid Waste Management Bill, 2017, Greening initiatives were implemented in different sectors, and National Spatial Plan 2015-2045.

To strengthen national sectoral climate policy, a multifaceted approach is proposed, encompassing efforts directed to financing, energy, agriculture, capacity building, and institutional frameworks. Initiatives include establishing a National Climate Change Fund for better mobilisation and disbursement of climate finance, enhancing access to funds for energy efficiency audits, implementing fiscal incentives for renewable energy, and revising the Feed-in Tariff (FiT) policy for more reliability in renewable energy revenues. The strategy also emphasises the importance of supporting the agricultural sector with climate-friendly technologies, enhancing climate change awareness and resilience through sector-specific trainings, and fostering better coordination among agencies. It also proposes to strengthen the monitoring, evaluation, and legislative process for climate action, and to promote integrated climate considerations in policy, planning, and investments.

4.8 Bibliography

- Abuodha, J. O. Z. (2002). Environmental Impact Assessment of the Proposed Titanium Mining Project in Kwale District, Kenya. *Marine Georesources & Geotechnology, 20*(3), 199–207. https://doi.org/10.1080/03608860290051895

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- Afrik21. (2021). *KENYA: $5m to build climate resilience in the Lake Victoria Basin*. https://www.afrik21.africa/en/kenya-5m-to-build-climate-resilience-in-the-lake-victoria-basin/
- Akinyi Addero, C. (2023). *Energy Taxes: A Comparison of Their Levying in Developing and Developed Countries*. https://www.kesra.ac.ke/energy-taxes-issue14-april-2023/
- Ambani, B. (2023). *Hydropower generation at record low on drought* [NATION Media Group]. https://nation.africa/kenya/business/hydropower-generation-at-record-low-on-drought-4155806
- Blair, H., & Wekongo, A. (2020). *Campaign to Raise Awareness for Kenya Energy Label*. CLASP. https://www.clasp.ngo/updates/clasp-launches-kenya-energy-label-campaign/
- Bomett, M., Wambua, J., & Mwinzi, A. (2021). *Building, Mining & Construction. Sector Profile*. https://kam.co.ke/wp-content/uploads/2021/04/Buildind-and-Construction-sector-2020.pdf
- Business Today. (2023). *Power Bills Set to Fall as Kenya Retires Expensive Diesel Plant*. https://businesstoday.co.ke/power-bills-set-to-fall-as-kenya-retires-expensive-kipevu-1-diesel-plant/
- CA Global. (n.d.). *Kenya Rare Earth Minerals*. https://www.caglobalint.com/post/kenya-rare-earth-minerals-1/
- Climate Action Tracker. (2022a). *Kenya Country Summary*. https://climateactiontracker.org/countries/kenya/
- Climate Action Tracker. (2022b). *Policies & action*. https://climateactiontracker.org/countries/kenya/policies-action/
- Climate Action Tracker. (2022c). *Policies & action*. https://climateactiontracker.org/countries/kenya/policies-action/
- ClimateWatch. (2023). *Kenya*. https://www.climatewatchdata.org/countries/KEN
- Climateworks Foundation. (2021). *Kenya's enhanced NDC promises fast action on super pollutants*. https://www.climateworks.org/blog/kenyas-enhanced-ndc-promises-fast-action-on-super-pollutants/
- Copenhagen Centre & Building Efficiency Accelerator. (2018a). *Energy Efficiency in Buildings Kenya*. https://c2e2.unepccc.org/wp-content/uploads/sites/3/2019/07/2018-10-ee-in-buildings-kenya-web.pdf
- Copenhagen Centre, & Building Efficiency Accelerator. (2018b). *Energy Efficiency in Buildings Kenya*. https://c2e2.unepccc.org/wp-content/uploads/sites/3/2019/07/2018-10-ee-in-buildings-kenya-web.pdf
- Covenant of Mayors. (2023). *Mombasa County embraces sustainable energy solutions*. https://comssa.org/en/news/mombasa-county-empowering-sustainable-energy-solutions
- Domingo, E. (2023). *The Achilles' heel of Kenya's growing digital economy*. https://ecdpm.org/work/achilles-heel-kenyas-growing-digital-economy
- EDGE. (n.d.). *KENYA GREEN BUILDING MARKET SNAPSHOT 2020*. Retrieved 27 October 2023, from https://edgebuildings.com/wp-content/uploads/2022/04/IFC0077-2021-Kenya-Green-Building-Market-Maturity-Sheet_FIN.pdf
- EDGE. (2023). *KENYA GREEN BUILDING MARKET SNAPSHOT 2020*. https://edgebuildings.com/wp-content/uploads/2022/04/IFC0077-2021-Kenya-Green-Building-Market-Maturity-Sheet_FIN.pdf
- EMBER. (2024). *Africa. Electricity access remains an urgent problem across the continent*. https://ember-climate.org/countries-and-regions/regions/africa/
- Energy & Petroleum Regulatory Authority. (2023). *Energy & Petroleum Statistics Report for the financial year ended 30th June 2023*. https://publicsectormag.net/wp-content/uploads/2023/12/Energy-and-Petroleum-Stats-Report-2023-1.pdf

Funded by the European Union

- Energy & Petroleum Regulatory Authority. (2024). *Bi-Annual & Petroleum Statistics Report Financial Year 2023/2024*. https://www.epra.go.ke/bi-annual-energy-petroleum-statistics-report-financial-year-2023-2024/
- EnergyCapital&Power. (2024). *Kenya Power Unveils EV Market Expansion Plan*. https://energycapitalpower.com/kenya-power-electric-vehicles-ev-plan/
- ENSight. (2023). *The Carbon Credit Trading and Benefit Sharing Bill, 2023*. https://www.ensafrica.com/news/detail/7447/the-carbon-credit-trading-and-benefit-sharing?utm_source=mondaq&utm_medium=syndication&utm_content=articleoriginal&utm_campaign=article
- EPRA. (n.d.-a). *Electric Mobility*. https://renewableenergy.go.ke/electric-mobility/
- EPRA. (n.d.-b). *User Manuals*. Energy and Petroleum Regulatory Authority. Retrieved 27 October 2023, from https://www.epra.go.ke/services/energy-efficiency-project/user-manuals/
- ESI Africa. (2023). *Kenya: Major plan for roll-out of electric vehicles, infrastructure*. https://www.esi-africa.com/business-and-markets/kenya-major-plan-for-roll-out-of-electric-vehicles-infrastructure/
- Food and Agriculture Organization of the United Nations. (2024). *Land Use*. https://www.fao.org/faostat/en/#data/RL
- GET.invest. (n.d.). *Kenya*. https://www.get-invest.eu/market-information/kenya/market-segments/
- GOGLA. (2021). *A big win for Kenya: Government reinstates VAT exemption on renewable energy products*. https://www.gogla.org/a-big-win-for-kenya-government-reinstates-vat-exemption-on-renewable-energy-products/
- Government of Kenya. (2018). *National Climate Change Action Plan 2018-2022 (NCCAP)*. https://climate-laws.org/document/national-climate-change-action-plan-2018-2022-nccap_a381
- Green Finance Platform. (2019). *The Kenya Green Bond Programme | Green Finance Platform*. https://www.greenfinanceplatform.org/policies-and-regulations/kenya-green-bond-programme
- Ho, M. (2019). *Kenya: The key economic hub in East Africa.* https://research.hktdc.com/en/article/MzQ4NDcwNjc2
- IEA. (2019a). *Africa Energy Outlook 2019*.
- IEA. (2019b). *Africa Energy Outlook 2019*.
- International Energy Agency. (n.d.). *Kenya*. https://www.iea.org/countries/kenya/emissions
- International Food Policy Research Institute. (2023). *From Climate Risk to Resilience: Unpacking the Economic Impacts of Climate Change in Kenyq*. https://africanclimatefoundation.org/wp-content/uploads/2023/11/800832-ACF-Kenya-country-note-04.pdf
- International Trade Administration. (2022). *Kenya—Country Commercial Guide*. https://www.trade.gov/knowledge-product/kenya-market-overview
- International Trade Administration. (2024). *Energy—Electric Power Systems*. https://www.trade.gov/country-commercial-guides/kenya-energy-electrical-power-systems
- IRENA. (2023). *Kenya Spearheads Landmark Renewable Energy Initiative at Africa Climate Summit*. https://www.irena.org/News/pressreleases/2023/Sep/Kenya-Spearheads-Landmark-Renewable-Energy-Initiative-at-Africa-Climate-Summit#:~:text=Nairobi%2C%20Kenya%2C%204%20September%202023,boost%20renewable%20energy%20in%20Africa.
- Kahlen, L., De Vivero, G., & Hecke, J. (2021). *Kenya Power's Decarbonising the Energy Mix Initiative.*

Funded by the European Union

Scoping Study. https://newclimate.org/sites/default/files/2022-03/a2aii-kplc_scopingstudy.pdf

- Karanja, J. (2021). *An Assessment of Kenya's Regulatory Framework on Growth of Wholesale and Retail Firms* (Kenya Institute for Public Policy Research and Analysis. KIPPRA Discussion Paper No 257, 2021). https://repository.kippra.or.ke/bitstream/handle/123456789/3946/DP257.pdf?sequence=1&isAllowed=y
- Kenya Building Research Centre. (n.d.). *Climate Change Action Plan. Green Building Agenda*. https://kbrc.publicworks.go.ke/climate-change-action-plan
- Kenya Forest Service. (n.d.). *Strategic Plan 2023-2027*. https://afr100.org/sites/default/files/2024-05/26%20March%202024%20Kenya%20Forest%20Strategic%20Plan.pdf
- Kenya National Bureau of Statistics. (2024). *Economic Survey 2024. Providing, managing and promoting quality statistics*. https://www.knbs.or.ke/wp-content/uploads/2024/05/2024-Economic-Survey.pdf
- Kenyaplex. (n.d.). *Colleges and universities offering Craft Certificate in Solar Installation(Solar Installation) in Kenya*. Retrieved 27 October 2023, from https://www.kenyaplex.com/courses/6671-craft-certificate-in-solar-installation-solar-installation.aspx
- Kimeu, C. (2024). *Kenya's first nuclear plant: Why plans face fierce opposition in country's coastal paradise* [The Guardian]. https://www.theguardian.com/global-development/article/2024/jun/17/kenya-plans-first-nuclear-power-plant-kilifi-opposition-activists
- Kiplagat, J. K., Wang, R. Z., & Li, T. X. (2011). Renewable energy in Kenya: Resource potential and status of exploitation. *Renewable and Sustainable Energy Reviews*, *15*(6), 2960–2973. https://doi.org/10.1016/j.rser.2011.03.023
- Kleinman Center for Energy Policy. (2023). *Kenya's Clean Energy Transition Gets a Boost from Solar Power*. https://kleinmanenergy.upenn.edu/news-insights/kenyas-clean-energy-transition-gets-a-boost-from-solar-power/#:~:text=Renewable%20energy%20sources%20generate%20over,percent%20clean%20energy%20by%202030
- KPMG. (2016). *Analysis of the Mining Act 2016*. https://assets.kpmg.com/content/dam/kpmg/ke/pdf/kpmg-mining-act-2016-analysis.pdf
- Martius, C., Guérin, L., Pingault, N., Mwambo, F., Wassmann, R., Cramer, L., & Shikuku, K. (2023). *Food systems emissions in Kenya and their reduction potential A country profile* [Occasional Paper 7. Bogor, Indonesia: Center for International Forestry Research (CIFOR); and Nairobi, Kenya: World Agroforestry (ICRAF).]. https://www.cifor-icraf.org/publications/pdf_files/OccPapers/CIFOR-ICRAF-OP-7.pdf
- Mbandi, A. M., Malley, C. S., Schwela, D., Vallack, H., Emberson, L., & Ashmore, M. R. (2023). Assessment of the impact of road transport policies on air pollution and greenhouse gas emissions in Kenya. *Energy Strategy Reviews*, *49*, 101120. https://doi.org/10.1016/j.esr.2023.101120
- Ministry of Agriculture, Livestock and Fisheries. (2017). *Kenya Climate Smart Agriculture Strategy 2017-2026*. https://adaptation-undp.org/sites/default/files/resources/kenya_climate_smart_agriculture_strategy.pdf
- Ministry of Energy. (2020a). *Bioenergy Strategy 2020-2027*. https://www.energy.go.ke/sites/default/files/KAWI/Other%20Downloads/Bioenergy-strategy-final-16112020sm.pdf
- Ministry of Energy. (2020b). *Kenya National Energy Efficiency and Conservation Strategy*.
- Ministry of Energy. (2020c). *Kenya National Energy Efficiency and Conservation Strategy*.
- Ministry of Energy. (2022). *Behaviour Change and Communication Strategy for Promoting Clean Cooking in Kenya*.

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the European Union

https://energy.go.ke/sites/default/files/KAWI/Other%20Downloads/BCC%20Strategy%20for%20Promoting%20Clean%20Cooking%20%20Kenya(1).pdf

- Ministry of Energy & Petroleum. (2023a). *Kenya Energy Transition & Investment Plan 2023—2050*. https://energy.go.ke/sites/default/files/KAWI/Kenya-ETIP-2050%202.pdf
- Ministry of Energy & Petroleum. (2023b). *Kenya Energy Transition & Investment Plan (ETIP)*. https://energy.go.ke/sites/default/files/KAWI/Other%20Downloads/Kenya%20ETIP%202050%20-%20full%20doc_final%20231023.pdf
- Ministry of Energy & Petroleum. (2023c). *Nuclear*. https://www.energy.go.ke/nuclear
- Ministry of Environment and Forestry. (2018). *National Climate Change Action Plan 2018-2022. Volume 3: Mitigation Technical Analysis Report*. https://climate-laws.org/documents/national-climate-change-action-plan-ncapp-2018-2022-volume-iii-mitigation-technical-analysis-report_f654?id=national-climate-change-action-plan-2018-2022-nccap_a381
- Ministry of Environment and Forestry. (2020). *Kenya's Updated Nationally Determined Contribution (NDC)*. https://unfccc.int/sites/default/files/NDC/2022-06/Kenya%27s%20First%20%20NDC%20%28updated%20version%29.pdf
- Ministry of Environment and Forestry. (2021). *National Climate Change Action Plan 2018-2022. Second Implementation Status report for th FY 2019/2020*. https://napglobalnetwork.org/wp-content/uploads/2022/01/napgn-en-2022-kenya-NCCAP-2018-2022-Implemantation-Status-Report.pdf
- Ministry of Environment and Natural Resources. (2016a). *Kenya National Adaptation Plan 2015-2030 Enhanced climate resilience towards the attainment of Vision 2030 and beyond*. https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Kenya_NAP_Final.pdf
- Ministry of Environment and Natural Resources. (2016b). *Kenya Strategic Investment Framework for Sustainable Land Management*. https://faolex.fao.org/docs/pdf/ken198041.pdf
- Ministry of Environment and Natural Resources. (2016c). *Sessional Paper No. 3 of 2016 National Climate Change Framework Policy*. https://www.undp.org/sites/g/files/zskgke326/files/migration/ke/0540af2c4328bfbad3dd0f5da6f817f450428f6bb96dc4e2c5d9647085794f93.doc#:~:text=The%20objectives%20of%20this%20Policy,the%20national%20and%20county%20levels.
- Ministry of Environment and Natural Resources. (2017). *Kenya's Nationally Determined Contribution (NDC) Update of Kenya's Emission Baseline Projections and Impact on NDC Target.*
- Ministry of Foreign Affairs. (2018). *Final Energy report Kenya*. https://www.rvo.nl/sites/default/files/2019/01/Final-Energy-report-Kenya.pdf
- Ministry of Lands and Physical Planning. (n.d.). *National Spatial Plan 2015-2045*. https://vision2030.go.ke/wp-content/uploads/2018/05/National-Spatial-plan.pdf
- Ministry of Mining, Blue Economy and maritime Affairs. (n.d.). *Mining Projects*. https://mibema.go.ke/ministry-projects
- Ministry of Roads and Transport. (2024a). *Dawn Of New Era as Ministry Launches Draft Electric Mobility Policy*. https://www.transport.go.ke/dawn-new-era-ministry-launches-draft-electric-mobility-policy
- Ministry of Roads and Transport. (2024b). *Draft National E-Mobility Policy, Kenya*. https://transport.go.ke/sites/default/files/Draft%20National%20e-Mobility%20Policy_For%20Circulation%2027.03.2024.pdf
- Ministry of Roads and Transport. (2024c). *Updated Integrated National Transport Policy*. https://transport.go.ke/sites/default/files/INTP%20REVIEWED%20MARCH%202024%20SESA.pdf

Funded by the European Union

- Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works. (2020). *Transport Sector Climate Change Annual report 2019 2020*. https://changing-transport.org/wp-content/uploads/Kenya-transport-annual-report_Jan-2021.pdf
- Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works. (2021). *Transport sector in Kenya's Nationally Determined Contribution*. https://changing-transport.org/wp-content/uploads/2021_GIZ_Factsheet_Transport-in-Kenyas-NDC.pdf
- Munene, M., Odongo, J., & Nyambane, A. (2019a). *ENERGY EFFICIENCY IN KENYA PUBLIC AWARENESS, STRATEGIES, CHALLENGES AND OPPORTUNITIES*.
- Munene, M., Odongo, J., & Nyambane, A. (2019b). *ENERGY EFFICIENCY IN KENYA PUBLIC AWARENESS, STRATEGIES, CHALLENGES AND OPPORTUNITIES*.
- Murphy, D., & Harris, M. (2014). *Policy and Regulatory Barriers in Kenya's National Climate Change Action Plan: Areas for Private Sector Action.* https://cdkn.org/sites/default/files/files/Policy-Regulation-Review.pdf
- Murungi-Omondi, N. (2024). *Kenya's Carbon Markets: The Goose That Lays The Golden Egg?* https://www.ifcreview.com/articles/2024/january/kenya-s-carbon-markets-the-goose-that-lays-the-golden-egg/
- National Environment Management Authority. (n.d.). *Towards 10 percent forest cover*. https://www.nema.go.ke/index.php?option=com_content&view=article&id=306:towards-10-percent-tree-cover&catid=10&Itemid=462
- Nduba-Banja, C., Mbithi, K., Arrumm, M., & Butt, Y. (2023). *Kenya: Development of Carbon Project and Trading Legal Framework: Enactment of the Climate Change (Amendment) Act, 2023*. https://bowmanslaw.com/insights/kenya-development-of-carbon-project-and-trading-legal-framework-enactment-of-the-climate-change-amendment-act-2023/
- NewClimate Institute, & EED Advisory. (2021). *The Kenyan Cooking Sector—Opportunities for Climate Action and Sustainable Development.* https://ambitiontoaction.net/wp-content/uploads/2021/07/A2A_Kenya_CleanCookingStudy_July2021.pdf
- Newell, P., & Phillips, J. (2016). Neoliberal energy transitions in the South: Kenyan experiences. *Geoforum*, *74*, 39–48. https://doi.org/10.1016/j.geoforum.2016.05.009
- Nuclear Power & Energy Agency. (n.d.). *Welcome to NuPEA*. https://www.nuclear.co.ke/
- Obura, D. (2019). *Court stops construction of Kenya's coal power plant. Here's why* [The Conversation]. https://theconversation.com/court-stops-construction-of-kenyas-coal-power-plant-heres-why-119550
- OECD. (2022). *Pricing Greenhouse Gas Emissions Carbon Pricing in Kenya*. https://www.oecd.org/tax/tax-policy/carbon-pricing-kenya.pdf
- Okadia, F. (2023a). How EPRA Could Improve the Effectiveness of MEPs. *IEA Kenya*. https://ieakenya.or.ke/blog/how-epra-could-improve-the-effectiveness-of-meps/
- Okadia, F. (2023b). How EPRA Could Improve the Effectiveness of MEPs. *IEA Kenya*. https://ieakenya.or.ke/blog/how-epra-could-improve-the-effectiveness-of-meps/
- Phiri, A. T., Charimbu, M., Edewor, S. E., & Gaveta, E. (n.d.). *Socio-economic, Institutional and Environmental Enablers and Barriers to Climate Smart Agriculture Adoption and Scaling in Kenya, Malawi and Nigeria*. https://aec.afdb.org/en/papers/socio-economic-institutional-and-environmental-enablers-and-barriers-climate-smart-agriculture-adoption-and-scaling-kenya-malawi-and-nigeria-634
- Rapid Transition Alliance. (2022). *Doing development differently: How Kenya is rapidly emerging as Africa's renewable energy superpower*. https://rapidtransition.org/stories/doing-development-differently-

Funded by
the European Union

how-kenya-is-rapidly-emerging-as-africas-renewable-energy-superpower/

- Republic of Kenya. (2012). *Sessional Paper No. 9 of 2012 on the National Industrialization Policy Framework of Kenya 2012-2030 'Transforming Kenya into a globally competitive regional industrial hub'*. https://repository.kippra.or.ke/bitstream/handle/123456789/1037/the-national-industrialization-policy.pdf?sequence=3&isAllowed=y
- Republic of Kenya. (2023a). *The Carbon Credit Trading and Benefit Sharing Bill, 2023*. https://kwcakenya.com/wp-content/uploads/2023/08/Carbon-Credit-Trading-Bill-Eighth-draft.pdf
- Republic of Kenya. (2023b). *Transport Sector Climate Change Annual report 2021/2022*. https://transport.go.ke/sites/default/files/Transport%20Annual%20Report%20-Final%20Draft-After%20Comments-05-01-2024.pdf
- SEFA. (2021). *Development of a Utility-run SUPER ESCO in Kenya*. https://www.afdb.org/sites/default/files/documents/projects-and-operations/kenya_-_development_of_a_utility-run_super_esco_in_kenya_-_project_appraisal_report_-_sefa.pdf
- SEZ Authority. (n.d.). *The Kenya Vision 2023*. https://sezauthority.go.ke/
- Solarafrica. (n.d.). Solar Learning for Women. *Https://Solafrica.Ch/En/*. Retrieved 27 October 2023, from https://solafrica.ch/en/projects/solar-learning-for-women/
- Statista. (2021). *Share of the construction industry in Kenya's Gross Domestic Product (GDP) from 2016 to 2020*. https://www.statista.com/statistics/1301341/construction-as-a-share-of-gdp-in-kenya/
- Statista. (2022). *Kenya: Share of economic sectors in the gross domestic product (GDP) from 2012 to 2022*. https://www.statista.com/statistics/451143/share-of-economic-sectors-in-the-gdp-in-kenya/
- Statista. (2024). *Share of the population with access to electricity in Kenya from 2012 to 2021*. https://www.statista.com/statistics/1221124/population-with-access-to-electricity-in-kenya/
- The Cable. (2023, August 15). *Kenya reinstates fuel subsidy for 30 days to curb soaring prices*. TheCable. https://www.thecable.ng/kenya-reinstates-fuel-subsidy-for-30-days-to-curb-soaring-prices
- The National Treasury and Economic Planning. (n.d.). *National Tree Planting Initiative Launch*. https://www.treasury.go.ke/national-tree-planting-intiative-launch/
- The national treasury and economic planning. (2022). *DRAFT NATIONAL GREEN FISCAL INCENTIVES POLICY FRAMEWORK*.
- The National Treasury and Economic Planning. (2023). *AERC 59th December 2023 Biannual Plenary Session*. https://www.planning.go.ke/wp-content/uploads/2023/11/Opening-Remarks-PS-James-Muhati-26-November-2023_Final.pdf
- Trium Limited Consultancy. (2024). *Mitigating the Impact of Flooding in Kenya: A Call to Action for Sustainable Development and Green Building Practices.* https://www.linkedin.com/pulse/mitigating-impact-flooding-kenya-call-action-3p41f/
- UNCCD. (2023). *Global Drought Snapshot.* https://www.unccd.int/sites/default/files/2023-12/Global%20drought%20snapshot%202023.pdf.
- UN Environment Programme. (2021). *Kenya kickstarts a Super ESCO for boosting energy efficiency*. UNEP-CCC. https://unepccc.org/kenya-kickstarts-a-super-esco-for-boosting-energy-efficiency/
- UN Environment Programme. (2022a). *2022 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION*.
- UN Environment Programme. (2022b). *2022 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION*.

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the European Union

- University of Cape Town. (2019). *Barriers and enablers to effective climate adaptation through the eyes of pastoral communities in Kenya*. https://assar.uct.ac.za/articles/2019-01-30-barriers-and-enablers-effective-climate-adaptation-through-eyes-pastoral-communities-kenya
- Wiesmann, U., Kiteme, B., Mwangi, Z., Samoei, P., Kipruto, S., Njuguna, E., Engesser, M., Trachsel, L., Wanyonyi, M., Nyarunda, V., Waweru, P., Kamula, G., Osoro, H., Musyimi, J., Odhiambo, E., Bowen, R., Peter, E., Ott, C., Lörcher, S., & Epprecht, M. (2014). *Socio-economic atlas of Kenya: Depicting the national population census by county and sub-Location.*
- World Bank, & CIAT. (2015). *Climate-Smart Agriculture in Kenya. CSA Country Profiles for Africa, Asia, and Latin America and the Caribbean Series*. https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA%20KENYA%20NOV%2018%202015.pdf
- World Bank Group. (2022). *Boosting Equitable Development as Kenya Strives to Become an Upper Middle-Income Country—Press Release*. https://www.worldbank.org/en/news/press-release/2022/11/22/-boosting-equitable-development-as-kenya-strives-to-become-an-upper-middle-income-country
- World Bank Group. (2023a). *Action Against Climate Change: Seizing opportunities in a decarbonizing world*. https://www.worldbank.org/en/news/feature/2023/06/13/action-against-climate-change-afe-seizing-opportunities-in-a-decarbonizing-world
- World Bank Group. (2023b). *Kenya Economic Update: A Balancing Act—Opportunities for Making Growth More Inclusive During Challenging Times*. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099121323045531282/p1797690868fd30930907305dfbdc54bcda
- World Resources Institute. (2023). *These 10 Countries Are Phasing Out Coal the Fastest*. https://www.wri.org/insights/countries-phasing-out-coal-power-fastest
- World Resources Institute. (2024). *A New Solution to Power Africa: Productive Use of Renewable Energy*.

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4.9 Annex

4.9.1 Industry

4.9.1.1 National-sectoral mitigation enablers and barriers

Table 23: Overview of enablers and barriers (industry sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Kenya's domestic market: over 50 million people; the country is a leading economy in sub-Saharan Africa: economic, commercial, financial, and logistics hub of East Africa (International Trade Administration, 2022) Variety of geographical features, including savannas, the Great Rift Valley, mountain highlands, and the coastline along the Indian Ocean Among the leading producers of high value gemstones including ruby, tsavorite, sapphire, spinel and others	Availability and accessibility of renewable resources like solar, wind, hydropower, and geothermal energy. Additional challenges include inadequate infrastructure, high initial costs, limited access to financing, and a shortage of local technical expertise. Policy and regulatory uncertainties, land use conflicts, and market structure issues further complicate the adoption process.
Environmental-ecological feasibility	Kenya possesses significant underground wealth, with around 970 minerals nationwide incl. base metals, precious metals, rare earth and radio-active minerals Mrima Hill, in the coastal county of Kwale, has one of the top five rare earth deposits in the world; region also contains niobium deposits projected to have a value of $35 billion (CA Global, n.d.)	Huge environmental risks with regard to mining activities; e.g. when toxic chemicals are used in heavy mineral separation processes in vulnerable ecological systems (e.g. Wasini channel; coastal area with fragile coral reefs and wildlife as well as crucial part of the economy as it supplies a living for a large number of people on the coastline) (Abuodha, 2002) Beside mining activities, deforestation, soil erosion, flooding, poaching, and pollution can also be consequences of industrial activities
Technological feasibility	Kenya is among African states a leader with regard to ICT (information and communication technologies); digital economy is expected to contribute to 9.24% of country's GDP by 2025 (Domingo, 2023)	Several governmental and private initiatives addressing ICT skills, but focus mainly on literacy and basic skills; not enough for rapidly growing society with high youth unemployment
Economic feasibility	Strong flow of foreign direct investment, particularly in the finance and insurance, renewable energy, trade, manufacturing, communication, and education sectors. There are a variety of private-equity entities present in Kenya, including multilateral institutions, such as the International Finance Corporation (IFC), the African Development Bank, and by bilateral bodies, including the U.S. International Development Finance Corporation (DFC) (International Trade	High initial investment costs for renewable energy projects and limited access to affordable financing options pose significant challenges. The lack of financial incentives and supportive government policies further discourages investment. Additionally, market structure issues, such as the dominance of established energy providers, and uncertainty in future industrial energy demand affect the attractiveness and scalability of renewable energy projects.

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	Administration, 2022; World Bank Group, 2023b)	
Sociocultural feasibility	Young, growing and educated English-speaking population with a high fluency in technology Transformation of KIRDI into a 'world class research institution' (Kenya Vision 2030): capacity building initiatives, upgrading equipment of the institute	Kenya must ensure that benefits of economic growth are more widely shared and sustained long term; poor and rural households have not participated much in Kenya's GDP growth (poverty rate: 38.6% of population in 2021) (World Bank Group, 2023b) Inequality of educational and other opportunities, weak job creation, and persistently low productivity growth; smaller share of women working in the industry sector
Institutional feasibility	Strong bilateral and multilateral trade relationships: Kenya is a member of the East African Community (EAC), Common Market for Eastern and Southern Africa (COMESA), and the Africa Continental Free Trade Area (AfCFTA) (International Trade Administration, 2022; World Bank Group, 2023b) Government has initiated pro-business reforms including regulations on starting businesses, obtaining access to electricity, registering property, protecting minority investors, and streamlining the business insolvency process (International Trade Administration, 2022; World Bank Group, 2023b) Special Economic Zones (Part of Kenya Vision 2030): Key enabler to the manufacturing sector which aims at delivering industrialisation and social transformation for investment attraction (SEZ Authority, n.d.)	Regulatory uncertainties, fragmented policies, and insufficient government incentives. There is often a lack of coordination among various governmental agencies, leading to overlapping and inconsistent regulations that hinder project development. Additionally, inadequate support for capacity building and technical training limits the ability of institutions to effectively manage and implement renewable energy initiatives.

4.9.1.2 Current status of national-sectoral climate policy

Table 24: Overview of policies and measures (industry sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**Constitution of Kenya 2010:** Provides guidance on the use and protection of natural resources. Sustainable development, a key aspect of trade development, is enshrined in the Constitution as a core	**Positives:** National Industrialisation policy framework: has been developed through a consultative process involving the public sector, private sector, civil society, development partners and non-governmental stakeholders; therefore, takes into account a broad variety of

	national value and principle of governance (Karanja, 2021) **Mining Act of 2016; Mining Bill 2015:** Vests ownership of mineral resources in the government as trustee of the people of Kenya **Kenya Vision 2030**: Aim to create "a newly-industrialising, middle income country providing a high quality of life to all its citizens in a clean and secure environment" (Karanja, 2021) **National Industrialisation policy framework**: In line with the Vision 2030 aspirations; "The overarching policy objective is to enable the industrial sector to attain and sustain annual sector growth rate of 15% and make Kenya the most competitive and preferred location for industrial investment in Africa leading to high employment levels and wealth creation"	stakeholders; recognises the role of agriculture for the country, the role of micro and small as well as medium and large industries, training and education of people. Includes monitoring and evaluation. **Challenges**: "The challenges and weaknesses affecting Kenya's Industrial sector include: low value addition; Inadequate market information resulting to limited market access and narrow export base; high cost of infrastructural services leading to uncompetitiveness; inadequate skilled industrial human resource; limited access to affordable long term finance; high cost of industrial land; limited industrial subcontracting linkages; influx of counterfeit, dumping and substandard goods thereby reducing production capacities; limited technology transfer; and low attraction of local and foreign direct investment." (Karanja, 2021)
Regulatory instruments (Karanja, 2021)	Kenya adopted the **Energy (Appliances' Energy Labelling and Performance) Regulations** in 2016. The Energy and Petroleum Regulatory Authority (EPRA) maintains a register of appliances that meet the MEPS, covering four main categories; refrigerators, air conditioners, motors and fluorescent lamps; it is illegal to sell appliances in the Kenyan market that do not meet these specified energy efficiency standards. This also leads to positive developments on the supply side as manufacturers and retailers are given the incentive to manufacture and sell energy-efficient products for the Kenyan market. (Okadia, 2023a)	**Positives:** Comprehensive framework aimed at addressing climate change and promoting renewable energy technologies. Policies like the Climate Change Act of 2016 and the National Climate Change Action Plan provide clear guidelines and targets for reducing greenhouse gas emissions. These regulations have created a supportive environment for renewable energy projects, attracting both local and international investments. Additionally, the policy emphasis on integrating climate change considerations into national and sectoral development plans has increased awareness and action across various industries. These merits demonstrate Kenya's commitment to sustainable development and its proactive approach to mitigating climate change impacts. **Challenges:** Numerous regulatory frameworks at both county and national Government levels, along with other regulatory agencies overseeing business registration, licensing, and trading permits. County governments impose varying levies and fees, hindering the sector's full exploitation of wholesale and retail trade opportunities across different counties. These regulatory complexities limit growth and

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		investment potential within the country's trade sector (Karanja, 2021)
Market-based instruments	**Climate Change (Amendment) Act, 2023;** will regulate carbon projects and trading in Kenya; coupled with the possible introduction of a carbon tax and environmental excise taxes to combat emissions (ENSight, 2023) **Carbon Credit Trading and Benefit Sharing Bill, 2023 (the "Carbon Trading Bill");** bill aims to establish a regulatory framework for carbon credit trading and benefit sharing, create a Carbon Trading and Benefit Sharing Authority, regulate carbon trading businesses, and set up a Carbon Credit Trading Tribunal 30/08/2024 15:40:00	**Positives:** These policies have introduced mechanisms such as feed-in tariffs and tax incentives that encourage investment in renewable energy projects by making them financially viable and attractive. The use of market-based instruments has stimulated private sector participation and innovation in the renewable energy sector, leading to increased capacity and diversity of energy sources. Additionally, these instruments help create a competitive market environment, driving down costs and improving efficiency. Overall, market-based policies have been effective in mobilizing resources and fostering a transition towards sustainable energy solutions in Kenya. **Challenges:** The majority of unpriced emissions from energy use were from the industry sector (OECD, 2022)
Information instruments	**Kenya National Cleaner Production Centre (KNCPC):** Established in July 2000 as part of the global UNEP/UNIDO National Cleaner Production Centre program with a mission to build national capacity for Resource Efficient and Cleaner Production application in enterprises through awareness creation, training, project implementation, and policy advice for increased enterprise productivity and sound environmental management.	**Positives:** These policies emphasize the dissemination of critical information, raising awareness, and educating stakeholders about the benefits and opportunities of renewable energy. Initiatives such as public awareness campaigns, training programs, and information-sharing platforms have been instrumental in building technical capacity and fostering community support for renewable energy projects. By improving access to relevant data and best practices, these information instruments enhance decision-making processes and empower industries and communities to adopt sustainable energy solutions. Consequently, they play a vital role in driving Kenya's transition towards a more resilient and low-carbon economy. **Challenges:** Despite efforts to disseminate information and raise awareness, there are gaps in reaching all relevant stakeholders, particularly in remote and rural areas. Limited access to up-to-date and reliable data hampers informed decision-making and project planning. Additionally, the lack of coordinated and consistent communication strategies among government agencies and stakeholders leads to fragmented information dissemination.

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		Insufficient technical training and educational programs further limit the capacity of industries and communities to implement renewable energy solutions effectively.

4.9.2 Energy

4.9.2.1 National-sectoral mitigation enablers and barriers

Table 25: Overview of enablers and barriers (energy sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Kenya possesses significant renewable energy potential, including geothermal, wind, solar, biomass, and biofuels. harnessing of abundant renewable resources like solar, wind, and geothermal energy, which are crucial for effective climate change mitigation. By capitalizing on the country's favorable geophysical conditions, such as high solar irradiance, strong wind patterns, and significant geothermal potential, Kenya can significantly reduce its dependence on fossil fuels and lower greenhouse gas emissions. These efforts not only enhance the country's energy security and diversify its energy mix but also stimulate economic growth through the development of renewable energy infrastructure and technology. Leveraging geophysical advantages supports a sustainable transition to cleaner energy sources, aligning with broader climate goals and fostering long-term environmental benefits.	However, the full potential of these resources is hindered by geographic and infrastructural challenges. Solar and wind energy, while abundant in certain regions, require substantial land and infrastructure investments to harness effectively. Hydropower is seasonally dependent, and geothermal resources, predominantly in the Rift Valley, require significant upfront capital and technical expertise. Reductions in reservoir levels can decrease hydroelectricity generation, leading to higher prices and greater use of fossil fuels, which increases GHG emissions (Ministry of Environment and Natural Resources, 2016c), Also more than one-half of Kenya's households use wood fuel for cooking.
Environmental-ecological feasibility	Emphasis on integrating renewable energy technologies with sustainable environmental practices. By prioritizing the development of renewable sources like solar, wind, and geothermal, Kenya reduces reliance on fossil fuels, leading to lower greenhouse gas emissions and a smaller carbon footprint. These technologies generally have a lower environmental impact compared to conventional energy sources, contributing to the preservation of natural ecosystems and biodiversity. Additionally, the implementation of environmental assessments and best practices in project design helps mitigate	While renewable energy sources offer significant climate change mitigation advantages, their development can have environmental consequences. For example, large-scale solar farms and wind turbines may affect land use and wildlife habitats, while hydropower projects can impact river ecosystems and aquatic life. Geothermal energy, although less invasive, requires careful management to avoid issues like land subsidence and water contamination. Balancing environmental concerns and economic growth: given the predicted rising energy demand vs. controversial plans to generate electricity from coal

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	potential ecological disruptions, ensuring that renewable energy projects align with environmental conservation goals while supporting climate change mitigation efforts.	
Technological feasibility	Promotion and integration of advanced renewable energy technologies, which play a critical role in climate change mitigation. By adopting and adapting cutting-edge technologies such as efficient solar panels, wind turbines, and geothermal systems, Kenya can effectively harness its renewable energy resources and improve energy efficiency. Technological advancements also facilitate the reduction of greenhouse gas emissions and enhance the reliability and scalability of renewable energy projects. Furthermore, the focus on technological feasibility supports innovation, builds local expertise, and fosters a competitive renewable energy sector, ultimately contributing to a sustainable and low-carbon energy future.	Limited access to advanced and cost-effective renewable energy technologies, as well as a shortage of local expertise for their implementation and maintenance. High initial costs of technology and infrastructure can be prohibitive, and there may be difficulties in adapting international technologies to local conditions. Additionally, technological constraints such as inefficient energy storage solutions and inadequate grid integration capabilities can hinder the effective deployment of renewable energy projects. Losses in electricity transmission increased from 18% to 23% in 2020 , i(Government of Kenya, 2018)adequate capacity for integration of intermittent power generation in the national grid, inadequate LPG infrastructure for cylinder filling, storage, and distribution (Ministry of Environment and Forestry, 2018) are also strong barriers. Access to modern energy services is required to reduce biomass (charcoal and wood) fuel dependency.
Economic feasibility	Long-term cost benefits and economic growth potential associated with renewable energy technologies. By investing in renewable energy, Kenya can reduce its reliance on expensive fossil fuels and lower energy costs over time. The development of renewable energy projects can stimulate job creation, attract investment, and drive innovation in the sector. Additionally, renewable energy technologies offer the potential for stable and predictable energy prices, enhancing energy security and economic stability. These economic advantages contribute to the broader goal of climate change mitigation by making renewable energy a more viable and attractive option for sustainable development.	high initial investment costs for renewable energy projects and limited access to affordable financing options. The economic viability of these projects is often constrained by the substantial capital required for technology, infrastructure, and grid integration. Additionally, the lack of sufficient financial incentives and supportive policies can deter private sector investment. Market uncertainties and competition from established energy sources further complicate the economic landscape. Overcoming these challenges necessitates innovative financing mechanisms, enhanced government support, and policies that make renewable energy investments more attractive and economically feasible. It is imperative for Kenya to attain energy security and accessibility to address the increasing energy demand. Foreseeable supply gaps with regard to renewable energy, might be closed by continuous use of fossil fuels (Rapid Transition Alliance, 2022).

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Sociocultural feasibility	Greater community engagement and acceptance by involving local populations in the planning and implementation of renewable energy projects. Renewable energy initiatives can enhance energy access in remote or underserved areas, improve living standards, and create local job opportunities. Additionally, these projects often align with traditional values of environmental stewardship and sustainability, which can further boost community support and participation. Emphasizing sociocultural feasibility helps ensure that renewable energy transitions are inclusive, equitable, and supportive of broader social and cultural goals. With an exponentially growing population, the share of people with access to electricity is also rising as well (26% in 2014 to 76.54% in 2021) (Statista, 2024) Kenya has expanded energy generation across various scales, including utility-scale wind and solar farms as well as rural microgrids and a wide range of technologies and business models cater to diverse energy needs. This diversity ensures there is an appropriate energy solution available for every requirement in Kenya.	Potential resistance from local communities due to land use conflicts, cultural differences, or perceived threats to traditional lifestyles. Renewable energy projects can sometimes disrupt local practices or land use, leading to opposition or delays. Additionally, there may be a lack of local awareness or understanding of the benefits of renewable energy technologies, which can affect community buy-in and participation. Other barriers include the inability of population to meet the cost of electrification and inability of the government to meet the cost of extending its power grid
Institutional feasibility	The government, in cooperation with several development partners, is promoting energy efficiency improvements in multiple ways, including through enacting energy regulations and implementing programs and projects at the institutional level (Ministry of Energy, 2020b). The government has adopted several policies that have simplified access to finance for renewable energy projects.	Most local stakeholders and activities are related to increasing household energy access rather than energy efficiency (Ministry of Energy, 2020b). The current regulatory framework does not allow firms and individual customers to sell excess electricity back to the grid (Murphy & Harris, 2014). Counties vs Ministry of Energy conflict: Dispute over resource control and grid extension responsibilities (Newell & Phillips, 2016) • Influence of different stakeholders: Representation of energy technologies and socio-technical arrangements crucial in policy enactment. • Role of smaller business associations: Kenyan Renewable Energy Association (KEREA) advocating distinct viewpoints compared to larger bodies like KEPSA and KAM. • Industry associations' stance: Larger bodies favoring least-cost energy solutions, potentially overlooking renewable energy alternatives.

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4.9.2.2 Current status of national-sectoral climate policy

Table 26: Overview of policies and measures (energy sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**Kenya Energy Transition & Investment Plan (ETIP) 2023-2050:** Provides a harmonized roadmap for energy sector; sets the stage for the development of energy sector targets to be incorporated into future National Blueprints **Bioenergy Strategy 2020-2027:** Aims to promote bioenergy as a key sector for Kenya's economic development; provides guidelines and identifies interventions to develop and sustainably utilize bioenergy resources from 2020-2027 **Kenya National Adaptation Plan 2015-2030**: aims to consolidate the country's vision on adaptation supported by macro-level adaptation actions that relate to the economic sectors and county-level vulnerabilities to enhance long-term resilience and adaptive capacity; includes proposed actions in the sectors energy, land use and transport **Kenya National Energy Efficiency and Conservation Strategy**: roadmap towards achieving energy efficiency goals; overall positive impact on Kenya's economy (e.g. reduced demand for fossil fuels and related GHG emissions)	**Positives:** Establishment of comprehensive frameworks that support climate change mitigation and the growth of renewable energy technologies. Effective policies, such as the Climate Change Act and the National Energy Policy, provide clear guidelines and targets, creating a stable environment for investment and development. Strong governance structures and planning instruments facilitate coordinated efforts across various government agencies, ensuring that renewable energy projects are effectively integrated into national development plans. These regulatory and governance measures promote transparency, accountability, and long-term strategic planning, which are crucial for achieving sustainable energy goals and advancing climate resilience. **Challenges**: Fragmented and inconsistent policy frameworks that hinder effective climate change mitigation and renewable energy development. Regulatory uncertainties and overlapping mandates among different governmental bodies can create confusion and inefficiencies. Additionally, inadequate enforcement of existing regulations and a lack of clear, long-term strategic planning can impede the successful implementation of renewable energy projects.

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Regulatory instruments	**Kenya Energy Act (2019)** consolidates and updates laws in the energy sector; repealing the previous Energy Act, the Geothermal Resources Act, and the Kenya Nuclear Electricity Board Order No. 131 of 2012. Aims to unify energy-related laws, define national and devolved government functions, exploit renewable energy sources, regulate petroleum and coal activities, and manage electricity supply and usage	**Positives:** The Act establishes clear mandates for increasing renewable energy integration into the national grid and sets out mechanisms for regulatory oversight and enforcement. It supports the development of renewable energy projects through incentives such as feed-in tariffs and streamlined approval processes, fostering a more attractive investment climate. Additionally, the Act emphasizes energy efficiency and environmental sustainability, contributing to Kenya's broader climate goals and encouraging a transition to a cleaner, more resilient energy sector. **Challenges:** Delays in regulatory processes and difficulties in translating policies into effective action. Additionally, the Act's incentives and support mechanisms may not be sufficiently robust or well-targeted to attract the needed investment in renewable energy. Regulatory inconsistencies and limited capacity within enforcement agencies can also hinder the effective oversight and integration of renewable energy projects, affecting overall progress toward climate change mitigation goals.
Market-based instruments	**Renewable Energy Feed-in Tariff** part of the new Kenya Energy Act. Aims to promote renewable energy generation and its distribution through local networks, encourage the adoption and innovation of renewable energy technologies, and reduce greenhouse gas emissions and Kenya's reliance on non-renewable energy sources **Kenya's VAT Act (2013) and amended VAT Act (2014):** renewable energy investors are exempt from value-added tax and import duties on both temporary and permanent materials and equipment needed for constructing renewable energy projects	The VAT Act, while intended to lower costs for renewable energy equipment, may face challenges in consistent application and ensuring that benefits reach all relevant stakeholders. The Renewable Energy Feed-in Tariff Act can encounter difficulties with delayed payments, regulatory bottlenecks, and financial sustainability of the tariff rates. Additionally, the success of these instruments depends on effective monitoring and enforcement, which can be undermined by administrative inefficiencies and inadequate infrastructure. These challenges can limit the overall impact of the policies on accelerating renewable energy adoption and achieving climate change mitigation goals.
Information instruments	• **Climate Change Act (2016)**: Establishes frameworks for reporting and monitoring climate-related information, promoting transparency, and setting	**Positives:** Development and implementation of policies and regulations designed to enhance transparency and facilitate the dissemination of critical information on climate change mitigation and renewable energy technologies. These efforts include establishing

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	targets for reducing greenhouse gas emissions. • **Energy Act (2019)**: Includes provisions for the dissemination of information related to energy production, consumption, and efficiency, supporting the development and implementation of renewable energy projects. • **Renewable Energy Feed-in Tariff Act**: Provides information on tariffs for renewable energy producers, ensuring financial predictability and encouraging investment in renewable energy technologies. • **National Climate Change Action Plan**: Outlines strategies for enhancing climate resilience and includes measures for improving access to and dissemination of climate-related information. • **Public Awareness Campaigns and Educational Programs**: Government initiatives and partnerships aimed at increasing public understanding of renewable energy benefits and climate change impacts, through media, workshops, and community outreach.	platforms for sharing data, conducting public awareness campaigns, and providing technical guidance on best practices for renewable energy adoption. By improving access to relevant information and fostering greater public and stakeholder engagement, these measures support more informed decision-making, promote the benefits of renewable energy, and drive the effective implementation of climate mitigation strategies in the energy sector. **Challenges**: Inadequate coverage and accessibility of critical information, leading to gaps in public awareness and stakeholder engagement. Despite efforts to disseminate data and best practices, there may be barriers such as limited reach to remote or underserved areas, lack of updated information, and insufficient resources for effective communication. Additionally, fragmented or inconsistent information can create confusion and hinder informed decision-making.

4.9.3 Transport

4.9.3.1 National-sectoral mitigation enablers and barriers

Table 27: Overview of enablers and barriers (transport sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Kenya possesses significant renewable energy potential, including geothermal, wind, solar, biomass, and biofuels, that enhance the capacity to decarbonise the transport sector.	Uneven terrain, underdeveloped infrastructure, and susceptibility to climate impacts like flooding and droughts
Environmental-ecological feasibility	Decongestion programs and junction improvements. Actions undertaken include the construction of footbridges, improvements to Pedestrian crossing points in Nairobi City County, Intelligent Transport	The increase in fossil fuel demand in the transportation sector contributes significantly to GHG emissions. The transport sector uses at least 70% of imported petroleum products.

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	System within Nairobi Western Ring roads, tree planting, landscaping and beautification, and Construction of walkway.	Public transport is dominated by minibuses with low passenger capacity. Traffic congestion in Nairobi and other cities and major towns, especially during peak hours, contributes to GHG emissions through the use of more fossil fuels and increases local air pollution, which has profound health implications. ((Ministry of Environment and Natural Resources, 2016a)
Technological feasibility	Comprehensive engagement of the private sector to promote the shift of cargo from road to rail. The government is involved in an E-mobility pilot with UN-Environment, where they will engage the City of Kisumu and Kenya Power & Lighting Company Limited through the deployment of 50 electric motorcycles on a pilot basis. Through the support of GIZ, the government is also engaging the private sector to identify impediments in the EV business (EPRA, n.d.-a).	Lack of climate-proof infrastructure- integration of climate change risks and opportunities in the design (Ministry of Environment and Natural Resources, 2016c). For instance, a robust transport network is essential to accommodate emergency services and planning, particularly concerning emergency evacuations. Poorly developed energy infrastructure limits the adoption of alternative forms of energy, such as electricity in the transportation sector. High cost of technology, including efficient vehicles, loading stations, and other infrastructure pertinent to e-mobility (Murphy & Harris, 2014).
Economic feasibility	Reduction of excise duty on electric vehicles: The Finance Bill of 2019 has proposed a reduction on the excise duty for all vehicles with electric motors for propulsion (BEVs) from 20% to 10% (EPRA, n.d.-a).	High cost to replace vehicles with those of low fuel efficiency.
Sociocultural feasibility	Job creation and public awareness campaigns	Public resistance to change, economic inequality making sustainable transport options unaffordable, lack of skilled workforce
Institutional feasibility	Support from international institutions, NGOs	Lack of coordination and resource limitations

4.9.3.2 Current status of national-sectoral climate policy

Table 28: Overview of policies and measures (transport sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	• **Climate Change Coordinating Unit** (CCCU) is a focal point with persons from relevant departments and agencies (Republic of Kenya, 2023b) • Integrated National Transport Policy reviewed to include climate change and other sustainability elements. • **Climate Change Act** • Construction of 70km of the Bus Rapid Transport for Nairobi. Construction of a	**Positives:** Kenya's climate policy has several merits that collectively promote sustainable development and resilience against climate change. It aligns with international agreements like the Paris Agreement, encouraging renewable energy development and reducing reliance on fossil fuels. The policy emphasizes environmental conservation, sustainable resource management, and climate-smart agriculture, enhancing food security and carbon

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	total of 33 km of non-motorized transport facilities. • **East African Rail Masterplan**: Extension of standard gauge railway (SGR) from Nairobi to Naivasha completed in 2019 shifting 30% freight from road to rail • 4,678,000 tons of freight from Mombasa to Nairobi shifted from road to rail. Road vehicle inspection standards adopted. Implementation of functional traffic light systems at key junctions and intelligent transportation systems. • **Nairobi Railway Masterplan** to upgrade Nairobi commuter rail system (transported 2.3m people in 2022) • 3,098 km of roads climate-proofed - 1,570.4 km by Kenya National Highways Authority [KeNHA] and 1,539.23 km by county governments. • Improving heavy-duty truck efficiency • Electric public buses /3 & 2 wheelers vehicles are being piloted in Nairobi (Republic of Kenya, 2023b)	sequestration. It also focuses on resilience and adaptation to protect vulnerable communities and sectors, while fostering green job creation and economic growth. Supported by the Climate Change Act of 2016, the policy ensures coordinated climate action through a robust legal and institutional framework. Public participation, technological innovation, and access to international climate finance are also key components, enhancing governance, accountability, and the overall effectiveness of Kenya's climate initiatives. **Challenges:** Kenya's climate policy faces several challenges that hinder its effectiveness. Financial constraints limit the implementation of climate initiatives, as accessing international funds involves complex procedures. Institutional and governance issues, such as lack of coordination between national and county governments and insufficient technical expertise, further impede progress. Public awareness and engagement in climate action need to be enhanced for widespread support. Technological and infrastructural limitations make adopting clean technologies difficult, especially in rural areas. Vulnerable communities face significant adaptation challenges, lacking resources and knowledge to implement effective strategies. Political and economic factors, such as instability and the pressure for rapid development, can disrupt climate action plans. Additionally, gaps in data collection and monitoring systems hinder the evaluation of progress, and enforcing legal frameworks requires robust mechanisms and resources. Addressing these challenges is crucial for the successful implementation of Kenya's climate policies and achieving sustainable development goals.
Regulatory instruments	• Draft regulation on the prevention of air pollution from shipping (international convention on prevention of pollution from ships) • **Euro-4 compliance** for all new truck (2023) • Draft **CORSIA** regulation	**Positives**: Kenya's air pollution regulation policy has several merits that contribute to environmental protection and public health. The policy aligns with international standards, ensuring that Kenya adheres to global best practices in air quality management. It promotes the reduction of emissions from key sources such as transport, industry, and energy production by encouraging the adoption of cleaner technologies and fuels. The policy also emphasizes monitoring and enforcement, with

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	• Standards for electric vehicles (Republic of Kenya, 2023b) • Vehicle age limit for importation (8 years)	established institutions responsible for tracking air quality and ensuring compliance with regulations. Overall, Kenya's air pollution regulation policy is comprehensive, promoting a healthier environment and contributing to the country's sustainable development goals. **Challenges**: Kenya's air pollution regulation policy faces several challenges that impact its effectiveness. Financial constraints limit the ability to implement and enforce air quality measures, as adequate funding is required for monitoring systems and regulatory enforcement. Institutional weaknesses, such as insufficient technical expertise and coordination between agencies, further hinder policy execution. Public awareness of air pollution issues remains low, leading to limited community engagement and compliance. Additionally, rapid urbanisation and industrialisation increase pollution sources faster than regulatory measures can be adapted. Technological limitations and outdated infrastructure pose barriers to adopting cleaner technologies and reducing emissions. Political and economic pressures, such as prioritizing economic growth over environmental protection, can also undermine regulatory efforts. Addressing these challenges is crucial for improving air quality and protecting public health in Kenya.
Market-based instruments	The Kenyan government eliminated subsidies for super petrol, but later reinstated them to curb the rising prices of petrol, kerosene and diesel (Okadia, 2023b; The Cable, 2023).	**Positives:** On the positive side, these instruments create economic incentives for reducing greenhouse gas emissions by putting a price on carbon, which encourages businesses and individuals to adopt cleaner technologies and practices. They can generate revenue that can be reinvested in sustainability projects and foster innovation. **Challenges**: However, challenges include the risk of market volatility and economic impact, particularly for industries heavily reliant on carbon-intensive processes. Implementing these instruments effectively requires robust regulatory frameworks and monitoring systems to prevent fraud and ensure transparency. Additionally, there can be resistance from stakeholders who may face increased costs or economic disruptions.

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Information instruments	• A study on the electrification of 2 and 3-wheelers was conducted, and recommendations were implemented to enable the switch to electricity. • Fifteen climate change focal points from the transport agencies trained on climate change planning, budgeting, and advancing transport and climate strategies. Three hundred people participated in webinars on fuel economy and electric mobility options. • Additional to improving heavy-duty truck efficiency, driver sensitisation in eco-driving was implemented • Feasibility study ongoing alternative source of marine power / sustainable aviation fuels /on the installation of shore power infrastructure for four berths (Republic of Kenya, 2023b)	**Positives:** Public awareness campaigns and stakeholder engagement are integral, fostering community involvement and support for air quality initiatives. Additionally, the policy supports research and development to find innovative solutions for air pollution control.

4.9.4 Buildings

4.9.4.1 National-sectoral mitigation enablers and barriers

Table 29: Overview of enablers and barriers (building sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Different climatic zones can support the adaptation of various building designs and technologies, promoting climate-friendly building policies	Intense rainfalls cause flooding in combination with poor urban planning, development in riparian areas and outdated drainage systems in urban areas have negative impacts on the building sector
Environmental-ecological feasibility		The lack of consideration of local climate context during the design and construction phases of the most modern buildings (Ministry of Energy, 2020c)
Technological feasibility	The Kenya Association of Manufacturers (KAM) – through an agreement with the Ministry of Energy, since 2006 KAM has hosted the national Centre for Energy Efficiency and Conservation (CEEC) and is involved in program administration on behalf of the Ministry of Energy During 2011-2015, UN-Habitat and UN Environment implemented a program	The insufficient research, development and innovation in clean cooking sector (Ministry of Energy, 2020c) The use of inefficient cookstoves due to high upfront expenditure (Ministry of Energy, 2020c) The inadequate number of testing labs for appliances, cookers and fuels (Ministry of Energy, 2020c)

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	"Promoting Energy Efficiency in Buildings in East Africa". The program's main target was to promote the construction of at least 400,000 energy efficient housing units through the provision of technical assistance on the design and implementation of new houses in the region International Finance Corporation (IFC) entered into an agreement with the Kenya Green Building Society (KGBS) to promote a greener construction sector in Kenya. Through the agreement, KGBS markets IFC's EDGE green building software and certification program to the Kenyan property industry and collaborates on future technical trainings	
Economic feasibility		The lack of public sector support for green buildings (IEA, 2019b) The lack of financial support for the development of local testing labs to support energy efficiency R&D activities (Munene et al., 2019b) The reluctance of homeowners to replace the inefficient devices with the efficient ones due to their high costs (Munene et al., 2019b) The lack of motivation of households to purchase energy efficiency technologies due to their low purchasing power (Munene et al., 2019b)
Sociocultural feasibility	In collaboration with the Ministry of Industrialisation and Enterprise Development and leveraging Global Environment Facility funding, UNDP has helped Kenya to introduce minimum energy performance standards and administered comprehensive campaigns aimed at informing retailers and consumers of the need to improve energy efficiency in residential, commercial and industrial sectors.	The rapid growth of building stock, mainly derived from the growth in the number of hotel and institutional buildings (Ministry of Energy, 2020c) The use of cookstoves with low efficiency due to the preference and lack of knowledge of the improved cookstoves and fuels (Ministry of Energy, 2020c) The lack of awareness of distributors and customers regarding energy efficiency (Munene et al., 2019b) The inadequate knowledge of distributors and customers regarding energy label (Munene et al., 2019b)

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Institutional feasibility	The Kenya Green Building Society (KGBS) – an independent, non-profit membership-based society registered with the World Green Building Council as its Kenya Chapter. KGBS has strong Ministry acknowledgement and is mandated to run certification schemes for the built environment, advocate for green buildings and train green building professionals.**Error! Bookmark not defined.** A number of bilateral agencies have either direct energy efficiency programs in Kenya or broader energy sector programs which target generation and access, but have strong energy efficiency components. Examples of these programs include the Power Africa flagship program of USAID; the Program for Energy Efficiency in Buildings (PEEB) of GIZ; the multi-donor Energising Development (EnDev) Kenya project; and direct support to the energy efficiency activities	The nascent market for green buildings (EDGE, n.d.) The lack of support for mandatory energy audits particularly for large residential projects (Munene et al., 2019b) No phasing-out of inefficient energy technologies (Munene et al., 2019b) The lack of enforcement of MEPs (Ministry of Energy, 2020c) The lack of capacity of the enforcement agencies to promote compliance with the MEPs (Munene et al., 2019b)

4.9.4.2 Current status of national-sectoral climate policy

Table 30: Overview of policies and measures (building sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	Kenya has not set a net zero targets (Climate Action Tracker, 2022c). Standardised guidelines for the construction and maintenance of green buildings are lacking (The national treasury and economic planning, 2022). There are no legislations or regulations specifying the standards that new buildings must meet to be energy-efficient and environmentally friendly (The national treasury and economic planning, 2022).	**Challenges:** Environmentally friendly design, the reduction of carbon footprints, and green construction practices are rarely considered by the Kenyan construction industry (The national treasury and economic planning, 2022).
Regulatory instruments	Since the mid-1960s, Kenyan **construction codes** have been based on British standards, but they will be now fully based on European construction guidelines (Eurocodes) (Copenhagen Centre & Building Efficiency Accelerator, 2018b). There has been a **draft energy efficiency building code** published for Kenya (Kenya, State Department for Public Works, 2022, as cited in UN Environment Program, 2022), but it has not	**Challenges:** High initial investment cost is considered as a barrier to the use of efficient lighting products (Ministry of Energy, 2020c).

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	yet taken effect (UN Environment Programme, 2022b). To comply with the code, buildings must do their utmost to conserve energy, utilise passive and natural cooling methods, and use natural daylight (Climate Action Tracker, 2022c). PV and wind are both considered in the code for use in new housing developments with solar hot water for bathrooms (Climate Action Tracker, 2022c). The **Energy Labelling and Performance regulations** were adopted in Kenya in 2016 (Okadia, 2023b). The EPRA is responsible for the registration of appliances that meets the MEPs (Okadia, 2023b). The MEPs are set for six electrical appliances, including motors, air conditioners, fridges, CFLs, magnetic ballasts, and fluorescent lamps (Ministry of Energy, 2020c). It is aimed that more product categories such as LEDs, computers, TVs, and cookstoves will be added to the MEPs coverage by 2025 (Ministry of Energy, 2020c).	
Market-based instruments	The CFC Stanbic and Cooperative Bank offers $33 million in **green credit lines to the energy efficiency projects.** In addition, HF Group has launched a credit facility for green mortgages with the support from IFC (Copenhagen Centre & Building Efficiency Accelerator, 2018b). The Kenyan government has announced the establishment of a Super **ESCO**, which will be operated by the Kenya Power and Lighting Company. The Super ESCO will be responsible for the development and implementation of energy efficiency projects in public and private sectors (UN Environment Programme, 2021). The **Kenya Green Bond Program** was initiated in 2017 with the aim of supporting financial sector innovation through the development of a domestic green bond market. A number of key developments have occurred since it was established, including the recent issuance of Kenya's first green bond in 2019. With the issuance of Climate	**Challenges:** There are a few Real Estate Investment Trusts (REITs) while there are no incentives for green building financing in the country (EDGE, n.d.). The programs aiming to provide financial incentives for energy efficiency in the building sector are limited (Copenhagen Centre & Building Efficiency Accelerator, 2018b). Solar and wind generation equipment, and clean cooking solutions, are among the renewable energy products that would benefit from a VAT exemption under the Finance Act 2021 (GOGLA, 2021). Kenya does not impose an explicit price on carbon. In 2021, fuel excise taxes, a form of implicit carbon pricing, were responsible for 18.9% of the emissions (OECD, 2022). Currently, Kenya's ESCO market is underdeveloped due to limited experience of ESCOs, high cost for project development and inadequate knowledge and understanding of financial institutions about energy efficiency projects (SEFA, 2021).

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	Bonds Certified, KSh 4.3 billion will be raised to provide eco-friendly, affordable housing to 5,000 university students in Nairobi (Green Finance Platform, 2019).	
Information instruments	In terms of building ratings and performance disclosure, the following international green building rating systems are available: • Green Star Kenya which certified 0.04 million sqm from 2017 to 2020 • EDGE which certified 0.3 million sqm from 2015 to 2020 • LEED certified 0.06 million sqm from 2012 to 2020 (EDGE, n.d.) The first **energy label** of Kenya was introduced in 2019 (Okadia, 2023b). The EPRA uses a five-star energy rating scheme where the highest-performing appliances receive five stars and the lowest receive one (EPRA, n.d.-b). Energy labelled appliances currently include refrigerators, air conditioners, and motors but more appliances including lighting will be included soon (Okadia, 2023b).	**Positives**: CLASP initiated a digital campaign called #KenyaEnergyLabel in collaboration with EPRA to educate customers about the benefits and utility of the **new energy label** (Blair & Wekongo, 2020). On **feedback measures**, there are some pilot studies underway: Installation of smart energy meters at Kongowea Market in Mombasa County is one of them. More installations for public buildings, including hospitals and the Governor's office are planned (Covenant of Mayors, 2023). The Technical University of Kenya (TUK) offers a **Green Building course** (EDGE, n.d.). There are colleges offering craft certificate in solar installation: • Baringo Technical College • Nuu Technical and Vocational College • COFA Institute of Technology • Kenya Coast National Polytechnic (Kenyaplex, n.d.) There are projects such as "Solar Learning For Women" **providing training** on solar technology and entrepreneurship (Solarafrica, n.d.). **Challenges**: Kenya's Green Building Market is in its infancy and is being developed gradually (EDGE, n.d.). Both distributors and consumers are unaware of the energy efficiency. The customers are unfamiliar with the different star ratings and the distributors are unable to explain to the consumers what exactly they mean. Therefore, the price of a product is the only factor considered by the customers to make a purchasing decision (Munene et al., 2019b). The clean cooking sector lacks innovation, research, and development (Ministry of Energy, 2020c): More financial resources should be allocated for the development of local testing

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		labs to support R&D. In addition, Kenyan academic institutions should receive more financial support for the research and development in energy efficiency (Munene et al., 2019b).

4.9.5 AFOLU

4.9.5.1 National-sectoral mitigation enablers and barriers

Table 31: Overview of enablers and barriers (AFOLU sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Policies such as the National Climate Change Action Plan and the Forest Conservation and Management Act aim to optimize land use and improve forest management, while the Agricultural Sector Transformation and Growth Strategy promotes climate-smart agricultural practices suited to local soil and climatic conditions. Additionally, the Geothermal Development Policy capitalizes on Kenya's geothermal potential, particularly in the Rift Valley, to provide a sustainable energy source. These measures align land and resource management with Kenya's geophysical features to enhance carbon sequestration, reduce emissions, and integrate renewable energy technologies effectively within the AFOLU sector. Reforestation program: Increased efforts toward achieving a tree cover of at least 10% of land area. Kenya has a forest cover of 7.4%, 3.6% short of the constitutionally accepted 10% forest cover (National Environment Management Authority, n.d.). Land use planning and zoning done to segregate and identify forest areas for conservation (Government of Kenya, 2018).	Challenges in aligning land and resource management with diverse geophysical conditions. These barriers include insufficient data on local geophysical features, which complicates effective land use planning and implementation of climate-smart practices. Inadequate infrastructure and investment in geophysical research limit the ability to optimize land for carbon sequestration and renewable energy projects. Additionally, conflicts over land use between agricultural expansion, forestry, and renewable energy projects can hinder comprehensive planning and integration. Overcoming these barriers requires improved data collection, investment in geophysical research, and better coordination among sectors to align land management with climate goals and renewable energy initiatives.
Environmental-ecological feasibility	Promotion of climate-smart agriculture with emphasis on efficient livestock management systems. Sustainable Land Management (SLM) has, in recent years, been of focus due to its potential to minimise degradation, rehabilitate degraded lands, and increase food production (Ministry of Environment and Natural Resources, 2016c)..	Land Conversion: The ongoing conversion of forests, wetlands, and other natural habitats into urban or agricultural areas contributes to deforestation and habitat loss, releasing stored carbon and reducing biodiversity (Ministry of Environment and Natural Resources, 2016c). Land use planning and zoning done to segregate and identify forest areas for conservation.

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	Climate change mainstreamed into environment audits, environmental impact assessments, and strategic environmental assessments (Government of Kenya, 2018).	
Technological feasibility	Supportive policies, technological innovation, and capacity-building initiatives. The government's focus on research and development, alongside partnerships with international organisations, facilitates the deployment of advanced technologies in sustainable agriculture, forestry, and renewable energy. Policies that provide technical guidelines, training programs, and access to modern tools and practices help enhance the adoption of climate-smart technologies. Additionally, financial support for technology transfer and pilot projects aids in demonstrating and scaling up successful innovations. These enablers collectively enhance the technological capabilities needed to advance climate change mitigation and integrate renewable energy solutions effectively Collaboration with international organisations / knowledge exchange	limited access to advanced technologies and insufficient technical expertise. High costs associated with acquiring and implementing new technologies can be prohibitive for local farmers and forestry managers. There is also a lack of infrastructure and support systems to facilitate the adoption and maintenance of innovative technologies. Additionally, gaps in research and development, combined with inadequate training programs, hinder the effective utilisation of climate-smart technologies and renewable energy solutions. Addressing these barriers requires investments in technology transfer, capacity building, and infrastructure development to enhance technological feasibility and support climate change mitigation efforts Absence of technological advancements, insufficient implementation of modern agricultural practices
Economic feasibility	targeted financial incentives, supportive policies, and innovative financing mechanisms that facilitate the adoption of climate-friendly practices and renewable energy technologies. Programs such as carbon credits and subsidies for sustainable agriculture and reforestation help offset initial costs and attract investment. Additionally, government policies that promote public-private partnerships and provide risk mitigation tools contribute to a more attractive investment climate. Access to international climate finance and development funds further supports economic feasibility by providing necessary capital and resources. These enablers collectively help lower financial barriers, making climate change mitigation and renewable energy technologies more economically viable.	high initial costs and limited access to financing for climate change mitigation and renewable energy projects. Investments in sustainable agricultural practices, reforestation, and renewable energy technologies often require significant capital, which can be prohibitive for smallholders and local communities. Additionally, there is a lack of financial incentives and support mechanisms to encourage investment in these areas. Economic uncertainty and market risks further deter private sector participation. Addressing these barriers involves developing innovative financing solutions, providing targeted subsidies and incentives, and improving access to capital to make climate-friendly practices and technologies economically viable for all stakeholders in the AFOLU sector. Lack of clear sources of climate finance for conservation and sustainable forest management in the medium and long term (Murphy & Harris, 2014). Arid and semi-arid lands are particularly vulnerable to climate change impacts, especially in the absence of

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		sufficient investments in mechanisms to build resilience.
Sociocultural feasibility	Community involvement and educational programs to promote sustainable land management practices. Collaboration with local communities can integrate traditional knowledge into modern conservation strategies.	Inadequate standards and training, limited knowledge, limited access to resources, high costs, need for broader education and awareness
Institutional feasibility	Collaboration with international and national organisations to address the land degradation problem through various programs and initiatives. The Kenya Strategic Investment Framework (KSIF) for sustainable land management is one of such collaborations with the World Bank and TerrAfrica aimed at scaling up SLM interventions and investments in Kenya (Ministry of Environment and Natural Resources, 2016b). Significant commitments toward sustaining natural resources through various agreements (such as UNCCD, UNFCCC, CBD, SDGs) (Ministry of Environment and Natural Resources, 2016b). Guidelines and standards for the establishment of green zones, as required by the Forest Act 2016, developed, which require linkage with County physical planning and development control functions (Government of Kenya, 2018).	Inadequate or weak land use regulations and policies may fail to address climate change concerns and promote unsustainable practices (University of Cape Town, 2019). Despite the legislative and policy push, Kenya's watersheds, agricultural, rangelands, and settled areas continue to face extensive land degradation.

4.9.5.2 Current status of national-sectoral climate policy

Table 32: Overview of policies and measures (AFOLU sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	• **Kenya Forest Service**, a state Corporation in the Ministry of Environment, Climate Change and Forestry (2007) • **Forest Conversation and Management Act** (2016) • **The National Forest Program** (2016-2030)	**Positives**: establishment of integrated policy frameworks and enhanced inter-agency coordination. Comprehensive planning instruments, such as the National Climate Change Action Plan and sector-specific strategies, provide clear guidelines and set ambitious targets for climate change mitigation and renewable energy adoption. Effective governance structures facilitate stakeholder engagement and ensure that policies

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	• **Comprehensive Africa Agriculture Development Program** (CAADP): African governments agreed to allocate at least 10% of national budgets to agricultural growth rates or at least 6% per annum. Targets for reducing poverty, increasing productivity, improving sustainability and use of natural resources • The National Plan for achieving 30% tree cover by 2032 • **2023-2027 Strategic Plan** with the aim to expand forest and tree cover for climate mitigation and adaptation, conservation and protection of forests for climate change resilience, economic development and livelihood improvement, organisational capacity building and collaboration (Kenya Forest Service, n.d.) • Campaign launched in 2022 to plant 15 billion trees by 2032 (The National Treasury and Economic Planning, n.d.) • **National Spatial Plan 2015-2045** (Ministry of Lands and Physical Planning, n.d.) • **Community Land Act** • **Lake Victoria Environmental Management Project** (LVEMP) (together with United Republic of Tanzania, Republic of Uganda) • The **Climate for Development in Africa** (ClimDev-Africa) Program is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (ECA) and the African Development Bank (AfDB) (www.climdev-africa.org). • **Kenya Climate Smart Agriculture Strategy 2017-2026**. The objective of the policy is to adapt to climate change, build resilience of agricultural systems while minimizing emissions	are well-coordinated and implemented consistently. Supportive institutional frameworks and capacity-building initiatives further strengthen governance and planning capabilities, promoting the successful integration of climate-smart practices and renewable technologies. The protection of forests is an important aspect in addressing desertification, land degradation and drought. There are ambitious goals to protect land / forests **Challenges**: inadequate coordination among various governmental and non-governmental bodies, leading to fragmented and sometimes conflicting policies. The lack of integrated planning and insufficient stakeholder engagement can result in poorly executed climate change mitigation strategies and inefficient implementation of renewable energy projects. Additionally, limited resources and capacity for effective governance and planning can hinder the development and execution of comprehensive and cohesive strategies. These challenges underscore the need for improved coordination, better resource allocation, and more inclusive planning processes to enhance the effectiveness of climate and energy policies Kenya has struggled with deforestation in recent years and policies may be changed in the short term. In recent years, many projects in the areas of agriculture, land use and forests have been completed.

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	for enhanced food and nutritional security and improved livelihoods (Ministry of Agriculture, Livestock and Fisheries, 2017) • **Agricultural Sector Development Strategy** • **Climate Change Act** • **Agricultural Productivity and Agribusiness Project** • **Kenya's National Wildlife Strategy 2030**	
Regulatory instruments	• **National Climate Change Action Plan**: Outlines strategies for optimizing land use and improving forest management, taking into account Kenya's diverse geophysical conditions to enhance carbon sequestration and reduce emissions. • **Forest Conservation and Management Act**: Promotes sustainable forestry practices that align with Kenya's geophysical features, aiming to increase forest cover and improve carbon sink capacity. • **Agricultural Sector Transformation and Growth Strategy**: Encourages the adoption of climate-smart agriculture practices tailored to Kenya's diverse soil and climatic conditions, which can improve soil carbon storage and reduce greenhouse gas emissions. • **Geothermal Development Policy**: Leverages Kenya's geothermal potential, particularly in the Rift Valley, to provide a renewable energy source that complements AFOLU activities by reducing reliance on fossil fuels. • **Land Use Planning and Management Frameworks**: Address land degradation and optimize land use based on	**Positives**: Establishment of clear and enforceable frameworks that promote climate change mitigation and the adoption of renewable energy technologies. Regulatory instruments, such as the Forest Conservation and Management Act and the National Climate Change Action Plan, set standards and provide guidelines for sustainable land management and forest conservation. These regulations create a structured environment for implementing climate-smart agricultural practices and integrating renewable energy solutions, ensuring that projects align with national climate goals. By providing legal and regulatory support, these instruments facilitate compliance, attract investment, and drive effective implementation of mitigation strategies **Challenges**: Challenges such as inconsistent enforcement of regulations and gaps in regulatory frameworks. The complexity and overlap of different regulations can create confusion and hinder effective implementation of climate mitigation and renewable energy initiatives. Additionally, limited resources and capacity for monitoring and enforcing compliance can weaken the impact of these regulations. Fragmented or outdated policies may also fail to address emerging issues or align with current climate goals. Addressing these barriers requires streamlining regulatory processes, improving enforcement mechanisms, and ensuring that policies are regularly updated and effectively communicated to stakeholders. Regulatory instruments are missing in Kenya with regard to the AFOLU sector

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	geophysical factors, promoting practices that enhance carbon sequestration and support sustainable land management.	
Market-based instruments	• Project to strengthen climate resilience in the Lake Victoria Basin. The project, which will benefit the people of Siaya and Busia in the west of the country, is funded with $5 million from the United Nations Framework Convention on Climate Change (UNFCCC) (Afrik21, 2021).	**Positives**: Introduction of financial incentives and supportive regulatory frameworks that promote investment in climate-friendly practices and renewable energy technologies. Market-based instruments, such as carbon credits and tradeable emissions permits, provide economic incentives for reducing greenhouse gas emissions and adopting sustainable land management practices. The implementation of these instruments is supported by clear policies and robust market infrastructure, which facilitate transparent trading and investment. Additionally, financial mechanisms such as subsidies and grants further encourage the adoption of renewable energy and climate-smart technologies by reducing financial barriers and enhancing economic feasibility. **Challenges**: Limited market infrastructure and insufficient liquidity for trading carbon credits and emissions permits. The complexity of market-based mechanisms can deter participation due to high transaction costs and a lack of clarity. Additionally, the effectiveness of these instruments can be undermined by inadequate monitoring and verification systems, which impact the credibility and reliability of carbon credits and other tradable assets. Furthermore, there may be resistance from stakeholders due to perceived financial risks or lack of understanding of market-based incentives. Addressing these barriers requires improving market infrastructure, enhancing transparency and monitoring, and building capacity to support effective implementation of market-based instruments. The measures have so far focused on one project. Comprehensive measures for financial support are not yet in place

Information instruments	• **Socio-Economic Atlas of Kenya** visualizing the present, envisioning a sustainable future (https://www.kenya-atlas.org/) • **The Climate for Development in Africa** (ClimDev-Africa) Program is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (ECA) and the African Development Bank (AfDB) (www.climdev-africa.org).	**Positives**: Enhanced transparency and improved stakeholder engagement in climate change mitigation and renewable energy initiatives. Policies and regulations that support information dissemination and knowledge sharing help raise awareness about climate-smart practices and renewable technologies. By providing access to reliable data, technical guidance, and best practices, these measures facilitate informed decision-making and encourage the adoption of sustainable practices in agriculture and forestry. Improved communication also fosters greater public and community involvement, supporting the effective implementation of climate mitigation strategies and the integration of renewable energy technologies in the AFOLU sector. The Socio-Economic Atlas offer high-resolution spatial depictions and analyses of data. The combination of geographic and socio-economic data enables policymakers and experts to gain a spatial understanding of dynamics affecting Kenya (Wiesmann et al., 2014) **Challenges**: insufficient dissemination and accessibility of relevant data and best practices. There may be gaps in reaching all stakeholders, particularly in rural or remote areas, leading to limited awareness and engagement with climate change mitigation and renewable energy technologies. Inadequate resources for information campaigns and fragmented communication strategies can also impede effective knowledge sharing. Additionally, the lack of up-to-date and comprehensive data on AFOLU practices can hinder informed decision-making. Overcoming these challenges requires enhancing data collection, improving information dissemination channels, and ensuring that communication efforts are inclusive and targeted to all relevant audiences.

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5 Sri Lanka – case study

5.1 Big picture: Current national-sectoral decarbonisation status and prospects

Sri Lanka (LKA), an island in the Indian Ocean, is a lower middle-income country with a population of 22 million and spreads across an area of 65,610 sq.km. Being a small island, Sri Lanka has a high population density of ~354 persons per sq.km, ranking 40th in the world. The country has been grappling with significant challenges in recent years, including prolonged effects of the COVID-19 pandemic, a severe economic crisis and increasing vulnerability to climate change impacts that has led to a decline in per capita GDP, reaching $3474 by mid-2022 (Central Bank of Sri Lanka, 2022a). The Sri Lankan economy is primarily driven by the services and industrial sectors, followed by agriculture (Central Bank of Sri Lanka, 2023a).

The energy sector is expected to play a crucial role in LKA's path to achieve the ambitious carbon neutral target by 2050 (Ministry of Environment, 2021a). However, the current primary energy mix relies heavily on imported petroleum products followed by biomass and hydropower. This dependence on imported fossil fuels makes the country vulnerable to global price fluctuations and supply disruptions, as experienced during the recent economic crisis. Therefore, making the most out of locally available energy resources and promoting the use of cleaner fuels has become a national prerogative (Ministry of Power and Energy, 2019).

Sri Lanka's geographic location and economic structure leave it highly vulnerable to the impacts of climate change. The country experienced an increase in the frequency and intensity of extreme weather events such as the devastating floods and landslides in October 2023 that affected several districts (Reliefweb, 2023). Droughts have also become more frequent and severe, particularly in the dry zone, impacting agricultural productivity and livelihoods. Changes in rainfall has also introduced significant challenges for agriculture and water resources management in Sri Lanka (World Bank, 2024) further straining the nation's economy.

The economic crisis in the country has compounded these challenges, leading to shortage of essential goods. In September 2022, the country reported the highest ever inflation rate in South Asia at 69.8% (Central Bank of Sri Lanka, 2023b). Additionally, the Sri Lankan Rupee has depreciated by 80% against the US Dollar in 2022 (Central Bank of Sri Lanka, 2022a). The country's foreign exchange reserves have been slowly depleted, and the government has had difficulties importing essentials. This includes fuels, leading to extensive power outages, disruptions in transportation, and shortages of medicine impacting healthcare services across the country. The economic hardships have caused widespread social unrest, with protests erupting across the country demanding government action to address the crisis.

Despite the challenges, the Sri Lankan government is pursuing measures to counter climate change and promote economic recovery. The initiatives range from investment in renewable energy generation and sustainable agriculture to disaster risk reduction. The government is also seeking international financial assistance to support these efforts.

In 2020, LKA's total greenhouse gas (GHG) emissions were 36.9 MtCO2e (Climate Watch, n.d.) (Figure 1). The energy sector (power, transport, buildings, other fuel combustion) contributes to ~59% while agriculture contributes to 14% of total GHG emissions constituting the leading emitting sectors of Sri Lanka. The industrial sector contribution accounted for ~8% and non-combustion emissions including waste, land-use and land-use change accounted for ~13% (Climate Watch, n.d.).

As a signatory of the Paris Agreement, Sri Lanka first submitted their Nationally Determined Contribution (NDC) in September 2016 (Ministry of Mahaweli Development and Environment, 2016). The overall mitigation target was to reduce GHG emissions by 20% in the energy sector (4% unconditional, 16% conditional) and by 10% in other sectors (transport, industry, forestry, and waste) by 2030. The reductions are compared to the Business as Usual (BAU) scenario where no GHG mitigation action is taken.

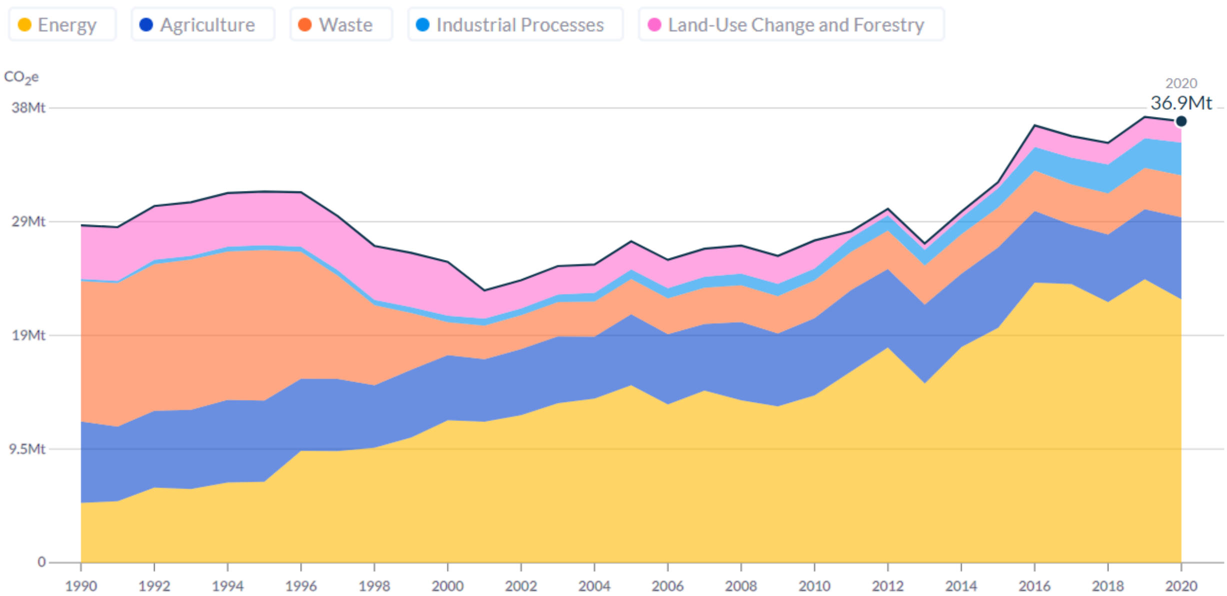

Figure 10: Sri Lanka's Historic GHG emissions.
Source: (Climate Watch, n.d.)

The next NDC of Sri Lanka was released in July 2021 (Ministry of Environment, 2021a) which was subsequently amended in September 2021. The key amendment between the two versions was that the government of Sri Lanka ambitiously advanced the carbon neutral target from 2060 to 2050. It was highlighted that the ambitious plans to decarbonize the power sector by substantially increasing the share of renewables would have a strong impact on GHG mitigation in Sri Lanka. The latest NDC states 14.5% of GHG reductions during the 2021-2030 period from power, transport, industry, waste, forestry and agriculture. This is further facilitated by the commitment to increase the forest cover to 32% by land area by 2030. A summary of the GHG reduction targets across the sectors for the period of 2021-2030 is given in Table 1.

Table 33: Sri Lanka's GHG emission reduction targets as outline in NDCs.
(Ministry of Environment, 2021a)

Sector		Target GHG emission reduction % compared to the BAU# scenario		
		Unconditional	Conditional	Overall
Industry		4	3	7
Power		5	20	25
Transport		1	3	4
Buildings		*No explicit target is mentioned in the NDCs*		
AFOLU	Waste Management	8.5	2.5	11
	Forestry*	2	5	7
	Agriculture (including livestock)	4	3	7

* Carbon sequestration capacity is expressed here
# Business-As-Usual scenario, representing emissions without any mitigation action

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5.2 Industry

5.2.1 Current decarbonisation status and prospects

Sri Lanka's industrial sector contributes significantly to the economy and employment, but also to GHG emissions. The sector relies heavily on biomass and fossil fuels for energy, with cement manufacturing being a major emitter of non-energy related GHG emissions (UNIDO, 2020). While energy consumption emissions are relatively well-accounted for, there is limited data on the emissions from industrial processes and product use. The heavy reliance on biomass and fossil fuels makes the sector vulnerable to fluctuations in fuel prices and supply chain disruptions caused by climate-related events. Current plans to reduce GHG emissions in the industry sector will account for a 7% reduction during the 2021 – 2030 period (Ministry of Environment, 2021a).

Sri Lanka's industrial sector is led by the textile and apparel industry which includes the production of garments, textiles, and accessories(UNIDO, 2024). However, the textile industry, which is a major export earner, is vulnerable to water scarcity caused by droughts and extreme weather events. In addition, there are solid and industrial tire manufacturing, boat and ship building, ceramics, tea, coconut-based products, gems and jewellery, food and beverages industries spread across the country.

Sri Lanka is a well-known tourist destination; a vital industry in Sri Lanka originated from its scenic beauty, historical sites, and cultural attractions (Sri Lanka Tourism Development Authority, 2024). However, tourism also notably contributes to GHG emissions due to energy-intensive activities such as transportation and accommodation.

The current trajectory for mitigating the GHG emissions from the industry sector leads with fuel switching and improving energy efficiency, followed by implementing resource efficient cleaner production practices. In the cement industry, it is identified to reduce GHG emission from clinker production by amending standards to allow more substitutes for clinker.

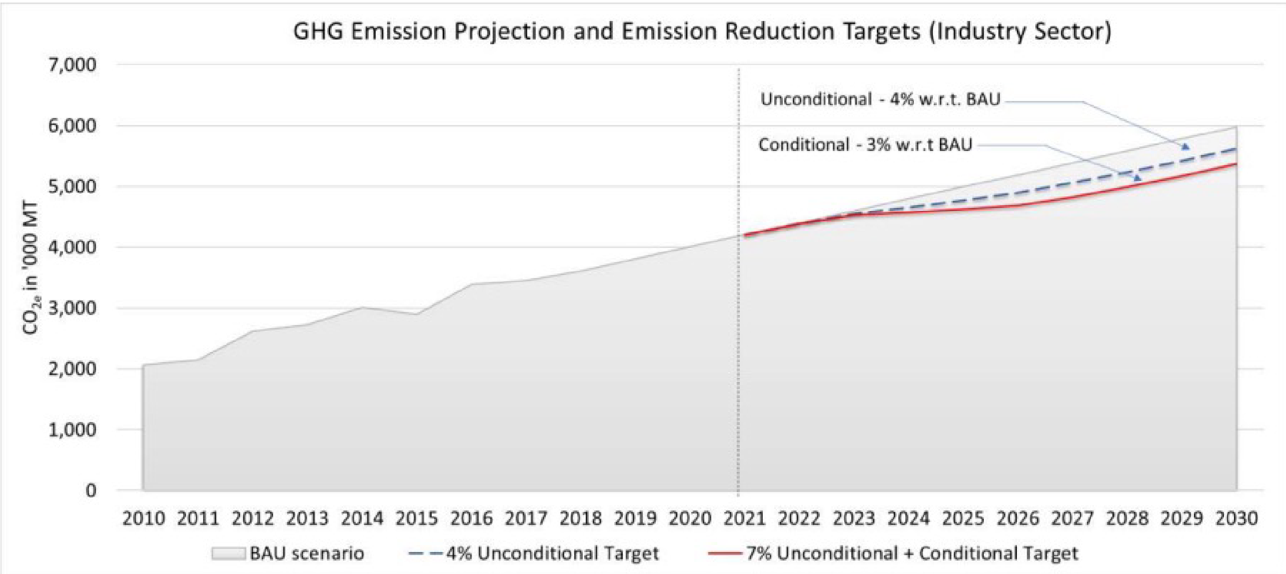

Figure 11: Emission reduction projections in the industry sector.
(Ministry of Environment, 2021a)

5.2.2 National-sectoral mitigation enablers and barriers

The industrial sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that

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support climate action. The enablers and barriers are categorized and explained in more detail in Table 6 (annex) and summarized below:

Geophysical feasibility: Sri Lanka possesses ample biomass resources such as agricultural residues and wood waste in certain regions (Maheepala and Jayasinghe, 2018). However, widespread adaptation and establishing a sustainable supply chain is limited as the industrial sector is geographically dispersed. In addition, Sri Lanka's agriculture sector is highly vulnerable to climate change impacts can further hinder the availability of sustainable biomass resource (Ministry of Environment, 2005). The diversity in geography and type of industries poses difficulties to adapt and monitor Resource Efficient Cleaner Production practices (Hemakumara and Dissanayake, 2020). Additionally, there is potential to transform existing industrial zones into eco-industrial parks, promoting the concept of a circular economy due to the diversity of industries present in Sri Lanka (Karunarathne and Madhushan, 2021). However, the land is limited and infrastructure for waste collection, sorting, and recycling hampers circular economy practices.

Environmental and ecological feasibility: There is a potential for pollution and resource depletion reduction through resource efficient cleaner production practices (RECP) (Ministry of Environment, 2005), the benefits of industrial eco-parks for resource sharing and waste minimisation (Karunarathne and Madhushan, 2021), and the circular economy's potential for resource conservation. Tri-generation can enhance energy efficiency and lower emissions, while clinker substitution can significantly cut GHG emissions from cement production. However, barriers include the risk of unsustainable biomass sourcing leading to deforestation, trade-offs in RECP and circular economy practices, and potential compromises in cement quality from clinker substitution.

Technological feasibility: Enablers include established technology for biomass boilers and efficient combustion, adaptable RECP technologies and methodologies, globally established eco-industrial park models (Karunarathne and Madhushan, 2021), and the increasing global adoption of circular economy principles. Additionally, mature tri-generation technologies are available. However, barriers include high upfront costs for SMEs to apply RECP technologies and upgrades, significant changes required in business practices for adopting circular economy models, high initial investment and complex implementation for tri-generation technologies, and limited access to finance and technology transfer for SMEs (Ministry of Industry and Commerce, 2015).

Economic feasibility: Climate mitigation options include reduced fossil fuel dependency through sustainable biomass, RECP, and circular economy practices aiming to reduce fuel costs in the long run. Tri-generation serve as an option to lower energy costs and enhance energy security for energy intensive industries, while clinker substitutions reduce production costs and carbon footprint in cement production. Policy incentives and market mechanisms further drive the adoption of low-carbon technologies. However, barriers include the short-term costs of implementing RECP and circular economy practices, the need for coordinated stakeholder collaboration, lack of support for new business model uncertainties, limited market acceptance of low-carbon cement, and economic instability in Sri Lanka affecting investment decisions (Fernando, 2021).

Sociocultural feasibility: Sri Lanka could benefit from job creation and improved working conditions through sustainable biomass supply chains and RECP practices, community benefits from eco-industrial parks, tri-generation facilities, and circular economy initiatives. Promoting low-carbon construction materials can highlight their advantages while raising awareness and fostering stakeholder engagement is crucial for success. However, barriers include resistance from industries accustomed to fossil fuels, lack of awareness and technical capacity, especially in the cement and manufacturing sectors, perceived risks of low-carbon materials, the need for mindset shifts towards sustainable consumption, and general lack of awareness about climate change issues among stakeholders.

Institutional feasibility: Enablers include crucial government support through policies and incentives for climate mitigation options. Strong institutions and coordination mechanisms are essential for effective

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implementation, although there are still some gaps in LKA despite efforts. However, barriers also exist like the lack of clear regulations, standards, enforcement, and monitoring mechanisms, which hinder RECP adoption, circular economy practices, and low-carbon cement production etc. Additionally, limited financial incentives, regulatory support, and institutional capacity and resources also pose significant challenges.

5.9.1 (Quicklink to table on enablers and barriers)

5.2.3 Current status of national-sectoral policy

Industry

As early as 1969, the *Industrial Development Act* (Parliament of Ceylon, 1969) was introduced, which implemented initiatives for industrial development, though it did not focus on climate protection. Since that time, there have been developments in Sri Lanka to promote a climate-friendly industry. Today, the aim of the Sri Lankan Government is to create a competitive and sustainable industry that has minimal damage to the environment. To achieve this, a national industrial policy strategic plan is being formulated by the Ministry of Industries.
In the area of **governance and planning instruments**, many areas of the policy package (2.2 Quicklink to report synthesis of existing knowledge) have been considered, such as long-term planning, initiatives and partnerships.

In Sri Lanka, there are current developments to implement a *National Policy for Industrial Development (NaPID)* (Fernando, 2021). The policy aims to create a globally competitive, high value-added, innovative, technology, and knowledge-based industry with minimal environmental impact. However, the policy has not yet been implemented, partly, due to comprehensive coordination issues between different ministries and agencies. The effectiveness of the policy requires a strong political will and commitment to the principles of sustainable development.

Another central measure taken is the *National Environment Action Plan (NEAP)* (Ministry of Environment, 2022), which outlines strategies and actions to address environmental challenges and achieve sustainable development in Sri Lanka explicitly including the industrial sector. Structural and informational barriers are addressed by establishing structures (like environmental agencies) and enforcing ministries to monitor and implement measures. Training programs and workshops are also being conducted, as well as dialogue formats with different stakeholders. However, the NEAP still faces the challenge of financing particularly for SMEs.

The *National Cleaner Production Policy* (Ministry of Environment, 2005) has already achieved CO_2 and waste reductions. This policy encourages the adoption of cleaner production practices by industries in Sri Lanka to minimize waste, conserve resources, and prevent pollution, with the objective of sustainable development, enhanced environmental quality, improved eco-efficiency, and poverty alleviation. The policy led to the establishment of the *National Cleaner Production Centre (NCPC)* which so far has been responsible for raising awareness and built capacity within the industrial sector. However, the challenge of closing the information gaps and the lack of knowledge (especially among SMEs) has not yet been fully achieved.

To support SMEs, the *National Policy Framework for SMEs* (Ministry of Industry and Commerce, 2015) has been implemented with a focus on raising awareness and capacity buildings on resource efficiency and clean production methods. Addressed barriers are information deficits and lack of financial resources, even if there is still room for improvement in terms of funding. Another element of the governance framework is the *Sustainable Consumption and Production Policy Sri Lanka* (Ministry of Environment, 2019), which works across a number of sectors and highlights the importance of sustainable consumption and production practice to further minimise the use of natural resources, toxic materials and waste generation. However, there is lack of mechanisms in place to enforce

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the compliance by industries.

Regarding **regulatory instruments**, Sri Lanka primarily employs standards and regulations on waste generation and disposal. The policy package lacks permits and licenses and measures to implement extended producer responsibility (for the whole lifecycle). There are three central regulatory measures affecting the industry in Sri Lanka. The *Industrial Discharge Standards* (Central Environmental Authority, 2020; Environmental Management Department, 2022)sets limits on the discharge of pollutants from industrial facilities into water bodies but lacks a comprehensive approach on environmental impacts from energy consumption and air pollution. The second regulation is the *National Emission Standards for Stationary Combustion Sources* (Central Environmental Authority, 2019), which sets emission limits for air pollutants from stationary combustion sources, such as boilers, furnaces, and turbines, in industrial and commercial facilities. However, this does not count explicitly for fugitive and process emissions. It only aims to improve air quality and reduce GHG emissions. The third regulation is the *Hazardous Waste Management Regulations* (Central Environmental Authority, 2008) that aims to control the generation, collection, transportation, storage, treatment, and disposal of hazardous waste. All above regulatory instruments lack enforcement and monitoring due to limited resources and capacity within regulatory agencies. To regularise and include environmental considerations into the procurements *Green Procurement Policy* (Government of Sri Lanka, 2017) has been introduced. Although projects with a demonstration character are primarily implemented and the activities remains limited in scope and scale.

Sri Lanka currently lacks **market-based instruments**, and most of the instruments are either in draft or planning stages. The government has developed a new *Green Bond Framework* (Mediwake, 2023) outlining the eligibility criteria, project categories, and reporting requirements for green bond issuances. Otherwise, there are still some gaps in the area of market-based instruments. No Carbon Tax and Emission Trading Scheme has yet been implemented. There have been discussions and initial steps, but no implementation has yet taken place. Further subsidies and grants or tax incentives to promote a climate-friendly industry that could address economic benefits (like high initial investments) are also lacking.

Information instruments in Sri Lanka include the *National Green Reporting System* (Ministry of Environment, 2011), that aims to encourage organisations to publicly disclose the environmental performance, including GHG emissions, resource consumption, and waste management practices. In addition, the *Industrial Energy Audit Program* (National Cleaner Production Centre, 2020) was implemented to promote energy efficiency and conservation in the industrial sector by conducting energy audits to identify potential energy-saving opportunities and to recommend appropriate measures. Despite its successes, the program's reach is still limited (especially for SME due to lack of awareness, financial constraints, or perceived high costs).

The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex in Table 7.

Table 34: Sri Lanka's policy package (industry sector)

Type of instrument	Status
Governance and planning instruments	The National Policy for Industrial Development in Sri Lanka (not yet implemented) (NaPID) National Cleaner Production Policy (2005) Industrial Development Act (IDA) of Sri Lanka (No.36 of 1969) National Environment Action Plan (NEAP) (2022) National Policy Framework for Small and Medium Enterprise (SME) Development – 2018 Sustainable Consumption and Production (SCP) Policy of Sri Lanka (2019-2030)
Regulatory instruments	Industrial Discharge Standards (2002) National Emission Standards for Stationary Combustion Sources (2019)

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	Hazardous Waste Management Regulations (2000)
Market-based instruments	Green Procurement Policy (2017) Green Bonds (2023)
Information instruments	National Green Reporting System (NGRS) of Sri Lanka Industrial Energy Audit Program of Sri Lanka

5.2.4 How to strengthen national-sectoral policy

The industrial sector[11] can substantially reduce emissions by encouraging cleaner production technologies, resource efficiency practices, and circular economy models. Operationalizing policies like the National Cleaner Production Policy and the National Environment Action Plan provide a suitable policy framework. The National Plan for Industrial Development in Sri Lanka that is currently formulated and not yet implemented has the potential to foster innovation and to attract green investment in industry. The task now is to implement the policy quickly. In this regard, political will is needed and a commitment to sustainable development principles.

The existing regulatory standards provide a good basis for developing the industry towards climate neutrality. However, there is potential to expand the existing standards (with a focus on water, waste, harmful pollutants) to other areas, such as energy efficiency, circular economy, or GHG emissions. The national-sectoral policy package could also be strengthened by additional economic instruments. So far, the focus has been on public procurement, which is an important lever for promoting low-emission products and exploiting economies of scale. However, there is still potential in the area of financial support for industry. In particular, innovative products and new production processes can be made more attractive for industry by implementing financial incentives or other economic instruments.

Capacity building through awareness and education programs (e.g. building up technical expertise) is also important, especially with regard to the implementation of new policy measures. The general resistance of certain industries to the perceived risks and uncertainties of moving to novel technologies and business models acts as one major hurdle. In Sri Lanka, information and training measures are already in place and could be expanded. Best practice examples and cooperation with other countries are also relevant here.

Regarding SMEs, financial incentives, technical assistance, and capacity-building programs would be crucial for diffusing cleaner production practices. Integrating environmental concerns into industrial development strategies and strengthening monitoring and enforcement of environmental standards are major steps toward sustainable growth.

5.3 Energy

5.3.1 Current decarbonisation status and prospects

Sri Lanka's energy sector is import-dependent; 43% of the primary energy supply is imported Petroleum (both crude oil and refined petroleum) products (SLSEA, 2019). In 2018, about USD 4 billion was spent on fuel imports, which approximately accounts for about 33% of LKA's non-petroleum export earnings (Asian Development Bank, 2019). Due to the fossil fuel dependency, Sri Lanka is highly vulnerable to global price fluctuations and supply disruptions caused by geopolitical events or climate-related disasters in oil-producing regions. Just about one-third of LKA's primary energy use comes from indigenous biomass. The rest is from petroleum, coal and

[11] With regard to specific instruments, only overarching recommendations can be provided here. Given the industry-specific differences in requirements, barriers, and enablers, it is essential to develop tailored solutions for each industry branch (cement, textile and clothing industry, solid and industrial tire production, boat and shipbuilding, ceramics, tea, coconut products, etc).

renewables including a major share from large hydro.
Coal is imported for the sole purpose of power generation whereas petroleum is used in both the transport and power sectors. Recent explorations indicate that the country has natural gas and other petroleum reserves in the northwest of the Island (Ministry of Highways Road Development and Petroleum Resource Development, 2019). However, commercialisation of these reserves is not expected in the short or medium time horizon.
Power generation in LKA is dominated by coal (33%) and oil (16%) followed by large hydro (34%) and other renewable sources (17%) (CEB, 2022). The large hydro power share makes the power system vulnerable to droughts and changing rainfall patterns caused by climate change. This has led to power outages and disruptions in electricity supply.
The country is nearly 100% electrified, the highest rate in the South-Asian region. The peak power consumption was approximately 2,717MW whereas installed power capacities are about 4,400MW in 2020 (CEB, 2022). The average emission factor for 2020 was estimated to be 0.5294 kg-CO_2/kWh.
The key target for decarbonising the power sector is to increase the share of electricity generated by renewable sources; predominantly solar and wind to 70% by 2030. Notably, the "Battle for Solar Energy" program (SLSEA, n.d.) has spurred a significant increase in rooftop solar installations. Simultaneously, the Energy Efficiency Improvement & Conservation (EEI&C) program (Wickramasinghe, 2009) including operation demand side management has been actively promoting energy-efficient appliances and practices to reduce electricity demand. Furthermore, it has been decided to halt further coal power with transitioning existing oil-based plants to use natural gas (Ministry of Environment, 2021a).
Overall, implementation of the current NDCs will result in GHG emission reduction by 25% from the power generation sector during 2021 – 2030 period. Emission reduction projections in electricity (power) sector are illustrated in the next figure.

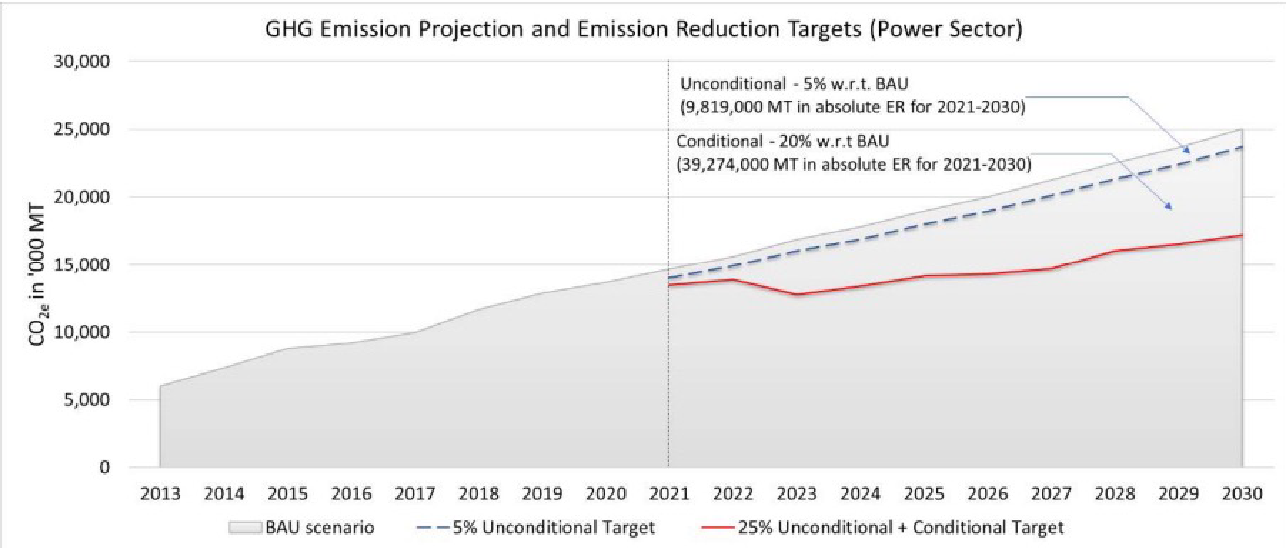

Figure 12: Emission reduction projections in electricity (power) sector.
(Ministry of Environment, 2021a)

National-sectoral mitigation enablers and barriers
The energy sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in Table 8 (annex) and summarized below:

Geophysical feasibility: Enablers include abundant solar and wind resources, excellent topography for hydropower, and biomass availability from agricultural waste (Ministry of Power and Energy, 2019). Additionally, potential exploration the natural gas resource in the Mannar basin, new renewable technologies like ocean and

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geothermal energy can replace carbon intensive energy sources to support climate action (Ministry of Environment, 2021a). Conversely, barriers include the intermittent nature of renewable energy sources, land availability and environmental concerns of large-scale projects. In addition, there is still uncertainty about the technical and economic feasibility of alternative renewable energy sources.

Environmental and ecological feasibility: Reduced GHG emissions and air pollution compared to fossil fuels, potential for carbon neutrality, energy savings across various sectors, and diversification of the energy mix to reduce reliance on conventional sources are potential benefits of energy policy (Climate Change Secretariat of Sri Lanka, 2012). On the other hand, there are also potential negative impacts on biodiversity and land use from large-scale energy projects (Batel, 2018), environmental impacts of natural gas extraction and transportation, and the need for careful assessment of potential environmental impacts of new technologies such as geothermal and wave energy.

Technological feasibility: Mature technologies for solar PV, wind, and small hydro exist, along with growing expertise in biomass power generation. Energy-efficient appliances, lighting, and building design are well-established (Sugathapala, 2020), and proven technology are available for natural gas power plants. There's also potential for developing local expertise in renewable energy and low-carbon technologies. Barriers arise from the need for grid integration and storage solutions for intermittent renewables alongside substantial reinforcement of existing electricity grid infrastructure, significant investment in additional infrastructure for natural gas, limited local expertise and R&D resources, and dependence on foreign technology and expertise.

Economic feasibility: Enablers include decreasing costs of renewable energy technologies, potential for long-term cost savings, increased energy security with diversified fuel sources, and improved reliability and quality of electricity supply through grid upgrades (Ministry of Power and Energy, 2019). However, barriers include high upfront investment costs for renewable energy projects, potential grid instability with high renewable energy penetration, lack of access to financing for energy efficiency upgrades, especially for low-income households and SMEs, high costs for replacing old appliances, risk of stranded assets with the shift to natural gas, cost recovery mechanisms impacting electricity tariffs, and high costs and risks associated with pilot projects and long commercialisation lead times.

Sociocultural feasibility: In Sri Lanka, there is a growing public awareness and acceptance of renewable energy, particularly for rooftop solar PV supported by government incentives for rooftop solar and in addition initiatives to promote energy-efficient appliances (Sugathapala, 2020). However, also barriers exist like the resistance from communities affected by large-scale renewable energy projects, resistance to changing behaviour and habits, concerns about the safety of natural gas infrastructure, and disruptions in electricity services during grid upgrades and maintenance (Batel, 2018).

Institutional feasibility: The government has implemented supportive policies and initiatives for renewable energy development, financial incentives for rooftop solar, and institutions like the Sustainable Energy Authority supporting DSM programs, pilot projects, and research. Additionally, established regulatory frameworks for energy efficiency standards, electricity tariffs, and grid management are in place. However, barriers include regulatory obstacles, bureaucratic delays, regulatory hurdles, lack of institutional coordination within long-term energy planning, limited enforcement of energy efficiency standards, insufficient capacity for monitoring and evaluation of DSM programs, and limited financial resources and technical capacity for project implementation and grid modernisation.

5.9.2 (Quicklink to table on enablers and barriers)

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5.3.2 Current status of national-sectoral policy

The energy sector in Sri Lanka is undergoing a radical transformation, with great movement on renewable sources of energy. The National Energy Policy focuses on key three pillars; ensure energy security, equity, and sustainability by diversifying the energy mix and reducing dependence on fossil fuel resources. The government is actively encouraging the use of renewable sources of energy, such as solar, wind, hydro, and biomass. The country's long-term goal of carbon neutrality in the power sector by 2050 reflects its commitment toward a sustainable energy future.
With the *Electrification Policy* (Asian Development Bank, 2023a), Sri Lanka aimed to achieve universal electricity access by 2016, bringing power to all households, businesses, and public institutions. Today, the country is nearly 100% electrified, the highest rate in the South-Asian region. However, the power generation sector is still dependent on imported fuels (coal and petroleum) and the significant potential on solar and wind energy due to favourable geophysical conditions is still largely untapped.

Sri Lanka's energy policy is shaped by **governance and planning instruments** like the *National Energy Policy* (Government of Sri Lanka, 2019) introduced in 2019 and the *Energy Sector Plan for a Knowledge-based Economy* (Ministry of Power and Energy, 2015). The first one is a comprehensive framework aimed at transforming the country's energy sector to be sustainable, secure, and affordable. It prioritizes maximizing the development and utilisation of domestic renewable energy sources to diversify the energy mix, reduce reliance on imported fossil fuels, and ensure equitable access to clean and reliable energy for all Sri Lankans. The policy has successfully driven an increase in renewable energy capacity, particularly in solar and wind power. The *'Battle for Solar Energy'* (SLSEA, n.d.) program was introduced to promote the setting up of small solar power plants on the rooftops of households, religious places, hotels, commercial establishments and industries. This program aims to add 1,000 MW of solar energy by 2025 and 1,500 MW by 2030. However, while progress has been made in rooftop solar, large-scale renewable energy projects, such as wind and hydro, have faced delays due to various factors, including land acquisition issues, environmental concerns, and financial constraints.

Another planning instrument is the *Energy Sector Development Plan for a Knowledge-based Economy*, which aims to guide Sri Lanka's energy sector towards a knowledge-based economy, focusing on energy security, efficiency, and sustainability. However, the plan's target of reducing annual energy demand growth by 2% through conservation and efficiency measures has not been fully achieved.

To strengthen the institutional capacity and to promote renewable energy and energy efficiency measures, the *Sri Lanka Sustainable Energy Authority (SLSEA)* was established (Parliament of the Democratic Socialist Republic of Sri Lanka, 2007). It plays a crucial role in overcoming institutional barriers. However, the SLSEA faces challenges in securing adequate financial resources to fully implement its mandate and scale up its programs and projects. Additionally, it remains a challenge to comprehensively consider grid integration and storage solutions in policy formulation and implementation.
Regulatory instruments include the *Sri Lanka Electricity Act* (Government of Sri Lanka, 2009), which provides the legal framework for the energy sector, including the regulation of power generation, transmission, and distribution. It enables the government to set standards for energy efficiency and renewable energy integration and enforce compliance through licensing and penalties. Over the years, several amendments (Parliament of the Democratic Socialist Republic of Sri Lanka, 2013) have been taking place for promoting renewable energy generation such as standardized power purchase agreements. However, provisions for smart grids, energy storage and DSM are still limited. The Regarding regulatory instruments, further policies and measures are missing like limits on emissions of new plants, quota on using renewables, environmental codes, etc. (see synthesis report Quicklink 2.1). Mandatory energy efficiency standards and labelling are already in place for lighting systems and ceiling fans but requires expansion to other common appliances across different sectors.

In terms of **market-based instruments**, a Feed-in Tariff (FiT) (PUCSL, 2011) has been implemented to address economic barriers on renewable energy investments. It offers long-term contracts to renewable energy producers, guaranteeing the purchase of electricity at a fixed tariff, typically higher than the grid electricity price. However, one major challenge is the financial sustainability of the FiT scheme. The fixed tariffs can be higher than the average electricity generation cost, potentially leading to increased electricity prices for consumers in the long run. Furthermore, frequent revisions of FiT is likely to discourage long-term investments. Another measure supporting renewable energy expansion is the *Net-Metering Scheme* (CEB, n.d.; PUCSL, 2023). It allows consumers to generate their own electricity using renewable energy sources, primarily rooftop solar, and offset their consumption from the grid. This has successfully incentivized the widespread adoption of rooftop solar PV systems. While it addresses the challenge of lacking financial incentives, the high upfront costs of installing solar PV systems can be a barrier, especially for low-income households, limiting their participation in the program. Targeted subsidies or financing mechanisms to make renewable energy more accessible to all is still missing in Sri Lanka. Also, in the area of market-based instruments is the *Sri Lanka Green Finance Taxonomy* (Central Bank of Sri Lanka, 2022b)., introduced in 2022 and therefore in its early stages. It is a classification system that defines and categorizes economic activities considered environmentally sustainable.

A significant gap exists regarding **informational instruments**. There is growing awareness and acceptance of renewable energy but also resistance to changes in behaviour and habits, and in large projects. Education and training programs, R&D, and public awareness campaigns are still gaps in the energy policy package. The *National Energy Benchmarking Portal (NEBP)* (U.S. Embassy in Sri Lanka, 2023) is the only instrument addressing information barriers. Developed by SLSEA, the NEBP is a digital platform aimed at tracking and benchmarking energy efficiency initiatives in the industrial, commercial, and government sectors. It allows organisations to voluntarily submit their energy consumption data for comparison against sector-specific benchmarks, promoting energy conservation and efficiency.

The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex in Table 9.

Table 35: Sri Lanka's policy package (energy sector)

Type of instrument	Status
Governance and planning instruments	National Energy Policy (2019) Energy Sector Development Plan for a Knowledge-based Economy 2015-2025 National Electrification Policy (2016): Sri Lanka Sustainable Energy Authority Act No. 35 of 2007
Regulatory instruments	Sri Lanka Electricity Act No. 20 of 2009 Electricity (Amendment) Act, No.31 of 2013 of Sri Lanka
Market-based instruments	Renewable Energy Feed-in Tariff Scheme Net-metering Sri Lanka Green Finance Taxonomy
Information instruments	National Energy Benchmarking Portal (NEBP) of Sri Lanka

5.3.3 How to strengthen national-sectoral climate policy

The energy sector has been actively engaged in climate policy implementation. However, when evaluating the policy package, it becomes clear that there are still numerous gaps, particularly in the area of economic and informational instruments. Existing instruments could also be expanded in order to extend the good approaches that are already in place to other actors and sectors to actually achieve high GHG emission savings.
Accelerating large-scale renewable energy projects should be pursued while addressing grid stability concerns

with investments in energy storage and smart grid technologies. Adequate investments in grid infrastructure and energy storage solutions are needed to address these challenges.

Policymakers should prioritize aggressive energy efficiency measures, streamline the regulatory framework for renewable energy integration, and ensure the financial sustainability of the feed-in tariff scheme. Expanding and mandating participation in the National Energy Benchmarking Portal across sectors would significantly contribute to broader energy conservation. Exploring innovative financial mechanisms, like the Sri Lanka Green Finance Taxonomy, and addressing data verification issues can help the country reduce GHG emissions and achieve NDC targets.

5.4 Transport

5.4.1 Current decarbonisation status and prospects

Sri Lanka's transport sector currently faces a decline in public transport usage and increasing GHG emissions due to the dominance of private vehicles. There is minimal role played by air and sea transportation modalities. Rail transport is concentrated around the city of Colombo (commercial capital) and nearby sub-urban areas for commuting (JAICA, 2014). To address these challenges, the government is focusing on revitalizing public transport, improving energy efficiency, and promoting environmentally sustainable transport practices (Asian Development Bank, 2012).

There is a tendency to use more private transport than public transport in Sri Lanka. The current composition of 6.4 million road vehicle fleet is 54% motorcycles, 16% three-wheelers (motor tricycles), and 11% motor cars, with only 1% of buses (Ministry of Environment, 2021a). Major mass public-transport projects such as the Light Rail Transit project offered in 2019 by the Japanese government was delayed significantly due to political and economic unrest in the country between 2019 and 2023, however, recent developments suggest a potential revival (News First, 2024). Consequently, there is a substantial increase in traffic congestions leading to reduced fuel economy and increased GHG emissions. Regardless of the Euro 4 emission standards and vehicle emission testing program currently put in place by the government, a considerable share of inefficient vehicles is in operation causing further increase in GHG emissions (Mobility Alliance, 2022).

Unlike the power sector, far less efforts have been taken towards decarbonising the transport sector. Current NDCs only take account for a GHG reduction of 4% from the transport sector, as illustrated in the next figure.

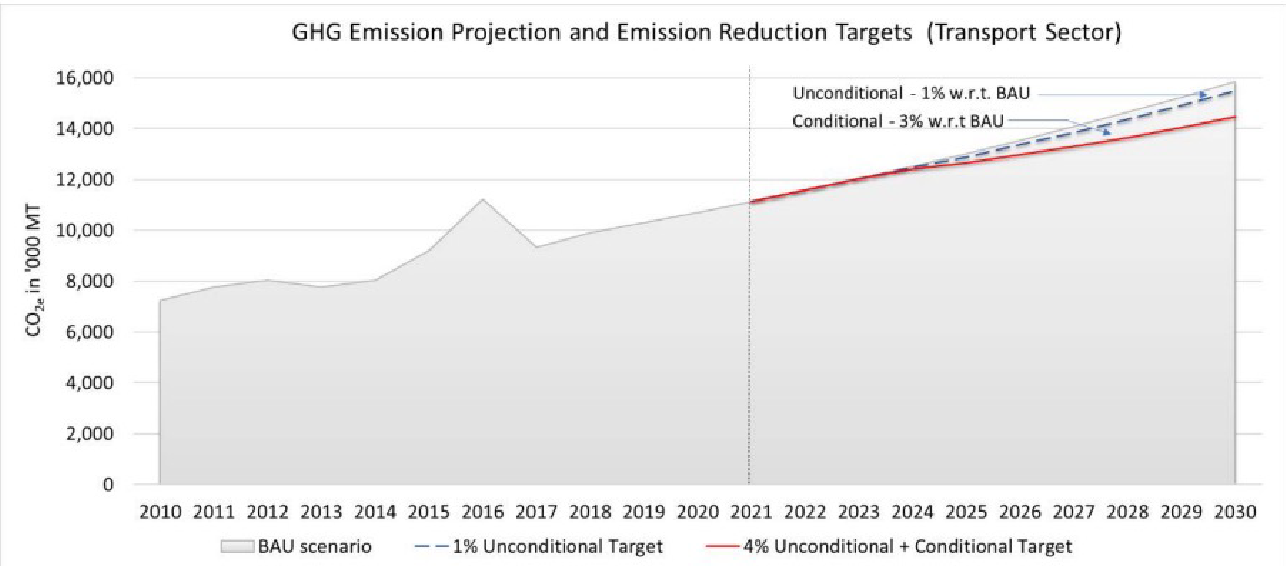

Figure 13: Emission reduction projection (transport sector)
(Ministry of Environment, 2021a)

Several initiatives are already in place to improve public transportation such as a dedicated bus lane system in urban areas to provide a faster and more reliable service aiming to reduce traffic congestions. There are railway upgrades and expansion taking place to provide more efficient transport service. Several multi-modal transport hubs were initiated integrating various modes of transport like busses, trains, and taxis for seamless passenger transfer. In addition to the actions already taking place there have been several government announcements on electrification of public buses (Climate & Clean Air Coalition, 2022) and Colombo sub-urban railways (Ministry of Transport and Highways, 2013).

5.4.2 National-sectoral mitigation enablers and barriers

The transport sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in Table 10 (annex) and summarized below:

Geophysical feasibility: Enablers include the provisions already set to improve and expand existing road and rail infrastructure while they are first build, develop Bus Rapid Transit (BRT) and Light Rail Transit (LRT) systems in major cities (Ministry of Transport, 2009), and utilize the suitable climate and terrain for walking and cycling. Additionally, rivers and canals offer potential for inland water transport. However, barriers include limited land availability for new infrastructure in urban areas, terrain challenges for rail expansion, limited rail connectivity to some industrial areas and ports, and significant seasonal water level changes in inland water systems.

Environmental and ecological feasibility: Sri Lanka's transport sector is a significant contributor to national GHG emissions, with road transportation accounting for over 80% of transport emissions (Ministry of Transportation and Civil Action, 2020). Understanding the enablers and barriers to GHG mitigation in this sector is crucial for achieving its emission reduction goals. Reduced congestion, air pollution, and GHG emissions through efficient transport systems and public transport shifts are potential benefits of an effective policy package (Mobility Alliance, 2022). Non-motorized transport modes offer zero emissions, while inland water transport and electric/hybrid vehicles can significantly lower emissions (Bastida-Molina et al., 2020). Improved vehicle fleet efficiency also reduces fuel consumption and emissions. However, also potential environmental impacts from new infrastructure construction, such as land use change and habitat loss are possible. Additionally, air pollution and safety concerns affect non-motorized transport in urban areas, and inland water transport may harm aquatic ecosystems. Electric vehicles need a clean electricity grid to maximize their environmental benefits.

Technological feasibility: Technologies for intelligent transport systems are already available, as well as for traffic management, and electric mobility (Higueras-Castillo et al., 2023). Existing rail infrastructure can be upgraded for freight transport, and technologies for intermodal transport, such as containerisation, are available. BRT and LRT technologies are mature and widely used globally (Ministry of Transport, 2009), and electric and hybrid vehicle technologies are readily accessible. However, policy measures also involve high upfront investment costs for technology upgrades and infrastructure, the need for investment in rail infrastructure and logistics, careful planning and integration of BRT and LRT systems with existing transport networks, limited charging infrastructure outside urban areas, and substantial retrofitting costs for older vehicles, which can be challenging for some income groups.

Economic feasibility: Enablers include the potential for taxes promoting public transport to generate substantial government revenue and improved transport efficiency reducing fuel costs and travel time, boosting productivity. Public transport can offer lower operating costs and fares compared to private vehicles (Pallawala, 2019), with job creation potential in the sector. Rapid Transit systems can enhance travel times and reliability, while electric vehicles have lower operating costs due to reduced fuel and maintenance expenses. Barriers include high upfront investment costs for BRT and LRT infrastructure, high costs of electric vehicles, potential negative impacts of public transport taxes on low-income groups, the need for government subsidies to keep public transport affordable, fare competitiveness with private vehicles, limited range of electric vehicles, and concerns about battery life.

Sociocultural feasibility: There is a potential for improved accessibility, safety, and comfort for passengers, increased convenience for urban residents through Rapid Transit modes, and a growing global trend towards electric mobility (Higueras-Castillo et al., 2023). Developed road infrastructure also contributes to better road safety and reduced travel time for commuters. However, other issues must also be considered like resistance to changing travel habits and preferences, negative perceptions of public transport due to overcrowding, unreliability, and safety concerns, cultural preference for motorized transport, limited public awareness and demand for inland water transport, unfamiliarity with electric vehicles, and resistance from the automotive industry and used vehicle importers to adopt fuel-efficient technologies.

Institutional feasibility: The Ministry of Transport and Highways is able to coordinate and implement transport system improvements (Ministry of Transport, 2009). The Department of Motor Traffic can enforce fuel efficiency standards, while public transport operators like the Sri Lanka Transport Board and Sri Lanka Railways should be strengthened and modernized. The Road Development Authority can lead infrastructure development, and existing tax and regulatory mechanisms can be adapted to promote public transport. Government incentives and policies can also support electric vehicle adoption (Pallawala, 2019). However, coordination challenges among agencies, limited institutional capacity for planning and implementation, lack of political will to prioritize public transport investment, limited financial resources and technical capacity for large-scale upgrades, and the need for regulations and standards for electric vehicle charging infrastructure exist.

5.9.3 (Quicklink to table on enablers and barriers)

5.4.3 Current status of national-sectoral policy

In the area of **governance and planning instruments**, the *National Transport Policy* (Ministry of Transportation and Civil Action, 2020) is a central strategic instrument, though it currently exists only as a draft and has not been officially adopted. It aims to guide the development of a safe, efficient, and sustainable transport system in Sri Lanka. It emphasizes prioritizing public transport, integrating different modes of transport, and reducing the sector's environmental impact. For example, the policy promotes the development of sustainable transport infrastructure such as dedicated bus lanes and cycling paths. The importance of improving energy efficiency and fuel economy in the transport sector is highlighted as a means of contributing to reduced emissions and lower fuel costs. However, as the policy is still in draft form, not only is its regulatory power limited, but its financing is also not secured.

Already implemented is the *Urban Transport Development Plan* (JAICA, 2014), which was developed with assistance from the Japan International Cooperation Agency and aims to address the growing challenges of urbanisation and traffic congestion in major cities. It outlines strategies for improving public transportation, managing traffic demand, and promoting sustainable transport modes (bus rapid transit, light rail transit). For instance, some concrete measures are the integration of different modes of transport through the development of multi-modal transport hubs (MMTHs), traffic demand management, parking management, etc. However, implementation obstacles exist, including funding constraints and land acquisition issues.
The *Integrated Road Investment Program* (Asian Development Bank, 2023b) also contributes to promoting a climate-friendly mobility with a smaller scope. It primarily aims to improve rural connectivity and modernize roads, but also includes measures for climate adaptation. Overall, in Sri Lanka, there is a lack of comprehensive strategies, goals, and urban/spatial/regional planning to consider the transport sector holistically and implement coordinated and long-term climate protection measures. Notably, the topic of modal shift policies has been

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insufficiently addressed.

In addition to the framework for sustainable mobility, specific policy measures have also been implemented. As a **regulatory measure**, the *National Emission Standards* (Central Environmental Authority, 2019) for new vehicles, which align with Euro-4 standards, can be mentioned first. It sets maximum permissible limits for various pollutants emitted by vehicles. The implementation has led to a significant reduction in emissions of harmful air pollutants such as particulate matter (PM), nitrogen oxides (NOx), and carbon monoxide (CO) from new vehicles. This is also related to the *Motor Vehicle Act* (Parliament of the Democratic Socialist Republic of Sri Lanka, 2009a)., which mandates periodic inspection of vehicles to ensure compliance with emission and safety standards. This helps to identify and address high-emitting vehicles, contributing to improved air quality and reduced emissions. However, this requires robust enforcement mechanisms and regular monitoring of vehicle emissions. The act also expands to speed limits depending on the area and vehicle type, though it is not explicitly linked to climate policy yet. *Vehicle imports* (Ministry of Transport and Highways, 2016) are also addressed through regulatory measures. This typically include age restrictions and emission standards for low-emission vehicles. This has helped to improve the overall fuel efficiency and emissions profile of the vehicle fleet in Sri Lanka. Tax incentives for low-emission vehicles were also introduced, but due to the lack of funding, these incentives are not effective as they do not sufficiently reduce costs compared to high-emission vehicles. Vehicle import regulations are not currently a part of a comprehensive strategy to reduce emissions from the transport sector.

Other **economic instruments** include *Road User Charges* (RDA, 2024), which, although currently only applied to certain expressways in Sri Lanka and not explicitly implemented as a comprehensive policy instrument for climate change mitigation, can be a mechanism to promote sustainable transport. By making driving more expensive, they can incentivize the use of public transport and other low-emission modes. The *Fuel Price Mechanism* (Ministry of Transport and Highways, 2011) has yet to realize its full potential, as Sri Lanka is yet to integrate carbon taxes into the fuel pricing mechanism, particularly focusing on fuels for road transport. Continued fuel subsidies, particularly for diesel, distort market signals, encourage overconsumption of fuel, and undermine the impacts of GHG emissions. Fuel prices in Sri Lanka are not fully cost-reflective, failing to account for the negative externalities of fuel consumption, such as air pollution and climate change impacts. This leads to under-pricing of fossil fuels and discourages the transition to cleaner alternatives.

The mentioned instruments are supported by **information instruments**. The *Measurement, Reporting, and Verification (MRV) Framework* (Climate Change Secretariat of Sri Lanka, 2019) for the Transport Sector in Sri Lanka is a system designed to track and assess the progress of climate actions and their impacts in the transport sector. It involves collecting and analysing data on GHG emissions, mitigation actions, and their effectiveness in reducing emissions. This has addressed the issue of the lack of information and monitoring of environmental data well, but the measures fall short of their potential as the necessary capacities for systematic data collection have not yet been established. Studies have also been conducted on how a *Nationally Appropriate Mitigation Action (NAMA)* (UNDP, 2015) can be implemented, investigating the introduction of electric buses. Further barriers were identified, such as financial resources, developing charging infrastructure, and training personnel. Public awareness campaigns and knowledge-sharing measures remain a gap in the policy package, as do measures to promote international cooperation.
The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex in Table 11.

Table 36: Sri Lanka's policy package (transport sector)

Type of instrument	Status
Governance and planning instruments	National Transport Policy (2020) – Draft Urban Transport Development Plan (2014) Integrated Road Investment Program (2023)

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Regulatory instruments	National Emission Standards for Vehicles (2018) Motor Vehicle Act (2007) Regulations on Vehicle imports in Sri Lanka
Market-based instruments	Fuel Pricing Mechanism Road User Charges
Information instruments	Measurement, Reporting, and Verification (MRV) Framework for the Transport Sector in Sri Lanka NAMA Design Document for the Transport Sector of Sri Lanka: Electric Bus Rapid Transit System

How to strengthen national-sectoral climate policy

Only a limited number of measures have been taken to reduce GHG emissions in Sri Lanka's transport sector. Strengthening climate policy involves finalizing and implementing the National Transport Policy, expanding public transportation infrastructure, implementing Traffic Demand Management measures, and encouraging non-motorized transport options.

Firstly, the National Transport Policy, currently in draft form, needs to be officially adopted to provide a robust regulatory framework for sustainable transport development. Its adoption could set a clear strategic direction for the transport sector's decarbonisation including incentives for potential investment on infrastructure and clean technologies. Effective implementation requires robust coordination among various institutions. Establishing a centralized coordinating body can streamline efforts and improve communication among stakeholders. Enhancing the capacity of existing institutions through training and resource allocation can ensure they are equipped to enforce regulations and implement sustainable transport initiatives. Developing clear regulations and emission standards for emerging technologies, such as electric vehicle charging infrastructure, is also essential.

Economic instruments need refinement to effectively promote sustainable transport. Integrating carbon taxes into the fuel pricing mechanism and phasing out fuel subsidies would create market signals that encourage the transition to cleaner alternatives. A comprehensive approach to road user charges and incentives for cleaner vehicles could contribute to achieving emission reduction targets. Increasing tax incentives for low-emission vehicles to make them more cost-competitive is also vital.

Strengthening the MRV-framework and fast-tracking the Nationally Appropriate Mitigation Action for electric buses are also relevant. Public awareness campaigns and knowledge-sharing initiatives are crucial to changing travel habits and increasing acceptance of sustainable transport options. These campaigns should focus on the benefits of public transport, non-motorized transport modes, and electric vehicles. Additionally, promoting international cooperation and leveraging global best practices can enhance the effectiveness of local policies.

Alongside all above measures, it is also important to establish a comprehensive social protection mechanism to mitigate adverse effects on affordability, particularly those who are struck by the ongoing economic crisis. This could include targeted subsidies for the less well-off, public transport fare discounts or even direct cash transfers to help with rising costs. Moreover, expanding and improving public transportation infrastructure can provide cheaper options other than owning private cars.

In conclusion, strengthening Sri Lanka's transport policy requires a multi-faceted policy package involving institutional coordination, economic incentives, public awareness, international cooperation, and innovative funding. These measures will collectively promote a sustainable, efficient, and climate-friendly transport sector in Sri Lanka.

5.5 Buildings

5.5.1 Current decarbonisation status and prospects

Sri Lanka's NDC does not explicitly layout a separate GHG emission reduction targets for the building sector. However, the mitigation efforts related to the building sector are integrated into the targets set out across other sectors, particularly the energy sector.

Sri Lanka's building sector is currently expanding particularly in the urban areas with high rise developments and

hospitality projects (Jayalath and Gunawardhana, 2017). There is also a high growth in individual housing unit constructions using conventional methods and materials which are natural resource intensive. Most of such constructions are conducted informally without adhering to regulations or quality standards (Senadeera et al., 2019). This hinders the implementation of sustainable practices and data collection for monitoring emissions.
In addition to the natural resource depletion, the sector's GHG emissions are accounted of the production of building materials like cement, calcite, and steel. Although the industrial sector, including construction, accounts only for 2.5% of Sri Lanka's total GHG emissions (Ministry of Environment, 2021a), the indirect emissions from energy consumption and transportation associated with construction are significant.
The Green Building Certification is active in Sri Lanka including guidelines for sustainable construction (Ministry of Urban Development and Housing, 2020) and Energy Efficient Building Codes (SLSEA, 2021). Although these regulatory frameworks are in place, the widespread adoption is hindered by weak stakeholder engagement and financial resources. It has been identified in the Energy Efficient Building Code that most significant opportunities for GHG emission reduction lie in the planning and design stages of building projects. In addition, plans are being made to implement mandatory building codes, energy efficiency standards for appliances, and green building certifications to drive the adoption of sustainable practices in the building sector of Sri Lanka.

5.5.2 National-sectoral mitigation enablers and barriers

The building sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in Table 12 (annex) and summarized below:

Geophysical feasibility: Sri Lanka's diverse climatic zones can support the adaptation of various building designs and technologies, promoting climate-friendly building policies (Herath et al., 2018). However, these zones also pose significant barriers due to their vulnerability to extreme weather events such as floods, cyclones, and droughts (Climate Change Secretariat of Sri Lanka, 2010). The frequency of these events has increased over the years, influenced by changes in the climate of the Bay of Bengal.

Environmental and ecological feasibility: The building sector can benefit from using locally sourced, low-impact materials for informal housing (Ministry of Urban Development and Housing, 2020), and there are opportunities for green infrastructure techniques like green roofs, rainwater harvesting, and grey water management (Herath et al., 2018). However, environmental impacts from resource extraction and construction waste disposal pose significant barriers if sustainable practices are not followed (Athapaththu et al., 2016). Additionally, rapid urbanisation is causing land-use changes and habitat loss, further complicating efforts to implement climate-friendly building policies (Abeysekera et al., 2016).

Technological feasibility: Enablers include access to modern construction techniques and materials, along with a growing interest in sustainable technologies like Compressed Stabilised Earth Block (CSEB) and solar PV for buildings. These factors promote climate-friendly building policies. However, barriers include the limited adoption of sustainable practices due to cost and lack of awareness (Athapaththu et al., 2016), as well as a shortage of skilled labour for implementing advanced technologies.
Economic feasibility: Climate-friendly building policies are supported by opportunities for cost savings through energy-efficient design and renewable energy integration, along with government incentives for green building certifications (Ministry of Urban Development and Housing, 2020). However, barriers include the high upfront costs of sustainable materials and technologies (Senadeera et al., 2019) and limited financial mechanisms and incentives for low-income housing to adopt sustainable designs.

Sociocultural feasibility: The ongoing energy crisis and high energy bills are driving public interest in sustainable living and green building concepts, promoting climate-friendly building policies. However, barriers include a strong cultural preference for traditional designs and materials, which may hinder the adoption of some sustainable practices. Additionally, there is a lack of awareness about the benefits of sustainable buildings (Athapaththu and Karunasena, 2018).

Institutional feasibility: Sri Lanka's climate-friendly building policies benefit from established institutions like the Green Building Council and the Urban Development Authority, which authorize Green Building certification schemes (Ministry of Urban Development and Housing, 2020). Additionally, government policies are being developed to promote sustainable urban planning (Ministry of Environment, 2019). There are established institutions in Sri Lanka responsible for establishing building codes and regulations such as the Department of Buildings and Construction Industry Development Authority (CIDA) functioning under the Ministry of Urban Development and Housing. However, these institutions lack capacity for monitoring and reinforcing the building codes and regulations nationwide (Senadeera et al., 2019). In addition, there is a lack of comprehensive data on building energy performance and emissions which are essential aspects of tracking the level of GHG emissions from the building sector.

5.9.4 (Quicklink to table on enablers and barriers)

5.5.3 Current status of national-sectoral policy

In Sri Lanka, a policy package has been implemented to promote climate-friendly new construction and existing buildings. This package comprises a governance framework, regulatory instruments, as well as economic and informational measures.

In terms of **governance and planning instruments**, two political bodies are mainly responsible for building policies, namely the *Ministry of Urban Development and Housing*, which is the primary responsible for formulating and implementing national policies related to urban development and housing, including building regulations and standards, and the *Urban Development Authority (UDA)*, which is a statutory body under the Ministry of Urban Development and Housing and is responsible for planning and regulating urban development activities, including enforcing building codes and regulations in urban areas. The *Sri Lanka Sustainable Housing and Construction Roadmap 2020-2050* (Ministry of Urban Development and Housing, 2020) outlines a comprehensive strategy for transitioning Sri Lanka's housing and construction sector towards sustainability. The roadmap provides a holistic and long-term vision for sustainable housing and construction, covering the entire lifecycle of buildings from planning to demolition (including urban planning, building design, materials, operations, appliances, clean energy, demolition, and resilience). Several capacity building programs and workshops have been conducted to enhance the knowledge and skills of professionals in the industry. However, it is important to note that there is a lack of comprehensive data on the environmental performance of the building stock in Sri Lanka. This makes it difficult to accurately assess the impact of the implementation of the roadmap and identify areas for improvement. Another overarching regulation is the *Protection of the Construction Industry Development Act, No.33 of 2014* (Parliament of the Democratic Socialist Republic of Sri Lanka, 2014), which aims to develop and regulate the construction industry in Sri Lanka, to ensure quality standards, to increase professionalism and to promote sustainable practices. The *Construction Industry Development Authority (CIDA)* was established to control and implement the Act's provisions. To address the lack of information, CIDA has initiated training programs and workshops for construction professionals to enhance their knowledge and skills. However, it also has to be mentioned that significant portion of the construction sector in Sri Lanka operates informally, with many small-scale projects being undertaken without adherence to regulations or standards. This hinders the implementation of sustainable practices and makes it difficult to monitor emissions from the sector. As cooling is very relevant for Sri Lanka, the *National Cooling Policy* (Ministry of Environment, 2021b) was formulated as a strategy to address the growing demand in Sri Lanka while minimizing the environmental impact. The document has not yet been officially adopted, but it aims to focus on improving access to cooling, increasing energy efficiency, reducing GHG emissions and protecting the ozone layer.

Regulatory instruments in particular include the *Energy Efficiency Building Code (EEBC)* (SLSEA, 2021), which is a key instrument for promoting a climate-friendly building sector. The EEBC aims to improve the energy performance of buildings by setting minimum requirements for energy efficiency in design, construction, and operation. It covers various aspects, including building envelope, HVAC systems, lighting, and appliances. The introduction of the EEBC has raised awareness among architects, engineers, and builders about the importance of energy efficiency in building design and construction, although there is still potential for further capacity building programs. However, it should be noted that the Building Codes currently only apply to commercial buildings, industrial facilities, and large-scale housing developments exceeding specific criteria (e.g., floor area, power demand, air conditioning capacity). Expanding the scope to include smaller residential buildings would have a greater impact on overall energy consumption and emission reductions. *Energy Efficiency Standards and Labelling Program* (SLSEA, n.d.) is set to reduce energy consumption from buildings by applying standards and providing consumers to choose efficient appliances. Expanding the scope to include other energy-consuming appliances, like televisions and washing machines, would further enhance the impact. While awareness has increased, some consumers still prioritize price over energy efficiency when purchasing appliances. Continued awareness campaigns and education programs are needed to encourage a shift towards more sustainable consumption patterns. However, these standards do not cover other aspects of building energy consumption such as building design and insulation.

There is still a large gap in the policy package when it comes to **economic instruments**. Many of the measures already mentioned will only develop their full potential if financing is secured. Examples of economic instruments include energy efficiency obligations, financial incentives (for highly energy efficient buildings, alternative forms of housing etc.), loans and grants.

In contrast, Sri Lanka has introduced a number **information instruments**, although these focus primarily on labels and certificates. The first of these is a *Voluntary Green Building Certificate* (Green Building Council of Sri Lanka, 2023). The number of certified green buildings in Sri Lanka has been steadily increasing, indicating a growing demand for sustainable buildings and a positive shift in the market. Furthermore, some buildings in Sri Lanka have achieved international *LEED Certification*, demonstrating its potential for green building development. This has increased awareness and acceptance of climate-friendly construction, particularly in commercial buildings, as homeowners and small-scale developers still face challenges like higher costs and lack of awareness. Certificates are not only an informational instrument but can also be counted among the market-based instruments. They can provide developers and building owners with an incentive to introduce environmentally friendly building technologies and practices. A *Green Labelling System for Sustainable Building Materials and Products (GREENSL)* (Green Building Council of Sri Lanka, 2022) is also available. This is a voluntary, third-party certification system that evaluates, and labels sustainable building materials and products based on their environmental performance across their lifecycle. Acceptance, however, is still limited. Many manufacturers and builders still opt for conventional materials due to cost considerations or lack of awareness about the benefits of sustainable alternatives.

Finally, it should be noted that in addition to the policy measures mentioned, the policy package for buildings also lacks other policies such as policies promoting energy services, public procurement and R&D policies.
The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex in Table 13.

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Table 37: Sri Lanka's policy package (building sector)

Type of instrument	Status
Governance and planning instruments	Sri Lanka Sustainable Housing and Construction Roadmap 2020-2050 Construction Industry Development Act, No.33 of 2014 National Cooling Policy (Draft)
Regulatory instruments	Energy Efficiency Building Code (EEBC) of Sri Lanka Energy Efficiency Standards and Labelling Program.
Market-based instruments	
Information instruments	Green Building Certifications in Sri Lanka Green Labelling System for Sustainable Building Materials and Products (GREENSL) in Sri Lanka

5.5.4 How to strengthen national-sectoral climate policy

First of all, improving governance and planning frameworks is crucial. In strengthening Sri Lanka's building sector climate policy, the government must finalize and implement the National Sustainable Housing and Construction Roadmap while addressing financial barriers and data gaps. Developing a comprehensive data collection system to monitor the environmental performance of buildings is essential for assessing the impact of implemented policies and identifying improvement potentials.

Strengthening the enforcement of existing regulations and expanding the scope of the Energy Efficiency Building Code (EEBC) to include smaller residential buildings can significantly enhance energy efficiency across the sector. Energy efficiency standards and labelling are currently only available for a few selected appliances. This regulation could be extended to other products and building technologies. Circular economy aspects could also be addressed more strongly here.

Furthermore, introducing more robust financial incentives, such as subsidies, tax rebates, and low-interest loans for green building projects, can encourage investment in energy-efficient technologies and materials. Additionally, establishing a fund for climate-resilient infrastructure can ensure consistent financial support for both new constructions and the renovation of existing buildings. This is still the biggest gap in the policy package.

Investing in technological innovation and capacity building is another key area. Promoting R&D in sustainable building technologies, such as advanced insulation materials, energy-efficient appliances, and renewable energy systems, can drive technological advancements in the sector.

Another key area in the Sri Lanka policy package for buildings are labelling and certification measures. In this regard, making green building certifications mandatory for some projects and increasing GREENSL-certified products could encourage broader sustainable practices. In addition, enhancing energy efficiency labeling programs to include more appliances and increase consumer awareness is crucial. Also, considering the informal construction sector, incentivizing sustainable building practices, and extending the Energy Efficient Building Code to smaller residential buildings would significantly reduce GHG emissions.

Additionally, expanding capacity-building programs and training for architects, engineers, and construction workers on the latest sustainable building practices can enhance the overall quality and sustainability of construction projects.

5.6 AFOLU

5.6.1 Current decarbonisation status and prospects

Out of the 65,610 km^2 of land in LKA, 35% is used for agriculture and about 30% remains as forests (Department of Land Use Policy Planning, 2016). Home gardens account for 18% of the total land area. The main agricultural products in LKA are rice/paddy, tea, rubber, and coconut. About 70% of the land available for agriculture is used for these major crops. The overall agricultural production contributes to about 7% of LKA's GDP whereas the sector has been the livelihood for more than 1.65 million smallholder farmers (Central Bank of Sri Lanka, 2023a). Most of these smallholder farmers lack access to modern technology and practices, leading to low productivity and high emissions.

According to the NDCs, Sri Lanka aims to reduce the GHG emissions in the forestry sector and in the agriculture and livestock sector by 7%, as illustrated in the next figure. This is planned to be achieved by current policy formulations aimed at promoting sustainable agriculture and environmentally conscious farming. This includes modernizing agriculture practices, using renewable energy, reducing water usage, and improving value addition and waste management in both crop and livestock sectors (Ministry of Agriculture, 2021).

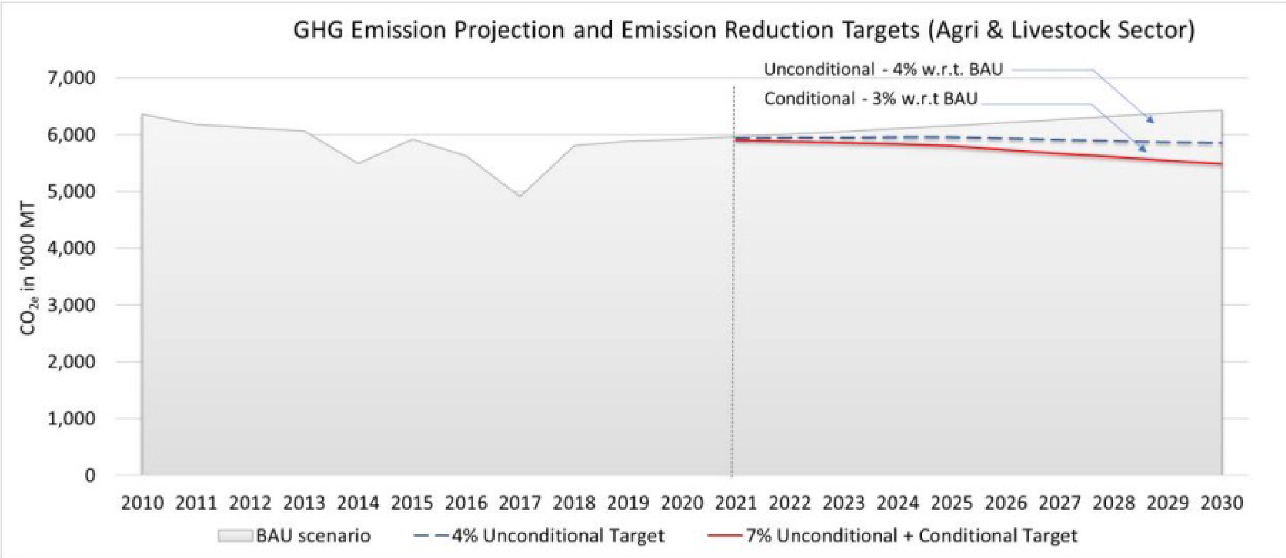

Figure 14: Emission reduction projection (agriculture and livestock)
(Ministry of Environment, 2021a)

The forest cover in Sri Lanka has been severely degraded due to land conversion for agriculture, plantations, and development activities like highway construction (Sri Lanka UN-REDD Programme, 2017). At the same time there have been natural forest fires. Deforestation remains a significant challenge to Sri Lankas's high biodiversity and has led to landslides, soil erosion and flooding, particularly in the wet zone.

One of the key highlight targets of Sri Lanka's NDCs is to increase the forest cover to 32% of the total land area by 2030 and subsequently increase the natural carbon sequestration capacity by 7% compared to the BAU scenario (Ministry of Environment, 2021a). To enhance carbon sequestration, the government is planning to prioritize reforestation, restoration of degraded land and agroforestry initiatives. Key strategies here are first to promote sustainable forest management practices and secondly to engage the public sector in those initiatives. To disaster risk reduction and climate change adaptation, it has been identified to utilize nature-based solutions such as mangrove restoration and forest conservation on steep slopes (Ekanayake and Theodore, 2017).

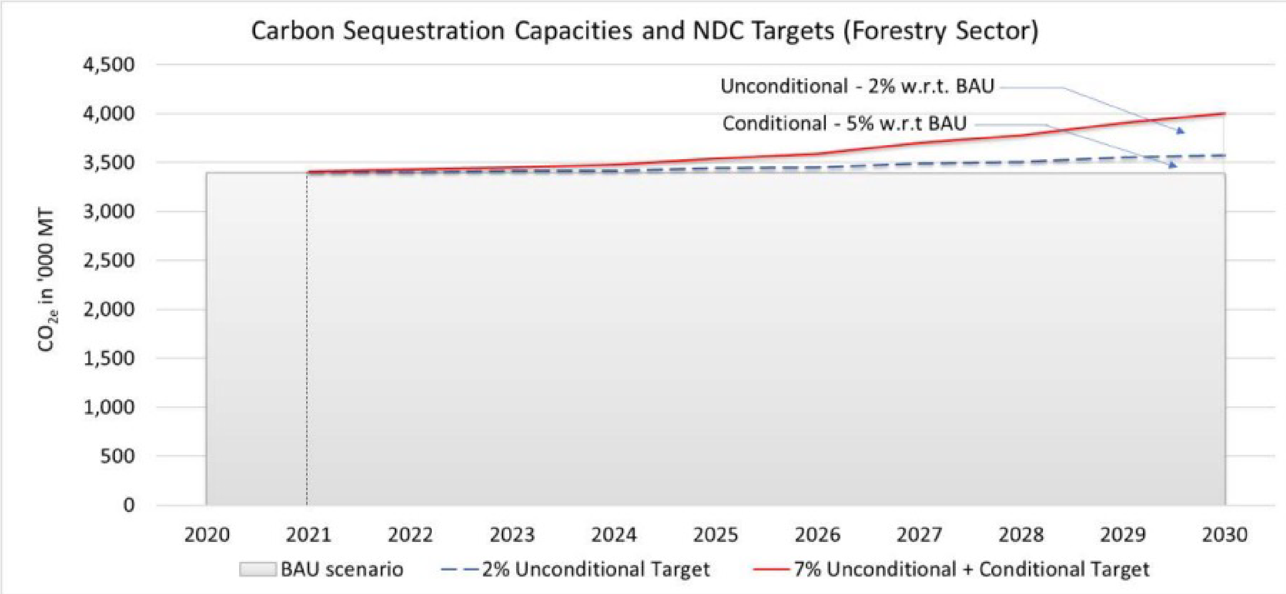

Figure 15: Carbon Sequestration Capacity Projections (Forestry Sector)
(Ministry of Environment, 2021a)

National-sectoral mitigation enablers and barriers

The AFOLU sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in Table 14 (annex) and summarized below:

Geophysical feasibility: Enablers include diverse climatic zones and soil types suitable for various tree species (Ekanayake and Theodore, 2017), diverse agro-ecological zones suitable for various crops and livestock systems, and potential for expanding renewable energy generation in rural areas (solar, biogas)(Department of Land Use Policy Planning, 2016). However, barriers include limited land availability due to competing land uses like agriculture and urbanisation, and vulnerability to extreme weather events such as droughts and floods, which can negatively impact reforestation efforts, crop yields, and livestock production (Climate Change Secretariat of Sri Lanka, 2012).

Environmental and ecological feasibility: Reforestation and afforestation efforts (De Zoysa, 2017), along with sustainable agriculture practices (Ministry of Environment, 2015) are enablers improving soil health, biodiversity and water resources. Forests are crucial to contribute to carbon sequestration and provide essential ecosystem services (Mattsson, 2012). The long-term success of these initiatives needs to address the barriers such as invasive plant species threatening native ecosystems, intensive agriculture practices leading to soil erosion and water pollution, and overgrazing and deforestation for agricultural expansion (Balasooriya et al., 2015; Ekanayake and Theodore, 2017).

Technological feasibility: Access to modern forestry techniques and technologies such as remote sensing, GIS and drones as well as improved tree varieties and agroforestry systems is an important factor (Mattsson, 2012). Improved plant varieties, precision farming technologies and efficient irrigation systems are also available. In addition, the current energy crisis has sparked interest in renewable energy applications in agriculture, such as solar-powered irrigation pumps and biogas digesters. However, barriers are also available and include limited uptake of these technologies due to high costs and lack of awareness among smallholder farmers (Jayalath and Gunawardhana, 2017), who face significant upfront costs and limited access to technology and technical capacity.

Economic feasibility: Enablers consist of income and employment opportunities from forest-based industries (De Zoysa, 2017), incentives from carbon credits and payments for ecosystem services, and increased productivity

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and reduced input costs through efficient resource management and technology adoption. Additionally, there is potential for higher income through value addition and market access for diversified crops and livestock products. However, barriers include high upfront costs for reforestation and forest management, competing economic interests in land use (such as energy generation, agriculture, and tourism), and high investment costs for technology adoption and infrastructure development for sustainable agricultural practices (Mattsson, 2012).

Sociocultural feasibility: The society's strong cultural and spiritual connection to forests supports community-based forest management models, fostering participation and ownership (De Zoysa, 2017). However, barriers include land tenure issues, conflicts over forest resources, and a lack of awareness and capacity among local communities regarding sustainable forestry practices. Moreover, resistance to change and adoption of new technologies among traditional farmers pose challenges. Additionally, land tenure issues and social inequalities can impede access to resources and opportunities within the farming community.

Institutional feasibility: Existing policies and institutions for forest conservation and management, along with government agencies supporting agriculture and livestock development, serve as enablers. Initiatives promoting sustainable agriculture practices and renewable energy adoption also contribute positively. However, weak enforcement of forestry regulations and illegal logging hinder deforestation reduction efforts (Ekanayake and Theodore, 2017). Limited coordination among different agencies involved in agriculture and land-use poses a challenge. Additionally, the weak enforcement of environmental regulations in the agricultural sector further complicates the implementation of climate-friendly policies.

5.9.5 (Quicklink to table on enablers and barriers)

5.6.2 Current status of national-sectoral policy

In Sri Lanka, there is potential through diverse climatic zones, soil types, and suitable areas for the expansion of renewable energies. Also, the strong cultural and spiritual connection of the Sri Lankan society to forests is important. On the other side, the sector faces challenges such as extreme weather events, intensive agriculture, water pollution, and loss of biodiversity. Therefore, it is crucial to focus on the AFOLU sector and implement measures to promote climate protection. The AFOLU sector is characterized by **governance and planning** instruments. The *National Environment Action Plan (NEAP) 2022-2030* (Ministry of Environment, 2022) outlines strategies and actions to address environmental challenges and achieve sustainable development in Sri Lanka. It encompasses various sectors, including land use, with a focus on sustainable land management, biodiversity conservation, and climate change adaptation and mitigation. However, the NEAP still lacks robust monitoring and evaluation mechanisms to track progress towards its goals.

Another policy addressing multiple areas is the *National Climate Change Policy* (Climate Change Secretariat of Sri Lanka, 2012). It also encompasses mitigation and adaptation strategies across various sectors, including land use (forestry and agriculture). The policy has implemented initiatives for forest conservation, reforestation, and afforestation. These efforts have contributed to increasing carbon sequestration and enhancing the resilience of ecosystems to climate change impacts. However, the policy lacks specific and quantifiable targets for GHG emission reduction. Limited availability of reliable and comprehensive data on land use and land-use change (LULUC) makes it challenging to monitor the progress of the policy's implementation and assess its impact on GHG emissions.

The *National Physical Planning Policy* (National Physical Planning Department, 2019) provides a comprehensive framework for guiding land use and development in Sri Lanka. It aims to promote sustainable development by integrating economic, social, environmental, and climate considerations into land use planning decisions. The policy identifies different zones for urban development, conservation, and agriculture, based on environmental and climate considerations. This can help minimize land-use conflicts and promote climate-resilient development.

As mentioned earlier, stakeholder engagement, closing data gaps and enforcing clear political will are crucial.

In addition, the *National Land Use Policy* (Department of Land Use Policy Planning, 2016) specifically addresses the AFOLU sector. It provides a framework to ensure proper land utilisation, balancing competing demands for food security, economic development, and environmental conservation. The policy recognizes the importance of sustainable livelihoods and climate resilience, but it lacks specific and quantifiable targets for reducing emissions. Conflicts between agriculture, urbanisation, infrastructure development, and conservation persist. The *National Forest Policy* (Ministry of Agriculture Lands and Forestry, 1995) aims to ensure the conservation, management, and sustainable development of forests in Sri Lanka. The policy has led to the establishment and expansion of protected areas, conserving biodiversity, and contributing to carbon sequestration. Despite the policy's objectives, deforestation and forest degradation continue to be significant challenges in Sri Lanka due to illegal logging, encroachment, and unsustainable land-use practices.

Reducing emissions from deforestation and forest degradation while promoting sustainable forest management, biodiversity conservation, and community livelihoods is the goal of the National REDD+ Strategy. The *National REDD+ Investment Framework and Action Plan (NRIFAP)* (The Ministry of Mahaweli Development and Environment, 2017) established a National REDD+ Steering Committee and a REDD+ Secretariat, providing a strong institutional structure for implementing REDD+ activities and coordinating efforts among different stakeholders.
In the area of **regulatory instruments**, three measures can be mentioned here, although especially standards and certification are still missing. Firstly, the *Forest Conservation and Management Act (FCMA) of Sri Lanka* Parliament of the Democratic Socialist Republic of Sri Lanka, 2009b) aims to regulate timber and forest produce transport and addresses issues related to forest conservation and utilisation. The Act emphasizes sustainable management of forest resources, including the utilisation of forest produce, promoting a balance between conservation and the use of forest resources for livelihoods and economic development. The second regulatory measure is the *Land Development Ordinance of Sri Lanka* (Ministry of Justice, 1935). Although ecological criteria play a role in its implementation, some provisions of the ordinance are outdated and do not reflect the current understanding of land use and environmental sustainability. The third measure is the *Soil Conservation Act* (The Ministry of Agriculure Development and Agrarian Services, 2009), which focuses on the conservation of soil resources, prevention, and mitigation of soil erosion, and protection of land against damage by floods, salinity, alkalinity, waterlogging, and drought. The Act was enacted in 1951 and amended in 1996, and some of its provisions are outdated and do not align with current challenges and scientific understanding of soil conservation and climate change. A review and update of the Act is necessary to ensure its effectiveness in addressing contemporary issues.

Among the **market-based instruments**, *Payment for Ecosystem Services (PES)* (Kallesoe and Alwis, 2005) is a main policy. It is a mechanism where beneficiaries of ecosystem services, such as carbon sequestration, watershed protection, or biodiversity conservation, provide financial or other incentives to landowners or managers who maintain or enhance those services. Initially, only pilot projects were implemented, but the concept of PES is gaining traction in Sri Lanka, with increasing awareness among government agencies, NGOs, and local communities about its potential benefits for both environmental conservation and economic development. Since the measure is still in an early stage, there are still implementation deficits. Clear guidelines and regulations are needed to ensure transparency, accountability, and fair distribution of benefits.

Another policy to address economic barriers is the *Green Financing System* (Central Bank of Sri Lanka, 2022b), which was established to finance investments in projects that promote environmental sustainability and climate action. In Sri Lanka, this includes loans, grants, and other financial mechanisms designed to support sustainable agriculture and forestry practices, and renewable energy in the AFOLU sector. An example is financial support to smallholder farmers for adopting sustainable agricultural practices, such as organic farming and agroforestry. However, challenges in implementation remain. Many farmers and small businesses face challenges in accessing green finance options due to limited financial literacy, collateral requirements, and complex application procedures. Additionally, the policy package in the area of economic instruments could be expanded through, for example, taxes on food waste, public procurement, and access to financial resources.

The barriers of missing **information** and acceptance, as in many other sectors, are only addressed by a few measures. The *National Land Use Information System* (Sri Lanka Survery Department, n.d.) is a centralized database and platform designed to collect, manage, analyse, and disseminate land-use and land-cover (LULC) data in Sri Lanka. The system enables the creation of detailed land-use maps and the analysis of land-use change over time. Measures to inform different stakeholders (knowledge and expertise development, educational programs, consumer empowerment, food information) or to convince them of climate-friendly activities and investments are lacking so far and could be an important and effective addition to the existing policy package.
The next table lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the annex in Table 15.

Table 38: Sri Lanka's policy package (AFOLU sector)

Type of instrument	Status
Governance and planning instruments	National Environment Action Plan (NEAP) 2022-2030 of Sri Lanka National Climate Change Policy (2012) National Land Use Policy (2016) National Forest Policy (1995) National Physical Planning Policy (2017-2050) National REDD+ Strategy Sri Lanka
Regulatory instruments	Forest Conservation and Management Act (FCMA) of Sri Lanka (2009 Amendment to the Forest Ordinance of 1907) Land Development Ordinance of Sri Lanka Soil Conservation Act
Market-based instruments	Payments for Ecosystem Services (PES) Green Financing
Information instruments	National Land Use Information System (NLUIS)

5.6.3 How to strengthen national-sectoral climate policy

To enhance Sri Lanka's AFOLU sector climate policy, the government must strengthen land-use conflict resolution, monitoring, and enforcement mechanisms. This is also important to track the progress of existing policies like the National Environment Action Plan and the National Climate Change Policy. Developing comprehensive databases and regular reporting frameworks can ensure greater transparency and accountability.
Furthermore, clear, quantifiable goals for reducing emissions and improving land-use practices are needed. Strengthening institutional coordination is another critical step. Improving collaboration among various government agencies involved in land use, forestry, and agriculture will streamline efforts and enhance policy implementation.
With regard to specific policy measures, policies like the National Forest Policy and Forest Conservation Ordinance need updating to integrate climate change adaptation strategies and address illegal logging and unclear land tenure. Additionally, addressing the financial barriers is necessary. Expanding access to green financing options and providing financial incentive programs can empower different actors like farmers to adopt sustainable practices. Expanding Payments for Ecosystem Services schemes, promoting sustainable land management practices, and ensuring adequate funding for conservation are essential.
Promoting public awareness and education on sustainable practices can foster acceptance. Implementing

educational programs and campaigns to inform different stakeholders about the benefits of climate-friendly activities and investments is an important step. Increased awareness and access to green financing, improved national land Use information system data, and integrating climate change considerations into agricultural policy can significantly reduce GHG emissions and achieve targets for climate protection.

5.7 Conclusion

Sri Lanka is currently facing an economic crisis with the prolonged effects of COVID-19 leading to a decline in per capita GDP, inflation and shortage of essential goods. In addition, Sri Lanka is prone to climate change impacts and is among the highly vulnerable countries. Despite these setbacks, the government has taken ambitious measures to address the climate change and rebuild the economy.

Emission reduction from the industrial sector of Sri Lanka is plausible by shifting toward cleaner production technologies, resource management and the principles of circular economy. These can be facilitated through operationalising policies such as the National Cleaner Production Policy, the National Environment Action Plan, and the National Plan for Industrial Development. It is also essential to enforce existing regulatory standards to include energy efficiency, circular economy principles, and GHG emissions, along with the additional financial incentives for green investments, could strengthen the policy structure. To overcome such a resistance, therefore, an organisation will need to engage in capacity building and awareness programs to promote the new technologies and business models.
The key proposals for the energy sector would need to adopt a proactive approach of developing utility-scale and residential-scale renewable energy projects, more investments in energy storage and smart-grid technologies and refines the level of dedication to aggressive energy efficiency standards. The regulatory framework needs to be streamlined for renewable energy integration and ensuring the financial sustainability of the feed-in tariff schemes. This is crucial for attracting investments to achieve the ambitious renewable energy targets thereby ensuring a secure and affordable energy supply. It is also recommended that the National Energy Benchmarking Portal is enhanced/expanded and mandated across all other sectors also to report annually to promote broader energy efficiency goals.

The transport sector leading with annual GHG emissions so far has the least level of activities conducted to reduce GHG emissions. Finalizing and enforcing transport infrastructure and public transport, setting up Traffic Demand Management programs, and promoting non-motorized means of transport are highly important for the transport sector. To achieve a faster emission reduction several actions must take place. These include taking a carbon taxation system into the fuel pricing mechanism, gradual reduction in fuel subsidies and setting-up economic instruments to promote sustainable transport choice. Improvement of the MRV framework and expedited implementation of NAMA and electric buses, combined with public awareness will encourage a transition to a climate-friendly and sustainable transport sector in Sri Lanka.
Finalizing and implementing the National Sustainable Housing and Construction Roadmap to address financial and data gaps is crucial to the building sector. To drive the adoption of energy-efficient building materials and technologies, the enforcement of current regulations that govern the sector, expanding the scope of the Energy Efficiency Building Code to include smaller residential buildings and introducing green building projects are essential. Investing in technological innovation, capacity building and promoting green building certifications and labelling programs will further enhance the sustainability of the building sector.

To enhance the climate policy in AFOLU sector, in Sri Lanka, it requires strengthening land-use conflict resolution, monitoring, and enforcement. Develop comprehensive databases, as well as regular reporting frameworks, will ensure transparency and accountability. It is important to set clear and quantifiable goals to reduce emissions, improve land-use practices, as well as strengthen institutional coordination. Furthermore, updating relevant policies like the National Forest Policy and Forest Conservation Ordinance to include climate change adaptation

strategies, and address issues like illegal logging and unclear land within tenure are essential. It is also important to ensure that Sri Lanka has access to green financing, promote sustainable land management practices, and public awareness raising through educational programs.
Overall, Sri Lanka needs better coordination among government agencies, aligning national goals with local implementations, and simplifying bureaucratic processes for effective sectoral climate policy. Financial resources must be secured, institutional capacity built, and policies executed effectively. Market-based instruments, like carbon pricing, should be incentivized. Improved data collection and knowledge sharing will enable effective decision-making and public awareness.

Policy implementation must consider local contexts and needs. Community-based approaches should be encouraged to empower local participation and tailor solutions. Social equity considerations ensure vulnerable communities are protected, and policies are inclusive. Regional differences must be acknowledged in policy design, requiring an understanding of socioeconomic factors and tailoring solutions accordingly.
By incorporating these recommendations, Sri Lanka can overcome barriers, accelerate progress toward climate goals, and achieve a sustainable future where national aspirations align with local realities. This requires continuous policy monitoring and assessment, adapting to new challenges and opportunities. Prioritizing coordinated action, efficient implementation, and equity-based solutions will pave the way toward a climate-resilient and prosperous Sri Lanka that thrives in a changing world.

5.8 Bibliography

- Abeysekera, M., Wu, J., Jenkins, N., Rees, M., 2016. Steady state analysis of gas networks with distributed injection of alternative gas. Appl. Energy 164, 991–1002. https://doi.org/10.1016/j.apenergy.2015.05.099
- Asian Development Bank, 2023a. On the road to achieving full electrification in Sri Lanka.
- Asian Development Bank, 2023b. Sri Lanka: Integrated Road Investment Program. South Asia Innovation Project Brief.
- Asian Development Bank, 2019. Sri Lanka: Energy Sector Assessment, Strategy, and Road Map, Asian Development Bank.
- Asian Development Bank, 2012. The Asian Development Bank's Support for the Transport Sector in Sri Lanka.
- Athapaththu, K., Karunasena, G., Ekanayake, E.M.A.C., 2016. Sustainable Construction practices of Sri Lankan Contractors, in: The 5th World Construction Symposium 2016: Greening Environment, Eco Innovations & Entrepreneurship. pp. 489–497.
- Athapaththu, K.I., Karunasena, G., 2018. Framework for sustainable construction practices in Sri Lanka. Built Environ. Proj. Asset Manag. 8, 51–63. https://doi.org/10.1108/BEPAM-11-2016-0060/FULL/XML
- Balasooriya, N., WM, S., Kularatne, M., Gunarathna, D.K.M.L.M.M., 2015. Impact of External Costs and Benefits of Paddy Farming in Sri Lanka. Int. J. Soc. Sci. Humanit. Res. 3, 104–116.
- Bastida-Molina, P., Hurtado-Pérez, E., Peñalvo-López, E., Cristina Moros-Gómez, M., 2020. Assessing transport emissions reduction while increasing electric vehicles and renewable generation levels. Transp. Res. Part D Transp. Environ. 88, 102560. https://doi.org/10.1016/J.TRD.2020.102560
- Batel, S., 2018. A critical discussion of research on the social acceptance of renewable energy generation and associated infrastructures and an agenda for the future. J. Environ. Policy Plan. 20, 356–369. https://doi.org/10.1080/1523908X.2017.1417120
- CEB, 2022. Statistical Digest 2022.

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- CEB, n.d. Net Metering Policy.
- Central Bank of Sri Lanka, 2023a. Economic and Social Statistics.
- Central Bank of Sri Lanka, 2023b. Measures of Consumer Price Inflation | Central Bank of Sri Lanka [WWW Document]. URL https://www.cbsl.gov.lk/en/measures-of-consumer-price-inflation (accessed 7.27.24).
- Central Bank of Sri Lanka, 2022a. Annual Report.
- Central Bank of Sri Lanka, 2022b. Sri Lanka Green Finance Taxonomy.
- Central Environmental Authority, 2020. General Standards and Criteria for the Discharge of Industrial Effluents Into Inland Surface Waters.
- Central Environmental Authority, 2019. National Environmental Act No. 47 of 1980., The Gazette of the Democratic Socialist Republic of Sri Lanka.
- Central Environmental Authority, 2008. Scheduled Waste Management (Hazardous Waste Management) Licensing [WWW Document]. URL https://www.cea.lk/web/en/2013-05-07-07-51-07/waste-management-division-sin/chemicals-hazardous-waste-management-unit?id=61 (accessed 7.27.24).
- Central Environmental Authority Sri Lanka, 2016. Technical Guidelines on Solid Waste Management in Sri Lanka. Tech. Guidel. Solid Waste Manag. Sri Lanka 1–57.
- Climate & Clean Air Coalition, 2022. Enabling Environment for Electric Buses for Public Transport and their Pilot Deployment in Colombo, Sri Lanka [WWW Document]. URL https://www.ccacoalition.org/projects/enabling-environment-electric-buses-public-transport-and-their-pilot-deployment-colombo-sri-lanka
- Climate Change Secretariat of Sri Lanka, 2019. Measurement, Reporting and Verification Framework for Transport Sector in Sri Lanka., Initiative for Climate Action Transparency.
- Climate Change Secretariat of Sri Lanka, 2012. The National Climate Change Policy of Sri Lanka.
- Climate Change Secretariat of Sri Lanka, 2010. National Climate Change Adaptation Strategy for Sri Lanka 2011 to 2016.
- Climate Watch, n.d. Historical GHG Emissions [WWW Document]. URL https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&chartType=area&end_year=2020&regions=LKA&source=Climate Watch&start_year=1990
- Colombo Stock Exchange, n.d. Green Bonds [WWW Document]. URL https://www.cse.lk/pages/green-bonds/green-bonds.component.html
- De Zoysa, M., 2017. Community-based forest management in Sri Lanka: Approaching a green economy and environment. Sri Lanka For. 38, 1–23.
- Department of Land Use Policy Planning, 2016. National Land Use Policy of Sri Lanka.
- Ekanayake, B., Theodore, M., 2017. Forest Policy for Sustainability of Sri Lanka's Forest. Int. J. Sci. 3, 28–33. https://doi.org/10.18483/ijsci.1174
- Environmental Management Department, 2022. Environmental Norms.
- Fernando, R., 2021. Proposed Sri Lanka National Policy for Industrial Development: A commentary [WWW Document]. EconomyNext. URL https://economynext.com/proposed-sri-lanka-national-policy-for-industrial-development-a-commentary-88493/
- Government of Sri Lanka, 2019. National Energy Policy and Strategies of Sri Lanka.

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- Government of Sri Lanka, 2017. Draft National Policy on Green Public Procurement for Sri Lanka.
- Government of Sri Lanka, 2009. Sri Lanka Electricity Act No. 20 2009.
- Green Building Council of Sri Lanka, 2023. Green Rating System for Built Environment: Project Certification Process [WWW Document]. URL https://www.srilankagbc.org/green-rating-system-for-built-environment/
- Green Building Council of Sri Lanka, 2022. GREENSL: Labelling System Certification Process [WWW Document]. URL https://www.srilankagbc.org/overview/
- Hemakumara, M.A.P.S., Dissanayake, D.M.K.T., 2020. The Impact of Industrialization on Environmental Sustainability: A case study in Gampaha district. NSBM J. Manag. 6, 26. https://doi.org/10.4038/nsbmjm.v6i1.52
- Herath, H.M.P.I.K., Halwatura, R.U., Jayasinghe, G.Y., 2018. Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy. Urban For. Urban Green. 29, 212–222. https://doi.org/10.1016/J.UFUG.2017.11.013
- Higueras-Castillo, E., Singh, Vedant, Singh, Virender, Liébana-Cabanillas, F., 2023. Factors affecting adoption intention of electric vehicle: a cross-cultural study, Environment, Development and Sustainability. Springer Netherlands. https://doi.org/10.1007/s10668-023-03865-y
- JAICA, 2014. Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs.
- Jayalath, A., Gunawardhana, T., 2017. Towards sustainable constructions: Trends in Sri Lankan construction industry, in: International Conference on Real Estate Management and Valuation 2017. pp. 137–143.
- Kallesoe, M.F., Alwis, D. De, 2005. Financial Incentives for Ecosystem Conservation: A Review of the Development of Markets for Environmental Services in Sri Lanka. IUCN Water, Nature and Economics Technical Paper No. 4, IUCN — The World Conservation Union, Ecosystems and Livelihoods Group Asia, Colombo, Sri Lanka.
- Karunarathne, E.A.C.P., Madhushan, W.A.P., 2021. Assessment of Industrial Symbiosis Implementation Opportunities: A Study in a Selected Industrial Zone, Sri Lanka. Asian J. Environ. Ecol. 15, 38–47. https://doi.org/10.9734/ajee/2021/v15i330230
- Maheepala, S.S., Jayasinghe, G.Y., 2018. Potential applications , limitations and future perspectives of cleaner production for sustainable manufacturing processes in Sri Lanka – A, in: JUICE 2018.
- Mattsson, E., 2012. Forest and land use mitigation and adaptation in Sri Lanka - Aspects in the light of international climate change policies. University of Gothenburge.
- Mediwake, K., 2023. Introducing Green Bonds to Sri Lanka [WWW Document]. Clim. Fact Checks. URL https://climatefactchecks.org/introducing-green-bonds-to-sri-lanka/
- Ministry of Agriculture, 2021. National Agriculture Policy.
- Ministry of Agriculture Lands and Forestry, 1995. Sri Lanka Forestry Sector Master Plan. National Forestry Policy and Executive Summary.
- Ministry of Environment, 2022. National Environmental Action Plan 2022-2030: Pathway to sustainable development.
- Ministry of Environment, 2021a. Sri Lanka Updated Nationally Determined Contributions.
- Ministry of Environment, 2021b. National Cooling Policy (Draft).
- Ministry of Environment, 2019. National Policy on Sustainable Consumption & Production for Sri Lanka.

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- Ministry of Environment, 2015. National Action Programme (NAP) for Combating Land Degradation in Sri Lanka.
- Ministry of Environment, 2011. National Green Reporting System of Sri Lanka- Reporting Guidelines.
- Ministry of Environment, 2005. National Policy and Strategy for Cleaner Production.
- Ministry of Highways Road Development and Petroleum Resource Development, 2019. National Policy on Natural Gas.
- Ministry of Industry and Commerce, 2015. National Policy Framework for Small and Medium (SME) Development.
- Ministry of Justice, 1935. Land Development Ordinance [WWW Document]. URL https://www.lawnet.gov.lk/land-development/
- Ministry of Mahaweli Development and Environment, 2016. Sri Lanka's Nationally Determined Contributions (2016).
- Ministry of Power and Energy, 2019. National Energy Policy and Strategies of Sri Lanka.
- Ministry of Power and Energy, 2015. Sri Lanka Energy Sector Development Plan for a Knowledge-Based Economy 2015 - 2025.
- Ministry of Transport, 2012. Motor Traffic (Speed Limits) Regulations, No. 1 of 2012, Gazette Extraordinary No. 1763/26 of June 22, 2012.
- Ministry of Transport, 2009. Draft National Policy on Transport In Sri Lanka.
- Ministry of Transport and Highways, 2016. Importation of a Used Motor Vehicle under Import Control License .
- Ministry of Transport and Highways, 2013. Urban Transport Master Plan for Colombo Metropoliton Region and Suburbas (Summary Sheet).
- Ministry of Transport and Highways, 2011. Sri Lanka Fuel Pricing Formula 18-10-2018 [WWW Document]. URL https://de.scribd.com/document/391152921/Sri-Lanka-Fuel-Pricing-Formula-Sinhala-English-18-10-2018#from_embed
- Ministry of Transportation and Civil Action, 2020. National Transport Policy Draft (Notice).
- Ministry of Urban Development and Housing, 2020. Sustainable Housing and Construction Roadmap Consultant Team Project team Monitoring and Reporting Manager UN-Habitat-Sri Lanka.
- Mobility Alliance, 2022. Mobility Policy for Sri Lanka [WWW Document]. URL https://mobility.lk/2020/08/02/national-transport-policy/
- National Cleaner Production Centre, 2020. Energy Management – NCPC [WWW Document]. URL https://www.ncpcsrilanka.org/services/energy-management/
- National Council for Sustainable Development, 2009. National Action Plan for Hatha Lanka Programme.
- National Physical Planning Department, 2019. National Physical Planning Policy & The Plan — 2017-2050.
- News First, 2024. Sri Lanka Expecting to Resume Japan-Funded LRT Project [WWW Document]. URL https://www.newsfirst.lk/2024/05/04/sri-lanka-expecting-to-resume-japan-funded-lrt-project
- OECD, 2022. Pricing Green House Gas Emissions - Country Notes of Sri Lanka.
- Ouedraogo, N.S., 2019. Opportunities, Barriers and Issues with Renewable Energy Development in Africa: a Comprehensible Review. Curr. Sustain. Energy Reports 6, 52–60. https://doi.org/10.1007/s40518-019-00130-7

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- Pallawala, R., 2019. Opportunities and Challenges to Promote Electric Vehicles in Sri Lanka. University of Colombo. https://doi.org/10.13140/RG.2.2.17635.58407
- Parliament of Ceylon, 1969. Industrial Develcpment Act No. 36 of 1969.
- Parliament of the Democratic Socialist Republic of Sri Lanka, 2014. Construction Industry Development Act No 33 of 2014.
- Parliament of the Democratic Socialist Republic of Sri Lanka, 2013. Sri Lanka Electricity (Amendment) Act, No.31 of 2013.
- Parliament of the Democratic Socialist Republic of Sri Lanka, 2009a. Motor Traffic (amendment) Act, No 8 of 2009.
- Parliament of the Democratic Socialist Republic of Sri Lanka, 2009b. Forest (Amendment) Act, No. 65 of 2009.
- Parliament of the Democratic Socialist Republic of Sri Lanka, 2007. Sri Lanka Sustainable Energy Authority Act (Act No. 35 of 2007).
- PUCSL, 2023. Rooftop Schemes in Sri Lanka [WWW Document]. URL https://www.pucsl.gov.lk/rooftop-solar-pv-connection-schemes/
- PUCSL, 2011. The Methodology for Feed-In-Tariffs - NCRE.
- RDA, 2024. Tariff Schedule for E01, E02, E03 [WWW Document]. URL http://www.exway.rda.gov.lk/index.php?page=tariff_schedule
- Reliefweb, 2023. Sri Lanka: Floods and Landslides - Oct 2023 [WWW Document]. URL https://reliefweb.int/disaster/fl-2023-000196-lka
- Senadeera, P.H.P., Senadheera, P., Gunasekara, K.A., Perera, K.K.S., 2019. Making Residential Buildings in Sri Lanka Sustainable Through Building Regulations, in: Construction Industry Development Authority Chapter 02 of 2019.
- SLSEA, 2021. Energy Efficiency Building Code of Sri Lanka, Web : www.energy.gov.lk +94.
- SLSEA, 2019. Sri Lanka Energy Balance 2019.
- SLSEA, n.d. Sooriyabala Sangaramaya (Battle for Solar Energy) [WWW Document]. URL https://www.energy.gov.lk/en/soorya-bala-sangramaya
- SLSEA, n.d. Introducing Standards [WWW Document]. URL https://www.energy.gov.lk/index.php/en/energy-management/introducing-standards
- Sri Lanka Survery Department, n.d. Land Information [WWW Document]. URL https://www.survey.gov.lk/sdweb/pages_service_land_info.php?id=817122c8f9f9958a8a7688733ed95c9c58fcb688
- Sri Lanka Tourism Development Authority, 2024. About Sri Lanka Tourism [WWW Document]. URL https://www.sltda.gov.lk/en
- Sri Lanka UN-REDD Programme, 2017. Sri Lanka ' s Forest Reference Level submission to the UNFCCC.
- Sugathapala, T., 2020. Multi-criteria assessment of energy sector nationally appropriate mitigation actions in Sri Lanka, in: IOP Conference Series: Earth and Environmental Science. https://doi.org/10.1088/1755-1315/463/1/012181
- The Ministry of Agriculure Development and Agrarian Services, 2009. Soil Conservation Act (Chapter 450).
- The Ministry of Mahaweli Development and Environment, 2017. National REDD+ Investment Framework and Action Plan.

- U.S. Embassy in Sri Lanka, 2023. USAID and Sri Lanka Sustainable Energy Authority (SLSEA) Collaborate to Empower Businesses with innovative Energy Efficiency Solutions. [WWW Document]. URL https://lk.usembassy.gov/usaid-and-sri-lanka-sustainable-energy-authority-slsea-collaborate-to-empower-businesses-with-innovative-energy-efficiency-solution/
- UN-REDD Sri Lanka, 2017. Sri Lanka ' s Forest Reference Level submission to the UNFCCC.
- UNDP, 2015. NAMA Design Document for Transport Sector of Sri Lanka.
- UNIDO, 2024. Industrial Energy Efficiency and Decarbonisation in Sri Lanka : A diagnostic assessment report. https://doi.org/10.1201/9781420003482.ch14
- UNIDO, 2020. Assisting Sri Lanka to transition to an urban economy with a low-carbon footprint [WWW Document]. Ind. Decarbonisation Accel. URL https://www.industrialenergyaccelerator.org/where-we-work/sri-lanka/
- Wickramasinghe, H., 2009. Sri Lanka Country Report on Energy Efficiency Improvement & Conservation, Sri Lanka Energy Government.
- World Bank, 2024. Cimate Change Overview - Country Summary of Sri Lanka. [WWW Document]. URL https://climateknowledgeportal.worldbank.org/country/sri-lanka#:~:text=The climate of Sri Lanka,removed to accommodate human use.

5.9 Annex

5.9.1 Industry

5.9.1.1 National-sectoral mitigation enablers and barriers

Table 39: Overview of enablers and barriers (industry sector)
(Fernando, 2021; Hemakumara and Dissanayake, 2020; Karunarathne and Madhushan, 2021; Maheepala and Jayasinghe, 2018; Ministry of Environment, 2005)

Dimension	Enablers	Barriers
Geophysical feasibility	Ample biomass resources available (e.g. agricultural residue, wood waste) to establish a sustainable biomass supply for industries in Sri Lanka. Resource efficient cleaner production practices (RECP) are applicable to most industrial processes and sectors across Sri Lanka. There is a potential to convert existing industrial zones to eco-industrial parks. Adapting circular economy concept can be facilitated by the diversity of industries available in Sri Lanka. Tri-generation is suitable for many industrial zones as they are with high energy demands for electricity, heating, and cooling.	Geographic constraints may limit sustainable biomass availability in certain regions. The types of industries are geographically dispersed. Therefore, the widespread adaptation and monitoring of RECP may be challenging. Eco industrial parks may face the challenge limited land availability and suitability. There is a lack of infrastructure and systems for waste collection, sorting and recycling which may hinder the use of circular economy concepts. Limited availability of suitable sites within the industrial zones to establish tri-generation plants. Limited availability of alternative material as substitutions to for clinker.
Environmental-ecological feasibility	Reduction in pollution and resource depletion can be achieved through RECP.	There is potential for unsustainable biomass sourcing if not managed properly leading to deforestation and land degradation.

	Industrial eco-parks have significant potential for resource sharing, waste minimisation, and pollution reduction. Significant potential for resource conservation, waste reduction and pollution prevention through circular economy. Tri-generation can significantly improve energy efficiency and reduce emissions compared to separate generation of electricity, heating and cooling. Clinker substitution can reduce GHG emissions significantly from cement production.	Some RECP practices and circular economy practices may require trade-offs with other environmental goals. Substitutions for clinker production can create a trade-off between clinker reduction and cement quality.
Technological feasibility	There is established technology existing in Sri Lanka for biomass boilers and efficient combustion. RECP technologies and methodologies are available and adaptable. Eco-industrial park models and technologies are well established globally. Circular economy principles and practices are increasingly adopted worldwide. Tri-generation technologies are mature and available.	Application of RECP technologies and upgrades still come with high upfront costs for SMEs. Adoption of circular economy models may require significant changes in business practices. High initial investment costs and complex implementation for tri-generation technologies in Sri Lanka. There is limited access to finance and technology transfer for SMEs in Sri Lanka.
Economic feasibility	Sustainable biomass can reduce fuel costs and dependence on fossil fuels in the long run. RECP and circular economy practices bring (long term) cost savings through resource optimisation and waste reduction. Tri-generation can reduce energy costs and improve energy security. Clinker substitutions can reduce production costs and carbon footprint of cement. Policy incentives and market mechanisms can drive adoption of low carbon technologies.	Short term costs of implanting RECPs and circular economy practices may deter some industries. Require coordinated planning and collaboration among multiple stakeholders to adopt eco-industrial parks and tri-generation. Lack of support to face with the uncertainties and risks associated with new business models within circular economy. Current market acceptance of low-carbon cement may be limited due to performance concerns. Current economic instability and fluctuating mark conditions can affect investment decisions.
Sociocultural feasibility	Sustainable biomass supply chains and RECP practices offer potential job creation and improved working conditions. Eco-industrial parks, tri-generation facilities, and circular economy initiatives offer community benefits and engage consumers. Low-carbon construction materials can be promoted to emphasize the benefits. Raising awareness and fostering stakeholder engagement are crucial for the success of all initiatives.	There is still resistance from industries accustomed to fossil fuels and lack of awareness /technical capacity may hinder adoption of certain RECP practices. Especially the cement and manufacturing industries have concerns to adopt low-carbon material due to perceived risks and uncertainties. There is a need for mindset/behaviour shifts towards sustainable consumption. Lack of awareness and understanding of climate change issues among stakeholders.

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Institutional feasibility	Government support through policies and incentives is crucial for biomass energy, eco-industrial parks, circular economy, tri-generation facilities, and low-carbon cement adoption. Strong institutions and coordination mechanisms are essential for effective implementation of all initiatives.	Lack of clear regulations, standards, enforcement, and monitoring mechanisms hinder sustainable biomass sourcing, RECP adoption, eco-industrial park development, circular economy practices, and low-carbon cement production. Limited financial incentives and regulatory support also pose challenges for RECP, tri-generation, and low-carbon cement initiatives. Additionally, limited institutional capacity and resources for can hinder overall progress.

Current status of national-sectoral climate policy

Table 40: Overview of policies and measures (industry sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**The National Policy for Industrial Development in Sri Lanka (NaPID)** is currently formulated and presented to the Cabinet of Sri Lanka. It has granted approval for inclusion in Sri Lanka's National Policy Framework (2023 – 2048) by the Committee on Economic Stabilisation Revitalisation and Growth Enhancement. (Fernando, 2021). The policy aims to create a globally competitive, high value-added, innovative, technology, and knowledge-based industry with minimal environmental impact.	**Positives:** The NaPID aligns well with sustainable development goals, fosters innovation and aims to attract green investments. It also provides a comprehensive framework for industrial development with sustainability at its core. **Challenges:** The NaPID is not yet implemented. Implementation and enforcement could be challenging due to the need for coordination across multiple ministries and agencies. The policy's effectiveness hinges on strong political will and commitment to sustainable development principles.
	National Cleaner Production Policy (2005): This policy encourages adoption of cleaner production practices by industries in Sri Lanka to minimize waste; conserve resources; and prevent pollution, with an objective of sustainable development, enhanced environmental quality,	**Positives:** The policy led to the establishment of the National Cleaner Production Centre (NCPC), which provides technical assistance and training to industries on cleaner production practices. This has helped raise awareness and build capacity within the industrial sector. Under this policy Several CP projects have been implemented in various industries, leading to significant reductions in waste generation, energy consumption, and water usage. These projects have demonstrated the economic and environmental benefits of cleaner production.

	improved eco-efficiency, and poverty alleviation (Ministry of Environment, 2005)	The principles of cleaner production have been integrated into sectoral policies for agriculture, tourism, and construction, promoting a more holistic approach to sustainable development. **Challenges**: Despite the efforts of the NCPC, awareness and adoption of cleaner production practices remain low among many small and medium-sized enterprises (SMEs) due to financial constraints, lack of technical expertise, and perceived high initial investment costs. The policy was formulated in 2005 and may not fully address the current environmental challenges and emerging technologies. A review and update of the policy are necessary to ensure its relevance and effectiveness in the current context
	Industrial Development Act (IDA) of Sri Lanka (No.36 of 1969) (Parliament of Ceylon, 1969) This act oversee and implement industrial development initiatives.	**Positives:** The act established the Industrial Development Board (IDB), and it has been instrumental in providing financial and technical assistance to industries, facilitating technology transfer, and promoting investment in the industrial sector. **Challenges:** The Act primarily focuses on economic development and does not adequately address environmental sustainability concerns. There is a need to integrate environmental considerations into industrial development strategies and practices. While the IDB provides support to industries, there is a need for more targeted assistance for small and medium-sized enterprises (SMEs) to enhance their competitiveness and adopt sustainable practices.
	National Environment Action Plan (NEAP) (2022): This action plan outlines strategies and actions to address environmental challenges and achieve sustainable development in Sri Lanka. It explicitly includes the industry sector, with a focus on resource efficiency, pollution control, and climate change mitigation (Ministry of Environment, 2022).	**Positives:** The NEAP has initiated efforts to integrate environmental considerations into sectoral policies and plans, including those related to industry. This is reflected in the increased focus on sustainable industrial practices in recent policy discussions and initiatives. The NEAP has outlined plans for building capacity within environmental agencies and relevant ministries, which can improve their ability to monitor and enforce environmental standards in the industrial sector. Some training programs and workshops have been conducted in this regard. The NEAP recognizes the importance of public-private partnerships in addressing environmental challenges and has begun to facilitate dialogues and collaborations between government, industry, and civil society organisations. **Challenges:** The NEAP's implementation is still in its early stages, and adequate funding remains a major challenge. Securing sufficient financial resources is crucial for implementing programs and projects related to industrial pollution control, resource efficiency, and climate change mitigation. The NEAP emphasizes the need for technology transfer and capacity building to enable industries to adopt cleaner production technologies and practices. However, progress in this area has been slow, particularly for small and medium-sized enterprises (SMEs) that lack the financial resources and technical expertise to adopt new technologies.

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	National Policy Framework for Small and Medium Enterprise (SME) Development – 2018: (Ministry of Industry and Commerce, 2015) This policy aims to create a conducive environment for the growth and development of Small and Medium Enterprises (SMEs) in Sri Lanka. It focuses on six core areas: enabling environment, modern technology, entrepreneurial culture, access to finance, market facilitation, and research and development.	**Positives:** The policy emphasizes the importance of resource efficiency and cleaner production practices. Several programs and initiatives have been launched to support SMEs in adopting cleaner technologies and processes, including training, awareness raising, and financial incentives. The policy has led to increased awareness among SMEs about the environmental impacts of their operations and the importance of adopting sustainable practices. The policy encourages the development of green businesses and provides support for SMEs involved in renewable energy, waste management, and other environmentally friendly sectors. **Challenges:** While the policy recognizes the importance of financial access for SMEs, there is a lack of dedicated funding mechanisms and incentives specifically targeted at green investments. This can hinder the adoption of cleaner technologies and sustainable practices by SMEs, particularly those facing financial constraints. The implementation and monitoring of the policy's environmental provisions remain weak. There is a need for stronger coordination among relevant agencies and more effective monitoring mechanisms to ensure that SMEs are adhering to environmental standards and adopting sustainable practices.
	Sustainable Consumption and Production (SCP) Policy of Sri Lanka (2019-2030) (Ministry of Environment, 2019)**:** This policy aims to promote sustainable consumption and production patterns in all sectors, including industry, by minimizing the use of natural resources, toxic materials, and waste generation throughout the product lifecycle. It focuses on resource efficiency, cleaner production, and sustainable lifestyles.	**Positives:** The policy has raised awareness among stakeholders, including industries, about the importance of sustainable consumption and production practices. This has led to increased interest in resource efficiency, waste reduction, and eco-friendly products. Several pilot projects have been implemented to demonstrate sustainable consumption and production practices in various industries, showcasing the benefits of resource efficiency and waste reduction. The policy has supported capacity-building initiatives for industries, providing training and technical assistance on cleaner production, eco-design, and sustainable supply chain management. **Challenges:** Stronger enforcement mechanisms are needed to ensure compliance by industries. The policy lacks strong financial incentives, such as tax breaks or subsidies, to encourage industries to adopt sustainable practices. Providing financial support can help overcome the high initial investment costs associated with cleaner technologies and processes. While awareness among industries has increased, consumer awareness about sustainable products and their benefits remains low
Regulatory instruments	**Industrial Discharge Standards (2002):** This regulation sets limits on the discharge of pollutants from industrial facilities into water bodies, aiming to protect water quality and prevent environmental pollution (Central Environmental Authority,	**Positives:** The standards have led to a measurable decrease in the discharge of harmful pollutants into water bodies, contributing to improved water quality and aquatic ecosystem health. The existence of these standards has encouraged industries to invest in wastewater treatment technologies and adopt cleaner production practices. This has led to increased compliance with environmental regulations and reduced the negative impact of industrial activities on water resources. **Challenges:** The standards primarily focus on regulating the discharge of pollutants into water bodies and do not comprehensively

	2020; Environmental Management Department, 2022)	address other environmental impacts of industrial activities, such as air pollution and energy consumption. Expanding the scope of the standards to cover a wider range of environmental impacts would align them more closely with the NDCs' comprehensive approach to climate change mitigation. Updating the standards to incorporate more stringent limits and advanced treatment technologies is essential.
	National Emission Standards for Stationary Combustion Sources (2019): (Published under the National Environmental Act No. 47 of 1980) This regulation sets emission limits for air pollutants from stationary combustion sources, such as boilers, furnaces, and turbines, in industrial and commercial facilities. It aims to improve air quality and reduce greenhouse gas (GHG) emissions. (Central Environmental Authority, 2019)	**Positives:** The standards have contributed to a reduction in emissions of harmful air pollutants like sulfur dioxide (SO2), nitrogen oxides (NOx), and particulate matter (PM) from industrial sources. The standards incentivize industries to adopt more efficient combustion technologies and practices, leading to reduced fuel consumption and lower GHG emissions. The existence of these standards has encouraged industries to invest in pollution control technologies and practices, leading to increased compliance with environmental regulations. **Challenges:** The standards focus on stationary combustion sources and do not cover all sources of industrial emissions. For example, emissions from industrial processes and fugitive emissions are not adequately addressed. Many industries still rely on outdated and inefficient technologies that contribute to higher emissions. The government needs to incentivize the adoption of cleaner and more efficient technologies through financial mechanisms and technical assistance programs.
	Hazardous Waste Management Regulations (2000): This regulation, under the National Environmental Act, aims to control the generation, collection, transportation, storage, treatment, and disposal of hazardous waste. It defines hazardous waste, sets standards for handling and disposal, and establishes a licensing system for waste management facilities. (Central Environmental Authority, 2008)	**Positives:** The regulations provide a comprehensive legal framework for managing hazardous waste, including definitions, classifications, and procedures for handling and disposal. This is crucial for ensuring the safe and environmentally sound management of hazardous waste. The regulations encourage the adoption of environmentally sound technologies for hazardous waste treatment and disposal, such as incineration, stabilisation, and solidification. This promotes the use of safer and more sustainable practices in waste management. **Challenges:** Sri Lanka lacks adequate infrastructure for the safe treatment and disposal of hazardous waste. This includes a shortage of licensed treatment and disposal facilities, as well as insufficient capacity for handling the increasing volume of hazardous waste generated by industries. Despite the existence of regulations, enforcement and monitoring remain a major challenge due to limited resources and capacity constraints within regulatory agencies. This can lead to non-compliance by industries and illegal dumping of hazardous waste.
	Green Procurement Policy (2017): This policy aims to integrate environmental considerations into the	**Positives:** Several pilot projects have been implemented to test and demonstrate the feasibility of green public procurement in the industrial sector, including the procurement of energy-efficient appliances, LED lighting, and recycled paper. These projects have showcased the benefits of green procurement in terms of cost

	public procurement process, promoting the purchase of goods, services, and works with lower environmental impacts (Government of Sri Lanka, 2017)	savings, reduced environmental impact, and improved product quality. The policy has successfully raised awareness among government agencies about the importance of considering environmental impacts in procurement decisions. **Challenges:** While the policy provides a framework for green procurement, its implementation remains limited in scope and scale. Many government agencies still prioritize price and quality over environmental considerations due to budget constraints and lack of awareness about the long-term benefits of green procurement. The availability of green products and services in the local market can be limited, especially for specialized items. This can make it difficult for government agencies to find suitable suppliers who meet the environmental criteria.
Market-based instruments	**Carbon Tax and Emission Trading Schemes** (OECD, 2022)	**Challenge:** Sri Lanka has not yet implemented carbon tax schemes, and a nationwide Emissions Trading Scheme (ETS). There have been discussions and initial steps towards exploring this mechanism.
	Green Bonds (Mediwake, 2023)	**Positives:** The government has developed a Green Bond Framework currently functioning with the Colombo Stock Exchange (Colombo Stock Exchange, n.d.), outlining the eligibility criteria, project categories, and reporting requirements for green bond issuances. This provides a clear structure for attracting investments in green projects. **Challenges:** The concept of green bonds is still relatively new in Sri Lanka, and there is limited awareness and understanding among potential issuers and investors. This can hinder the growth of the green bond market.
Information instruments	**National Green Reporting System (NGRS) of Sri Lanka:** The NGRS is a voluntary reporting framework that encourages organisations to publicly disclose their environmental performance, including greenhouse gas emissions, resource consumption, and waste management practices (Ministry of Environment, 2011).	**Positives:** NGRS has promoted greater transparency and accountability within the industrial sector by requiring companies to disclose their environmental performance. This allows stakeholders, including investors, consumers, and the government, to assess companies' environmental impact and make informed decisions. The NGRS recognizes companies that demonstrate strong environmental performance through awards and public recognition, which can serve as an incentive for other companies to adopt sustainable practices. **Challenges:** The NGRS is currently voluntary, and participation rates, especially among SMEs, remain low. This limits the comprehensiveness of environmental data available for the industrial sector.
	Industrial Energy Audit Program of Sri Lanka: This program functions under the National Cleaner Production Centre (National Cleaner Production Centre,	**Positives:** The program has successfully conducted numerous energy audits across various industries, identifying areas where energy can be saved through the implementation of energy-efficient technologies and practices. The program also provides technical assistance and recommendations on how to implement best practices.

	2020) to promote energy efficiency and conservation in the industrial sector by conducting energy audits to identify potential energy-saving opportunities and recommend appropriate measures.	**Challenges:** Despite its successes, the program's reach is still limited. Many SMEs have not yet benefited from energy audits due to factors such as lack of awareness, financial constraints, or perceived high costs. The broader adoption of energy audits across the industrial sector, particularly among SMEs, remains a challenge.

5.9.2 Energy

5.9.2.1 National-sectoral mitigation enablers and barriers

Table 41: Overview of enablers and barriers (energy sector)
(Batel, 2018; Climate Change Secretariat of Sri Lanka, 2012; Ministry of Environment, 2021a; Ministry of Power and Energy, 2019; Ouedraogo, 2019; Sugathapala, 2020)

Dimension	Enablers	Barriers
Geophysical feasibility	Abundant solar and wind resources, suitable terrain for hydropower, and availability of biomass from agricultural waste. Availability of natural gas resources in the region (e.g. Mannar basin) to be used in oil power stations converted to use natural gas. Potential for exploring new renewable energy technologies such as ocean energy, wave energy and geothermal energy.	Intermittent nature of solar and wind energy. Land availability constraints for large-scale projects. Environmental impacts of large hydro projects. Limited awareness of demand-side management (DSM) benefits among some consumers and businesses. There may be a dependence on imported natural gas. High upfront investment is required for grid modernisation. There is uncertainty about the technical and economic feasibility of alternative energy sources.
Environmental-ecological feasibility	Reduced GHG emissions and air pollution compared to fossil fuels. Potential for carbon neutrality, energy savings (in the residential, commercial, industrial sector), and diversification of energy mix to reduce reliance on conventional sources.	Potential negative impacts on biodiversity and land use from large-scale biomass plantations. Potential rebound effect, i.e. increased energy consumption due to lower costs with DSM. Environmental impacts of natural gas extraction and transportation to the coastal areas of Sri Lanka. Potential environmental impacts of new technologies (e.g. geothermal, wave) need to be carefully assessed.
Technological feasibility	Mature technologies for solar PV, wind, and small hydro including a growing expertise in biomass power generation. Mature technologies for energy-efficient appliances, lighting, and building design are available. Proven technology for natural gas power plants.	Need for substantial electricity infrastructure upgrades/reinforcements to transmit renewable electricity efficiently. Need for grid integration and storage solutions for intermittent renewables. Need for significant investment in infrastructure (pipelines, LNG terminals) for natural gas.

	Opportunity to develop local expertise and technology capabilities in renewable energy and other low-carbon technologies.	Technical challenges in integrating renewable energy into the grid. Limited local expertise and resources for R&D. Dependence on foreign technology and expertise.
Economic feasibility	Decreasing costs of renewable energy technologies. Potential for long-term cost savings and energy security (also for energy efficiency measures). Increased energy security with diversified fuel sources. Grid upgrades lead to improved reliability and quality of electricity supply.	High upfront investment costs for renewable energy projects. Potential for grid instability with high RE penetration. Lack of access to financing for energy efficiency upgrades, especially for low-income households and SMEs. High upfront costs for replacing old appliances and equipment. Shifting to natural gas has the risk of stranded assets if the transition to renewable energy accelerates. Cost recovery mechanisms for grid investments may impact electricity tariffs. High upfront costs and risks associated with pilot projects of new technologies. Long lead times for commercialisation in Sri Lanka.
Sociocultural feasibility	Growing public awareness and acceptance of renewable energy. Government incentives for rooftop solar. Government initiatives to promote energy-efficient appliances to reduce high investment costs.	There is resistance from communities affected by large-scale renewable energy projects. (e.g. Mannar wind power plant extension). Resistance to change in behaviour and habits lead to limited DSM opportunities. Concerns about the safety of natural gas infrastructure as it is new to Sri Lanka. Disruption of electricity services during grid upgrades and maintenance.
Institutional feasibility	There are number of supportive policies and initiatives for renewable energy development (like financial incentives for rooftop solar). Existence of institutions like the Sustainable Energy Authority to support DSM programs, pilot projects and associated research. There are established regulatory frameworks for energy efficiency standards, electricity tariffs, and grid management.	Regulatory barriers, bureaucratic delays, and lack of institutional coordination within long-term energy planning. Limited enforcement of energy efficiency standards and lack of capacity for monitoring and evaluation of DSM programs. Limited financial resources and technical capacity for project implementation and grid modernisation.

5.9.2.2 Current status of national-sectoral climate policy

Table 42: Overview of policies and measures (energy sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Energy Policy (2019)** is a comprehensive framework aimed at transforming the country's energy sector towards sustainability, security, and affordability. It prioritizes maximizing the development and utilisation of domestic renewable energy sources to diversify the energy mix, reduce reliance on imported fossil fuels, and ensure equitable access to clean and reliable energy for all Sri Lankans. (Government of Sri Lanka, 2019)	**Positives:** The policy has successfully driven a significant increase in renewable energy capacity, particularly in solar and wind power. This is evidenced by the 'Battle for Solar Energy' program, which aims to add 1,000 MW of solar energy by 2025 and 1,500 MW by 2030. The policy has encouraged various DSM initiatives, including promoting energy-efficient appliances and equipment, resulting in reduced energy consumption and GHG emissions. Supports the conversion of existing fuel oil power plants to natural gas and the establishment of new natural gas plants. Encourages R&D in new and emerging renewable energy sources, such as ocean and geothermal energy, to further diversify the energy mix and reduce reliance on fossil fuels. **Challenges:** While progress has been made in rooftop solar, large-scale renewable energy projects, such as wind and hydro, have faced delays due to various factors, including land acquisition issues, environmental concerns, and financial constraints. The increasing penetration of intermittent renewable energy sources like solar and wind poses challenges for grid stability and management. Adequate investments in grid infrastructure and energy storage solutions are needed to address these challenges.
	Energy Sector Development Plan for a Knowledge-based Economy 2015-2025 (Ministry of Power and Energy, 2015) This plan aims to guide Sri Lanka's energy sector towards a knowledge-based economy, focusing on energy security, efficiency, and sustainability. It sets ambitious targets for renewable energy, energy efficiency, and reducing the sector's carbon footprint.	**Positives:** The plan has contributed to a significant increase in renewable energy capacity, particularly solar PV, energy efficiency improvements, and DSM programs. **Challenges:** The plan's target of reducing annual energy demand growth by 2% through conservation and efficiency measures has not been fully achieved, indicating a need for more aggressive implementation of energy efficiency programs. The plan's implementation requires effective coordination among various government agencies and stakeholders. However, there have been challenges in ensuring seamless collaboration and timely execution of projects.
	National Electrification Policy (2016): This policy aimed to achieve universal electricity access in Sri Lanka by 2016, bringing electricity to all households, businesses, and public institutions. It also focused on improving the quality	**Positives:** By expanding the electricity grid and increasing generation capacity, the policy has strengthened Sri Lanka's energy security and reduced the risk of power outages. **Challenges:** While the policy successfully achieved universal access, it primarily focused on extending the grid and increasing generation capacity, with limited emphasis on promoting energy efficiency and sustainable practices.

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	and reliability of electricity supply and promoting the use of renewable energy sources (Asian Development Bank, 2023a).	
	Sri Lanka Sustainable Energy Authority Act No. 35 of 2007 (Parliament of the Democratic Socialist Republic of Sri Lanka, 2007) establishes the Sri Lanka Sustainable Energy Authority (SLSEA) with the mandate to promote and develop renewable energy resources, implement energy efficiency measures, and conserve energy resources. It also provides for the declaration of Energy Development Areas and regulates renewable energy projects.	**Positives:** The Act successfully established the SLSEA, providing a dedicated institution for promoting renewable energy and energy efficiency. The SLSEA has played a crucial role in developing and implementing policies, programs, and projects that contribute to reducing GHG emissions in the energy sector since its inception. The SLSEA has been instrumental in promoting the growth of renewable energy in Sri Lanka, particularly through the implementation of the "Battle for Solar Energy" program, which has led to a significant increase in rooftop solar installations. The SLSEA has supported research and development in renewable energy and energy efficiency, fostering innovation and the development of new technologies that can further reduce GHG emissions. **Challenges:** The SLSEA faces challenges in securing adequate financial resources to fully implement its mandate and scale up its programs and projects. This can hinder the pace of renewable energy development and energy efficiency improvements. The regulatory framework for renewable energy and energy efficiency still needs further development and streamlining. There are challenges related to grid integration, licensing procedures, and tariff structures that can create barriers for investors and developers.
Regulatory instruments	**Sri Lanka Electricity Act No. 20 of 2009** (Government of Sri Lanka, 2009): This act provides the legal framework for the electricity sector, including the regulation of power generation, transmission, and distribution. It enables the government to set standards for energy efficiency and renewable energy integration, as well as enforce compliance through licensing and penalties.	**Positives:** The Act allows for the licensing of renewable energy power plants and the establishment of feed-in tariffs, providing a regulatory framework for the growth of renewable energy in Sri Lanka. The Act empowers the Public Utilities Commission of Sri Lanka (PUCSL) to issue regulations and standards for energy efficiency, promoting the use of energy-efficient appliances and equipment in the energy sector. **Challenges**: While the Act aims to promote competition, the electricity market in Sri Lanka remains largely dominated by the Ceylon Electricity Board (CEB). This can limit the potential for innovation and cost reduction in the sector. The Act provides for grid modernisation to accommodate renewable energy integration. However, progress in this area has been slow due to financial constraints and technical challenges.
	Electricity (Amendment) Act, No.31 of 2013 of Sri Lanka (Parliament of the Democratic Socialist Republic of Sri Lanka, 2013): This is an amendment to the	**Positives:** The amendment introduced standardized PPAs for renewable energy projects, streamlining the process for developers and investors, thereby promoting renewable energy generation. This aligns with the NDCs' goal of increasing the share of renewable energy in the energy mix. **Challenges:** The amendment does not explicitly address the need for energy storage solutions, which are essential for integrating

	Electricity Act of 2009 and introduces provisions for the promotion and regulation of renewable energy generation, including the establishment of standardized power purchase agreements and the authorisation of new generation plants.	intermittent renewable energy sources like solar and wind into the grid. This can hinder the full potential of renewable energy in ensuring a stable and reliable electricity supply. The existing grid infrastructure may not be adequately equipped to handle the increasing penetration of renewable energy. Investments in grid modernisation and smart grid technologies are needed to ensure smooth integration and avoid grid instability. The amendment primarily focuses on the supply side of electricity generation and does not address the potential for demand-side management (DSM) to reduce energy consumption and peak demand.
	Energy Efficiency Standards and Labelling Program was introduced by the Sri Lanka Standards Institute (SLSI) and SLSEA promotes energy-efficient appliances and equipment (SLSEA, n.d.)	**Positives**: There is already compiled and published energy efficiency standards for lighting systems and ceiling fans. Voluntary labelling scheme is available for refrigerators and these standards are now being expanded towards air conditioning and electric motors. In addition, minimum energy performance standards (MEPS) provide a level playing field in competitive markets by discouraging the worst performing products without diminishing consumer choice. **Challenges:** The range of appliances to which the energy efficiency standards being applied, and availability of labelling are limited. Furthermore, there is lack of enforcement and monitoring on the said standards.
Market-based instruments	**Renewable Energy Feed-in Tariff Scheme**: The FiT scheme in Sri Lanka is a policy mechanism designed to accelerate investments in renewable energy technologies. It offers long-term contracts to renewable energy producers, guaranteeing purchase of electricity at a fixed tariff, typically higher than the grid electricity price. This incentivizes the development of renewable energy projects by assuring a stable revenue stream (PUCSL, 2011)	**Positives**: The FiT scheme has successfully stimulated substantial growth in Sri Lanka's renewable energy sector, particularly in solar and wind power. It has attracted numerous private sector investments, contributing to the diversification of the energy mix and reduction of greenhouse gas emissions. The scheme has been particularly beneficial for small-scale projects, such as rooftop solar installations, enabling households and businesses to generate their electricity and contribute to the national grid. **Challenges**: One major challenge is the financial sustainability of the FiT scheme. The fixed tariffs can be higher than the average electricity generation cost, potentially leading to increased electricity prices for consumers in the long run. The government has periodically revised the FiT rates, leading to uncertainty among investors and potentially discouraging long-term investments in renewable energy projects.
	Net-metering : The Net Metering schemes in Sri Lanka allows consumers to generate their own electricity using renewable energy sources, primarily rooftop solar, and offset	**Positives:** Net metering has successfully incentivized the widespread adoption of rooftop solar PV systems in Sri Lanka, particularly among residential and commercial consumers. This has resulted in a substantial increase in renewable energy generation and contributed to reducing greenhouse gas emissions in the electricity sector. Net metering empowers consumers to become active participants in the energy transition by generating their own clean electricity. This

	their consumption from the grid (CEB, n.d.; PUCSL, 2023)	can foster a sense of ownership and engagement in sustainable energy practices. **Challenges:** The increasing penetration of rooftop solar can pose challenges for grid stability and management due to its intermittent nature. Investments in smart grid technologies and energy storage solutions are needed to address these challenges and ensure a reliable electricity supply. The high upfront costs of installing solar PV systems can be a barrier for low-income households, limiting their participation in the net metering scheme. The government could consider providing targeted subsidies or financing mechanisms to make renewable energy more accessible to all.
	Sri Lanka Green Finance Taxonomy: Launched in 2022, The Sri Lanka Green Finance Taxonomy (SLGFT) is a classification system that defines and categorizes economic activities considered environmentally sustainable. It serves as a guide for investors, businesses, and financial institutions to identify and invest in green projects, aligning financial flows with environmental objectives (Central Bank of Sri Lanka, 2022b).	**Challenges:** The SLGFT is still in its early stages of implementation, and its full impact on green investments in the energy sector is yet to be realized. Building awareness and capacity among financial institutions and investors is crucial for its effective adoption. In addition, SLFGT is yet to be integrated with other relevant policies such as the National Energy Policy and the NDCs.
Information instruments	**National Energy Benchmarking Portal (NEBP) of Sri Lanka** (U.S. Embassy in Sri Lanka, 2023): Developed by the Sri Lanka Sustainable Energy Authority (SLSEA), the NEBP is a digital platform aimed at tracking and benchmarking energy efficiency initiatives in the industrial, commercial, and government sectors. It allows organisations to submit their energy consumption data for comparison against sector-specific benchmarks, promoting energy conservation and efficiency.	**Positives**: The NEBP enables the collection and analysis of energy consumption data from various sectors, providing valuable insights into consumption patterns and potential areas for improvement. This increased transparency aligns with the NDCs' emphasis on data-driven decision-making for climate action. The portal allows organisations to compare their energy performance against established benchmarks, fostering a competitive environment that encourages energy conservation and efficiency. This aligns with the NDCs' goal of promoting energy efficiency in all sectors. By analysing energy consumption data, the NEBP can help identify areas where energy efficiency can be improved, leading to reduced energy consumption and GHG emissions. **Challenges**: Currently, the NEBP focuses on supermarkets and the financial sector. While these are important sectors, expanding its coverage to other energy-intensive sectors like manufacturing and hospitality would be crucial for achieving broader impact and meeting the NDCs' goals for overall energy sector emission reductions. The participation of organisations in the NEBP is currently voluntary. Making it mandatory for certain sectors or large energy consumers

		could significantly enhance its effectiveness in promoting energy efficiency and achieving emission reduction targets. Ensuring the accuracy and completeness of data submitted by organisations is essential for reliable analysis and benchmarking. Implementing robust data verification mechanisms and providing support to organisations for data collection and reporting could address this challenge.

5.9.3 Transport

5.9.3.1 National-sectoral mitigation enablers and barriers

Table 43: Overview of enablers and barriers (transport sector)
(Bastida-Molina et al., 2020; Higueras-Castillo et al., 2023; Ministry of Transport, 2009; Ministry of Transportation and Civil Action, 2020; Mobility Alliance, 2022; Pallawala, 2019)

Dimension	Enablers	Barriers
Geophysical feasibility	Existing road and rail infrastructure can be improved and expanded. Potential for developing Bus Rapid Transit (BRT) and Light Rail Transit (LRT) systems in major cities. Suitable climate and terrain for walking and cycling is available in many areas. Existing rivers and canals offer potential for inland water transport.	Limited land availability for new infrastructure in urban areas. Terrain challenges for rail expansion in some regions. Limited rail connectivity to some industrial areas and ports. There are significant seasonal water level changes in inland water systems.
Environmental-ecological feasibility	Reduction in congestion, air pollution, and GHG emissions through efficient transport systems including a shift to public transport. Air pollution and safety are of concern in using non-motorised transport, particularly in urban areas. Feasibility of non-motorised ways as a zero-emission transport mode. In-land water transport has potential for lower emissions compared to road transport and tourism development. Electric and hybrid vehicles have the potential for significant reductions in air pollution and GHG emissions from road transport. Improved vehicle fleet efficiency leads to reduced fuel consumption and emissions from existing vehicles.	Potential environmental impacts of new infrastructure construction (e.g., land use change, habitat loss). In-land water transport may have negative impacts on aquatic ecosystems and water quality. Electric vehicles (EVs) require clean electricity grid to maximise environmental benefits.
Technological feasibility	Technologies for intelligent transport systems, traffic management and electric mobility are already available. Existing rail infrastructure can be upgraded for freight transport. Technologies for intermodal transport (e.g., containerisation) are available. BRT and LRT technologies are mature and widely implemented globally. Electric and hybrid vehicle technology is mature and available.	High upfront investment costs for technology upgrades and infrastructure. Need for investment in rail infrastructure and logistics for efficient freight handling. BRT and LRTs require careful planning and integration with existing transport systems in urban areas. Limited charging infrastructure, particularly away from urban areas. Cost of retrofitting older vehicles with fuel-efficient technologies can be substantial for some income groups.

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Economic feasibility	Introduction of taxes to promote public transport can generate substantial revenue for the government. Improved transport efficiency can reduce fuel costs and travel time, boosting economic productivity. Public transport can lead to lower operating costs and fares compared to private vehicles. Potential for job creation in the public transport sector. Rapid Transit systems can have improved travel times and reliability for commuters. Lower operating costs for electric vehicles due to lower fuel and maintenance costs.	High upfront investment costs for BRT and LRT infrastructure. High upfront costs of electric vehicles. If not implemented carefully, the taxation to promote public transport may affect low-income groups. Requires government subsidies to maintain affordability of public transport. Fare structures in public transport and Rapid Transit modes need to be affordable and competitive with private vehicles. Limited range of electric vehicles and concerns about battery life.
Sociocultural feasibility	Potential for improved accessibility, safety, and comfort for passengers with improved transport sector. Rapid Transit modes have increased accessibility and convenience for urban residents. Growing global trend towards electric mobility. Developed road infrastructure leads to better road safety and reduced travel time for commuters.	Resistance to change in travel habits and preferences. Negative perception of public transport (e.g., overcrowding, unreliability, personal safety). Cultural preference for motorized transport may hinder shift to non-motorized modes. Limited public awareness and demand for inland water transport. Lack of awareness and familiarity with electric vehicles. Resistance from the automotive industry and used vehicle importers to retrofit means of fuel-efficient technologies.
Institutional feasibility	There are number of established institutions related to the transport sector: Ministry of Transport and Highways can coordinate and implement transport system improvements / The Department of Motor Traffic can implement fuel efficiency standards and regulations. Existing public transport operators (e.g., Sri Lanka Transport Board) can be strengthened and modernized. Sri Lanka Railways can implement and manage the upgrades to rail transport. Road Development Authority can lead road infrastructure development. Existing tax and regulatory mechanisms can be adapted to promote public transport. Government incentives and policies can promote electric vehicle adoption.	Coordination challenges among different agencies and stakeholders. Limited institutional capacity for planning and implementation. Lack of political will and commitment to prioritize public transport investment. Limited financial resources and technical capacity for large-scale upgrades in the transport systems. Need for regulations and standards for electric vehicle charging infrastructure.

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5.9.3.2 Current status of national-sectoral climate policy

Table 44: Overview of policies and measures (transport sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Transport Policy (2020 - Draft):** The draft National Transport Policy builds on the existing policy established in 2009 (Ministry of Transport, 2009), with aims to guide the development of a safe, efficient, and sustainable transport system in Sri Lanka. It emphasizes prioritizing public transport, integrating different modes of transport, and reducing the sector's environmental impact (Ministry of Transportation and Civil Action, 2020)	**Positives:** The policy strongly advocates for prioritizing public transport over private vehicles. Furthermore, there is strong emphasize in improving intermodal connectivity between rail, road, and water-based transport, which can enhance efficiency and reduce emissions by optimizing the use of different modes for specific needs. The policy promotes the development of sustainable transport infrastructure, such as dedicated bus lanes, cycling paths, and pedestrian walkways, which can encourage the use of low-carbon transport modes and reduce congestion. The importance of improving energy efficiency and fuel economy in the transport sector is highlighted as a means of contributing to reduced emissions and lower fuel costs. **Challenges:** The policy remains in draft form and has not been officially adopted, limiting its legal and regulatory power to drive change in the transport sector. Implementing the proposed measures, such as expanding public transport and developing sustainable infrastructure, requires significant financial investments. Securing adequate funding remains a challenge, especially in the context of Sri Lanka's economic difficulties.
	Urban Transport Development Plan (2014): The Urban Transport Master Plan (UTMP) in Sri Lanka, developed with assistance from JICA (Japan International Cooperation Agency), aims to address the growing challenges of urbanisation and traffic congestion in major cities. It outlines strategies for improving public transportation, managing traffic demand, and promoting sustainable transport modes (JAICA, 2014)	**Positives:** The UTMP prioritizes the development of public transportation systems, including bus rapid transit (BRT) and light rail transit (LRT) in Colombo. This is evident in the ongoing implementation of the Colombo BRT project. The plan promotes the integration of different modes of transport through the development of multi-modal transport hubs (MMTHs). This can facilitate seamless transfers between different modes, encouraging their use and reducing reliance on private vehicles. The plan includes Traffic Demand Management (TDM) strategies like congestion pricing and parking management to discourage private vehicle use and incentivize the use of public transport, contributing to reduced emissions and congestion. **Challenges:** The implementation of rail-based rapid transit systems like LRT has faced delays and setbacks due to various factors, including funding constraints and land acquisition issues. The implementation of TDM measures, such as congestion pricing, requires strong political will and effective enforcement mechanisms. However, progress in this area has been slow, limiting the impact of these measures on reducing traffic congestion and emissions

	Integrated Road Investment Program (2023): The Integrated Road Investment Program (iRoad) (Asian Development Bank, 2023b), supported by the Asian Development Bank (ADB), is a multi-tranche financing facility aimed at improving rural connectivity with a focus on upgrading provincial and local roads, as well as strengthening road asset management capacities. It is planned to improve the efficiency of rural transport thereby lower vehicle emissions in the long-run.	**Positives:** The program has successfully upgraded a significant number of provincial and local roads, improving access to markets, healthcare, education, and other essential services for rural communities. This indirectly contributes to reducing emissions by shortening travel distances and improving the efficiency of transport. The program has incorporated climate resilience considerations into road design and construction, such as improving drainage and using climate-resilient materials. This helps to ensure that the upgraded roads can withstand extreme weather events and continue to function effectively in the face of climate change. **Challenges:** The program primarily focuses on road infrastructure and does not explicitly address the need to shift towards more sustainable modes of transport, such as public transport or non-motorized options.
Regulatory instruments	**National Emission Standards for Vehicles** were adopted in line with the Euro 4 standards in 2018 (Central Environmental Authority, 2019). This regulation aims to reduce emissions of harmful pollutants and GHGs from the transport sector by setting maximum permissible limits for various pollutants emitted by vehicles. This was published under the Sri Lanka National Environmental Act No.47 of 1980.	**Positives**: The implementation of Euro 4 standards has led to a significant reduction in emissions of harmful air pollutants such as particulate matter (PM), nitrogen oxides (NOx), and carbon monoxide (CO) from new vehicles. This aligns with the NDCs' objective of improving air quality and protecting public health. Euro 4 standards often encourage the use of more fuel-efficient technologies in vehicles, contributing to lower fuel consumption and reduced GHG emissions. **Challenges**: The Euro 4 standard applies only to new vehicles, while a significant portion of the vehicle fleet still consists of older, less efficient models with higher emissions. This limits the overall impact of the policy on reducing emissions from the transport sector. The effective implementation of emission standards requires robust enforcement mechanisms and regular monitoring of vehicle emissions. However, there are challenges in ensuring compliance due to limited resources and capacity constraints within regulatory agencies.
	Motor Vehicle Act (2007): This act consolidates and amends the laws relating to motor traffic in Sri Lanka. It covers various aspects of vehicle registration, licensing, road safety, and traffic management (Parliament of the Democratic Socialist Republic of Sri Lanka, 2009a). The **Motor Traffic Act (2012)** (Chapter 203) expands the regulation to speed limits, though it is not explicitly linked to climate	**Positives:** The Act empowers the relevant authorities to prescribe emission standards for vehicles as a significant step of reducing greenhouse gas emissions from the transport sector. The Act mandates periodic inspection of vehicles to ensure compliance with emission and safety standards. This helps to identify and address high-emitting vehicles, contributing to improved air quality and reduced emissions. The Act provides for the regulation and promotion of public transport services, including buses and trains. Under the act, vehicle speed limits are enforced depending on the vehicle type and area (built-up area, non-built-up area).

	policy yet (Ministry of Transport, 2012)	**Challenges:** A significant portion of Sri Lanka's vehicle fleet consists of older, less fuel-efficient models with higher emissions. The Act does not have specific provisions for phasing out or incentivizing the replacement of these older vehicles. The Act does not explicitly address fuel efficiency standards for vehicles, which is a key factor in reducing GHG emissions. While the adoption of Euro 4 standards indirectly promotes fuel efficiency, more direct measures could be implemented. The vehicle speed limits do not explicitly enforce or linked related to climate policy yet.
	Regulations on Vehicle imports in Sri Lanka: Sri Lanka has implemented regulations (Ministry of Transport and Highways, 2016)on vehicle imports aimed at controlling the quality and age of imported vehicles, promoting fuel efficiency, and reducing emissions. These regulations typically include age restrictions, emission standards, and tax incentives for low-emission vehicles.	**Positives:** The age restrictions on imported vehicles have limited the inflow of older, less fuel-efficient models, which tend to have higher emissions. This has helped to improve the overall fuel efficiency and emissions profile of the vehicle fleet in Sri Lanka. The government has introduced tax incentives and reduced import duties for hybrid and electric vehicles, incentivizing their purchase and promoting the adoption of cleaner technologies. **Challenges**: Despite incentives for hybrid and electric vehicles, taxes on newer, more fuel-efficient vehicles in general can be high, making them unaffordable for many consumers. This can slow down the transition to a cleaner vehicle fleet. The regulations on vehicle imports are not currently a part of a comprehensive strategy to reduce emissions from the transport sector. A more holistic approach that combines import regulations with measures like improving public transport, promoting non-motorized transport, and implementing fuel economy standards would be more effective. The ongoing economic crisis in Sri Lanka has led to further restrictions on vehicle imports, which can hinder the transition to cleaner vehicles and slow down the progress in reducing emissions from the transport sector.
Market-based instruments	**Fuel Pricing Mechanism (OECD, 2023):** Sri Lanka's fuel pricing mechanism has traditionally involved government control over retail prices, with adjustments made periodically to reflect changes in global oil prices and exchange rates. However, in recent years, there have been discussions and proposals to introduce a more automatic and transparent pricing mechanism.	**Challenges**: Sri Lanka is yet to integrate carbon taxes into the fuel pricing mechanism, particularly with a focus on the fuels for road transport. Although an automatic fuel pricing formula was approved in 2018 (Ministry of Transport and Highways, 2011), its implementation has been delayed due to political resistance and concerns about potential social and economic impacts. The continued fuel subsidies, particularly for diesel distort market signals, encourage over consumption of fuel and undermine the impacts of GHG emissions. The current tax structure is not well-aligned with environmental objectives, as it imposes higher taxes on gasoline than diesel, favouring private car owners over public

		transport and freight transport, which are generally more fuel-efficient. Fuel prices in Sri Lanka are not fully cost-reflective, failing to account for the negative externalities of fuel consumption, such as air pollution and climate change impacts. This leads to under-pricing of fossil fuels and discourages the transition to cleaner alternatives.
	Road User Charges: Proposed for certain highways in Sri Lanka to generate revenue for infrastructure development and potentially influence traffic flow. While not explicitly implemented as a comprehensive policy instrument for climate change mitigation, Sri Lanka has implemented tolls on certain expressways. There is a potential of road user charges as a mechanism to manage traffic congestion, promote sustainable transport, and generate revenue for infrastructure development (RDA, 2024)	**Positives:** Road user charges can be used as a tool to manage traffic congestion, particularly in urban areas. By making driving more expensive, they can incentivize the use of public transport and other low-emission modes. **Challenges:** Road user charges are currently limited to specific expressways and have not been implemented as a comprehensive policy instrument across the road network. There is no overarching framework for road user charges in Sri Lanka, which could outline clear objectives, pricing mechanisms, and revenue allocation strategies. Implementing road user charges requires significant investment in infrastructure, such as electronic toll collection systems. It also necessitates public awareness campaigns and effective enforcement mechanisms.
Information instruments	**Measurement, Reporting, and Verification (MRV) Framework for the Transport Sector in Sri Lanka** (Climate Change Secretariat of Sri Lanka, 2019): The MRV framework is a system designed to track and assess the progress of climate actions and their impacts in the transport sector. It involves collecting and analysing data on GHG emissions, mitigation actions, and their effectiveness in reducing emissions.	**Positives:** The MRV framework enhances transparency in the transport sector's climate actions by providing a systematic approach to data collection and reporting. This allows for better assessment of progress towards the NDCs' emission reduction targets and holds stakeholders accountable for their commitments. The implementation of the MRV framework has led to improved data collection and analysis in the transport sector, providing a more accurate picture of the sector's emissions and the impact of mitigation measures. **Challenges:** Building capacity within relevant agencies to effectively collect, analyse, and report data under the MRV framework remains a challenge. Training and technical assistance are needed to ensure the proper implementation and utilisation of the system. Despite improvements in data collection, there are still gaps and limitations in the availability and quality of data, particularly for certain sub-sectors and modes of transport. This can hinder the accuracy and comprehensiveness of the MRV system.
	NAMA Design Document for the Transport Sector of Sri Lanka: Electric Bus Rapid Transit System (UNDP, 2015)**:** This document proposes a Nationally	**Positives:** An initial feasibility assessment for the introduction of electric buses in the Galle BRT system has been completed, providing valuable insights into the technical, financial, and operational aspects of the project. The NAMA is aligned with several national policies and plans, including the National Action Plan for the Haritha Lanka

	Appropriate Mitigation Action (NAMA) for Sri Lanka focused on the promotion and adoption of electric buses within a Bus Rapid Transit (BRT) system.	Program (National Council for Sustainable Development, 2009), the NDCs, the National Transport Policy, and the Urban Transport Master Plan (Climate Change Secretariat of Sri Lanka, 2019). This demonstrates a strong policy commitment to sustainable transport solutions. The proposed NAMA has the potential to significantly reduce GHG emissions from the transport sector by replacing diesel buses with electric buses in the BRT system. **Challenges**: The implementation of the NAMA requires significant financial resources for procuring electric buses, developing charging infrastructure, and training personnel. Securing adequate funding remains a challenge, as the NAMA document explicitly states the need for external support. The integration of electric buses into the existing BRT system requires careful planning and technical expertise to ensure smooth operation and reliable charging infrastructure. There is a need for increased public awareness and education about the benefits of electric buses and their role in reducing emissions and improving air quality. This can help create public support and acceptance for the project.

5.9.4 Buildings

5.9.4.1 National-sectoral mitigation enablers and barriers

Table 45: Overview of enablers and barriers (building sector)
(Athapaththu et al., 2016; Climate Change Secretariat of Sri Lanka, 2010; Herath et al., 2018; Ministry of Environment, 2019; Ministry of Urban Development and Housing, 2020; Senadeera et al., 2019)

Dimension	Enablers	Barriers
Geophysical feasibility	Sri Lanka has a diverse climatic zone which can be beneficial for the adaptation of various building designs and technologies.	The diverse climatic zones are inherently vulnerability to extreme weather events (floods, cyclones, and droughts) requires resilient construction. The frequency of extreme weather events in Sri Lanka resulted due to the changes in climate of the Bay of Bengal has increased over years.
Environmental-ecological feasibility	For the informal house unit construction, there is potential for using locally sourced, and low-impact materials. There are ample opportunities available for green infrastructure techniques (green roofs, rainwater harvesting, grey water management).	There can be environmental impacts of resource extraction and construction waste disposal if sustainable practices are not adhered to. Rapid urbanisation is leading to land-use change and habitat loss.
Technological feasibility	There is ample access to modern construction techniques and materials in Sri Lanka and within the South Asia region. A growing interest is there in sustainable building technologies such as Compressed Stabilised Earth Block (CSEB) as a	Limited adoption of sustainable practices due to cost and lack of awareness. There is lack of skilled labour for implementing advanced technologies in Sri Lanka.

	sustainable alternative to traditional burnt clay brick or concrete blocks. In addition, solar PV as a sustainable energy source for buildings.	
Economic feasibility	Ample opportunities are there for cost savings through energy-efficient design (passive design strategies) and renewable energy integration. Government incentives are available for green building certifications.	There is a high upfront cost for sustainable materials and technologies. Financial mechanisms and incentives are limited for low-income housing to adopt sustainable building design and construction.
Sociocultural feasibility	Due to the ongoing energy crisis and high energy bills, there is growing attention on the public of sustainable living and green building concepts.	Sri Lanka is a country with a diverse cultural preference for traditional designs and materials which may hinder the adaptation of some sustainable building practices. Lack of awareness about the benefits of sustainable buildings.
Institutional feasibility	Green Building Council and Urban Development Authority are already established to authorise Green Building certification schemes. Government policies are being developed to promote sustainable urban planning.	There is limited enforcement of adhering to building codes and regulations. So far there is a lack of comprehensive data on building energy performance and emissions. Weak institutional capacity for monitoring and enforcement.

5.9.4.2 Current status of national-sectoral climate policy

Table 46: Overview of policies and measures (building sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**Sri Lanka Sustainable Housing and Construction Roadmap 2020-2050** (Ministry of Urban Development and Housing, 2020): This roadmap outlines a comprehensive strategy for transitioning Sri Lanka's housing and construction sector towards sustainability. It covers various aspects, including urban planning, building design, materials, operations, appliances, clean energy, demolition, and resilience.	**Positives:** The roadmap provides a holistic and long-term vision for sustainable housing and construction, covering the entire lifecycle of buildings from planning to demolition. The roadmap has raised awareness among stakeholders about the importance of sustainable building practices and the potential for reducing GHG emissions in the sector. Several capacity building programs and workshops have been conducted to enhance the knowledge and skills of professionals in the industry. The roadmap emphasizes the importance of green building certifications, such as those offered by the Green Building Council of Sri Lanka (GBCSL) and the Urban Development Authority (UDA). This has led to increased interest in green building design and construction, contributing to energy efficiency and resource conservation. The roadmap promotes the use of resource-efficient materials and technologies, such as compressed stabilized earth blocks (CSEBs) and solar energy, which can reduce the environmental

		impact of construction and operation of buildings. **Challenges:** The adoption of sustainable building technologies and materials can be costly, particularly for low-income households and small-scale projects. The lack of adequate financial incentives and support mechanisms hinders the wider adoption of green building practices. There is a lack of comprehensive data on the environmental performance of the building stock in Sri Lanka. This makes it difficult to accurately assess the impact of the roadmap's implementation and identify areas for improvement.
	Construction Industry Development Act, No.33 of 2014 (Parliament of the Democratic Socialist Republic of Sri Lanka, 2014)**:** This Act aims to develop and regulate the construction industry in Sri Lanka, ensuring quality standards, enhancing professionalism, and promoting sustainable practices. It established the Construction Industry Development Authority (CIDA) to oversee and implement the Act's provisions.	**Positives:** The establishment of CIDA has provided a dedicated institution to oversee the development and regulation of the construction industry, including promoting sustainable construction practices. CIDA has initiated training programs and workshops for construction professionals to enhance their knowledge and skills in sustainable construction practices. The Act mandates the registration and grading of contractors based on their capacity and specialisation, ensuring that construction projects are undertaken by qualified professionals, which can indirectly contribute to better quality and more sustainable construction practices. The Act mandates the development of a National Policy on Construction, which includes provisions for promoting sustainable and environmentally friendly construction practices. **Challenges:** Significant portion of the construction sector operates informally, with many small-scale projects being undertaken without adherence to regulations or standards. This hinders the implementation of sustainable practices and makes it difficult to monitor and control emissions from the sector. The Act does not provide specific financial incentives or mechanisms to encourage the adoption of sustainable construction practices. This can be a barrier for smaller businesses and individual homeowners who may not have the resources to invest in more expensive green building technologies.
	National Cooling Policy (Draft) (Ministry of Environment, 2021b)**:** The Draft National Cooling Policy (NCP) aims to address the growing demand for cooling in Sri Lanka while minimizing its environmental impact. It focuses on improving	**Positives:** The draft policy strongly emphasizes energy efficiency in the cooling sector, aligning with the NDCs' goal of reducing energy consumption and GHG emissions in the building sector. It proposes measures such as promoting energy-efficient appliances, developing minimum energy performance standards (MEPS), and implementing labelling programs. The policy encourages the adoption of sustainable cooling

	access to cooling, enhancing energy efficiency, reducing GHG emissions, and protecting the ozone layer.	solutions, such as passive cooling techniques and district cooling systems, which can significantly reduce energy consumption and GHG emissions. The policy addresses the issue of refrigerant management, aiming to phase out ozone-depleting substances (ODS) and hydrofluorocarbons (HFCs) in line with the Montreal Protocol. This can contribute to mitigating climate change, as HFCs are potent greenhouse gases. **Challenges**: The policy is still in draft form and has not been officially adopted, limiting its regulatory power to drive change in the cooling sector. Implementing the proposed measures, such as promoting energy-efficient appliances and developing renewable energy-based cooling systems, requires significant financial investments. Securing adequate funding remains a challenge, especially for low-income households and small businesses. Promoting sustainable cooling practices requires raising awareness among consumers and businesses about the benefits of energy efficiency and alternative cooling solutions.

Regulatory instruments	**Energy Efficiency Building Code (EEBC) of Sri Lanka** (SLSEA, 2021): Introduced in 2020 by the Sri Lanka Sustainable Energy Authority, the EEBC aims to improve the energy performance of buildings by setting minimum requirements for energy efficiency in design, construction, and operation. It covers various aspects, including building envelope, HVAC systems, lighting, and appliances.	**Positives**: The EEBC provides a legal framework for enforcing energy efficiency standards in buildings, which aligns with the NDCs' goal of promoting energy conservation and reducing GHG emissions in the building sector. The code mandates energy performance assessments for certain types of buildings, providing a benchmark for evaluating their energy efficiency and identifying areas for improvement. The introduction of the EEBC has raised awareness among architects, engineers, and builders about the importance of energy efficiency in building design and construction. This has led to increased consideration of energy-saving measures in new building projects. **Challenges**: The EEBC currently applies only to commercial buildings, industrial facilities, and large-scale housing developments exceeding specific criteria (e.g., floor area, power demand, air conditioning capacity). Expanding the scope to include smaller residential buildings would have a greater impact on overall energy consumption and emission reductions. The EEBC does not offer financial incentives for building owners to adopt energy-efficient measures beyond the minimum requirements. Providing incentives, such as tax breaks or subsidies, could encourage greater uptake of energy-efficient technologies and practices. Many stakeholders in the building sector, especially smaller builders and contractors, may lack the technical expertise to design and construct energy-efficient buildings. Capacity building programs and technical assistance are needed to bridge this gap and facilitate compliance with the code.
	Energy Efficiency Standards and Labelling Program: Promotes energy-efficient appliances and equipment (SLSEA, n.d.).	**Positives:** The program encourages the use of energy efficient appliances and equipment leading to reduced energy consumption from buildings. This also translates to lower GHG emissions from power generation. The manufacturers are also incentivised to produce more energy-efficient products to meet the standards and be available to consumers seeking energy saving options. **Challenges:** The program applies only for appliances while other aspects of building energy consumption such as building design, insulation and lighting remain unaddressed. Especially in a market with a large informal sector, it is challenging to ensure the compliance with the energy efficiency standards and labelling.

Information instruments	**Green Labelling System for Sustainable Building Materials and Products (GREENSL) in Sri Lanka** (Green Building Council of Sri Lanka, 2022)**:** This is a voluntary, third-party certification system that evaluates, and labels sustainable building materials and products based on their environmental performance across their lifecycle. It aims to encourage the use of environmentally friendly materials in the construction industry.	**Positives:** GREENSL has increased awareness among industry professionals and consumers about the environmental impacts of building materials. It has established a benchmark for sustainable materials, encouraging manufacturers to improve their products. The label provides a recognizable mark for environmentally friendly products, helping consumers make informed choices and creating a demand for sustainable materials. The use of GREENSL®-certified materials can significantly reduce the environmental impact of construction projects, including lower embodied energy, reduced waste generation, and improved resource efficiency. **Challenges:** GREENSL is a voluntary certification, and its adoption remains limited. Many manufacturers and builders still opt for conventional materials due to cost considerations or lack of awareness about the benefits of sustainable alternatives. The current range of certified products under GREENSL is still relatively limited, particularly for certain categories of building materials. This can restrict the choices available to builders and designers who want to use sustainable materials.
	Green Building Certifications in Sri Lanka: Green building certifications(Green Building Council of Sri Lanka, 2023) and aim to promote sustainable construction practices by providing a framework for designing, constructing, and operating buildings with reduced environmental impact.	**Positives**: Green building certifications have raised awareness about sustainable construction practices and have helped to establish a benchmark for environmental performance in the building sector. Certifications provide a market-based incentive for developers and building owners to adopt green building technologies and practices, leading to reduced energy consumption, water usage, and waste generation. The number of certified green buildings in Sri Lanka has been steadily increasing, indicating a growing demand for sustainable buildings and a positive shift in the market. Furthermore, some buildings in Sri Lanka have achieved international LEED certification, demonstrating its potential for green building development. **Challenges**: While green building certifications are gaining traction in the commercial sector, their adoption in the residential sector, particularly for affordable housing, remains limited. This is due to the perceived higher costs associated with green building practices and lack of awareness among homeowners and small-scale developers. Green building certifications are currently voluntary in Sri Lanka. Making them mandatory for certain types of buildings, such as

		government buildings and large commercial projects, could significantly increase their adoption and impact.

5.9.5 AFOLU

5.9.5.1 National-sectoral mitigation enablers and barriers

Table 47: Overview of enablers and barriers (AFOLU sector)
(Balasooriya et al., 2015; Central Environmental Authority Sri Lanka, 2016; Climate Change Secretariat of Sri Lanka, 2012; De Zoysa, 2017; Department of Land Use Policy Planning, 2016; Ekanayake and Theodore, 2017; Jayalath and Gunawardhana, 2017; Mattsson, 2012; Ministry of Environment, 2015)

Dimension	Enablers	Barriers
Geophysical feasibility	Diverse climatic zones and soil types are suitable for various tree species. Diverse agro-ecological zones in Sri Lanka are suitable for various crops and livestock systems. There is potential for expanding renewable energy generation in rural areas (solar, biogas).	Limited land availability due to competing land uses (agriculture, urbanisation). The vulnerability to extreme weather events (droughts, floods) can affect reforestation efforts, crop yields and livestock production.
Environmental-ecological feasibility	Reforestation and afforestation can improve soil health, biodiversity, and water resources. Natural forests act as carbon sinks and provide ecosystem services. Sustainable agricultural practices (e.g., agroforestry, organic farming) can improve soil health, water quality, and biodiversity. Reduced use of chemical fertilizers and pesticides can mitigate environmental pollution. Furthermore, livestock manure management systems can reduce methane emissions.	Invasive plant species can threaten native ecosystems. Intensive agriculture practices can lead to soil erosion, water pollution, and loss of biodiversity. Overgrazing and deforestation for agricultural expansion can worsen environmental degradation.
Technological feasibility	There is access to modern forestry techniques and technologies (e.g., remote sensing, GIS, drone technology) including the availability of improved tree varieties and agroforestry systems. Improved crop varieties, precision agriculture technologies, and efficient irrigation systems are available. Due to current energy crisis, there is growing interest in renewable energy applications for agriculture (e.g., solar-powered irrigation pumps, biogas digesters).	Limited adoption of technology due to cost and lack of awareness among smallholder farmers. Smallholder farmers need to bear high upfront costs and have limited access to technology. Lack of awareness and technical capacity among farmers can hinder the uptake in sustainable agricultural practices.
Economic feasibility	Forest-based industries can provide income and employment opportunities. Carbon credits and payments for ecosystem services can incentivize sustainable forestry practices.	High upfront costs are there for reforestation and forest management. There are number of competing economic interests in land use such as energy generation, agriculture, and tourism.

	Improved productivity and reduced input costs can be realised through efficient resource management and technology adoption. There is potential for increased income through value addition and market access for diversified crops and livestock products.	High investment costs for technology adoption and infrastructure development to adapt sustainable agriculture practices.
Sociocultural feasibility	The Sri Lanka society has a strong cultural and spiritual connection to forests. Therefore, community-based forest management models can promote participation and ownership.	Many people, especially in rural areas, have insecure land rights due to unclear or informal tenure arrangements. This lack of secure tenure can hinder investments in land improvement and sustainable practices. Conflicts over forest resources, and lack of awareness and capacity among local communities regarding sustainable forestry practices. Some traditional farmers show resistance to change and adopt to new technologies. Land tenure issues and social inequalities can hinder access to resources and opportunities among the farming community.
Institutional feasibility	There are existing policies and institutions for forest conservation and management (e.g., Forest Department, National REDD+ Investment Framework). Various government agencies and policies exist in supporting agriculture and livestock development (e.g., Department of Agriculture, Ministry of Livestock). There are also initiatives promoting sustainable agriculture practices and renewable energy adoption in the sector.	Weak enforcement of forestry regulations and illegal logging will be incapable of reducing deforestation. There is limited coordination and cooperation among different agencies involved in agriculture and land-use. The enforcement of environmental regulations in the agricultural sector remains weak so far.

5.9.5.2 Current status of national-sectoral climate policy

Table 48: Overview of policies and measures (AFOLU sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Environment Action Plan (NEAP) 2022-2030 of Sri Lanka** (Ministry of Environment, 2022): This action plan outlines strategies and actions to address environmental challenges and achieve sustainable development in Sri Lanka. It encompasses various sectors, including land use, with a focus on sustainable	**Positives**: The NEAP promotes sustainable land management practices across sectors, aiming to minimize land degradation, soil erosion, and deforestation. The NEAP emphasizes the protection and expansion of protected areas, including forests, wetlands, and other critical ecosystems. This contributes to biodiversity conservation and carbon sequestration, supporting the NDCs' climate change mitigation goals. The NEAP promotes climate-smart agriculture practices, such as water-efficient irrigation, drought-resistant crops, and

	land management, biodiversity conservation, and climate change adaptation and mitigation.	integrated pest management. These practices can enhance agricultural productivity, reduce vulnerability to climate change impacts, and contribute to climate change mitigation. **Challenges**: Land use changes, such as deforestation for agriculture or urbanisation, continue to pose a significant challenge to sustainable land management and biodiversity conservation. Balancing competing land use demands remains a complex issue. The NEAP lacks robust monitoring and evaluation mechanisms to track progress towards its goals and assess the effectiveness of implemented measures. This makes it difficult to identify gaps and areas for improvement.
	National Climate Change Policy (2012) (Climate Change Secretariat of Sri Lanka, 2012)**:** This policy, adopted in 2012, serves as the overarching framework for addressing climate change in Sri Lanka. It encompasses mitigation and adaptation strategies across various sectors, including land use (forestry and agriculture).	**Positives:** The policy has spurred initiatives for forest conservation, reforestation, and afforestation. These efforts have contributed to increasing carbon sequestration and enhancing the resilience of ecosystems to climate change impacts. Encourages the adoption of sustainable agricultural practices, such as organic farming, agroforestry, and water-efficient irrigation. These practices can reduce GHG emissions from agriculture and enhance soil health and water management. **Challenges:** Land-use change, driven by factors such as urbanisation, infrastructure development, and agricultural expansion, continues to be a major challenge. Balancing competing land use demands while ensuring environmental sustainability and climate resilience remains a complex issue. The policy lacks specific and quantifiable targets for GHG emission reduction in the land-use sector. This makes it difficult to track progress and assess the effectiveness of the policy. Limited availability of reliable and comprehensive data on land use and land-use change (LULUC) makes it challenging to monitor the progress of the policy's implementation and assess its impact on GHG emissions.
	National Land Use Policy (2016): Provides a framework to ensure proper land utilisation, balancing competing demands for food security, economic development, and environmental conservation. It aims to guide decisions on land allocation, productivity improvement, and conversion of agricultural land to other uses (Department of Land Use Policy Planning, 2016).	**Positives:** The policy prioritizes food security and agricultural development, recognizing their importance for sustainable livelihoods and climate resilience. The policy promotes rational land allocation and prioritizes increasing land productivity before considering the conversion of agricultural land to other uses. This approach can help minimize deforestation and land degradation, contributing to carbon sequestration. **Challenges:** The policy lacks specific and quantifiable targets for reducing emissions and improving land-use practices. This makes it difficult to measure progress and assess the policy's contribution to achieving the NDCs' goals. The policy emphasizes the need for balancing different land use demands, but conflicts between agriculture, urbanisation, infrastructure development, and conservation persist. Resolving these conflicts and ensuring sustainable land use

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		practices require strong governance and effective coordination among stakeholders.
	National Forest Policy (1995): This policy aims to ensure the conservation, management, and sustainable development of forests in Sri Lanka. It focuses on protecting natural forests, promoting sustainable forestry practices, and enhancing the contribution of forests to national development and climate change mitigation (Ministry of Agriculture Lands and Forestry, 1995).	**Positives:** The policy has led to the establishment and expansion of protected areas, conserving biodiversity, and contributing to carbon sequestration. The policy promotes sustainable forest management practices, such as selective logging and reforestation, which can help maintain forest health and productivity while reducing emissions from deforestation and degradation. **Challenges:** Despite the policy's objectives, deforestation and forest degradation continue to be significant challenges in Sri Lanka due to illegal logging, encroachment, and unsustainable land-use practices. Stronger enforcement and monitoring mechanisms are needed to address these issues. Unclear land tenure and ownership issues can create conflicts and hinder the implementation of sustainable forest management practices, especially in areas with overlapping claims and competing interests.
	National Physical Planning Policy (2017-2050): This policy package provides a comprehensive framework for guiding land use and development in Sri Lanka. It aims to promote sustainable development by integrating economic, social, environmental, and climate considerations into land use planning decisions (National Physical Planning Department, 2019).	**Positives:** The policy explicitly aligns with the 17 Sustainable Development Goals, including those related to climate action (SDG 13), sustainable cities and communities (SDG 11), and life on land (SDG 15). This reflects a commitment to holistic development that considers environmental and social factors alongside economic growth. The policy identifies and demarcates different zones for urban development, conservation, and agriculture, based on environmental and climate considerations. This can help minimize land-use conflicts and promote climate-resilient development. The policy encourages the integration of green infrastructure, such as parks, urban forests, and green corridors, into urban planning. This can contribute to carbon sequestration, improve air quality, and enhance the resilience of urban areas to climate change impacts. **Challenges**: The policy's integration with other sectoral policies, such as agriculture, forestry, and energy, needs to be strengthened to ensure a cohesive approach to sustainable land use and climate action. The availability of accurate and up-to-date data on land use and land cover change is crucial for effective planning and monitoring. However, there are still data gaps that need to be addressed to inform decision-making and evaluate the policy's impact. The successful implementation of the policy requires strong political will and commitment from all levels of government, as well as active engagement and participation of diverse stakeholders, including local communities, civil society organisations, and the private sector.

	National REDD+ Strategy Sri Lanka: Sri Lanka's National REDD+ Strategy (The Ministry of Mahaweli Development and Environment, 2017), formalized as the National REDD+ Investment Framework and Action Plan (NRIFAP) 2018-2022, aims to reduce emissions from deforestation and forest degradation (REDD+) while promoting sustainable forest management, biodiversity conservation, and community livelihoods.	**Positives:** The NRIFAP established a National REDD+ Steering Committee and a REDD+ Secretariat, providing a strong institutional structure for implementing REDD+ activities and coordinating efforts among different stakeholders. Sri Lanka has successfully developed and submitted its Forest Reference Emission Level (UN-REDD Sri Lanka, 2017) to the UNFCCC, which serves as a benchmark for measuring emission reductions from deforestation and forest degradation. The country has developed a National Forest Monitoring System to monitor forest cover and carbon stocks, providing crucial data for assessing the effectiveness of REDD+ interventions. **Challenges:** Unclear land tenure and ownership rights can create conflicts and hinder the implementation of REDD+ activities, especially in areas with overlapping claims and competing interests. Illegal logging and encroachment continue to pose significant threats to forests in Sri Lanka. Strengthening law enforcement and monitoring mechanisms is crucial for the success of REDD+ initiatives. While the NRIFAP identified potential funding sources, securing adequate and sustained financing for REDD+ activities remain a challenge. This can hinder the implementation of projects and programs aimed at reducing deforestation and forest degradation.
Regulatory instruments	**Forest Conservation and Management Act (FCMA) of Sri Lanka (2009 Amendment to the Forest Ordinance of 1907)** (Parliament of the Democratic Socialist Republic of Sri Lanka, 2009b): This act consolidates and amends the laws first established as the Forest Ordinance in 1907 relating to the conservation, protection, and sustainable management of forest resources in Sri Lanka. It aims to regulate timber and forest produce transport, and addresses issues related to forest conservation and utilisation.	**Positives**: The FCMA has strengthened the legal framework for forest conservation and protection in Sri Lanka. It has provisions for declaring Conservation Forests and establishing Management Plans for them, ensuring better protection of these critical ecosystems. The Act emphasizes sustainable management of forest resources, including the utilisation of forest produce. This promotes the balance between conservation and the utilisation of forest resources for livelihoods and economic development. **Challenges**: The FCMA does not explicitly address the impacts of climate change on forests, such as increased risk of forest fires, droughts, and pests. Integrating climate change adaptation strategies into forest management plans is crucial for ensuring the long-term resilience of forest ecosystems. While the Act recognizes the role of communities in forest conservation, their involvement in decision-making and management processes is often limited. Empowering local communities and ensuring their meaningful participation in forest management can enhance the effectiveness and sustainability of conservation efforts.
	Land Development Ordinance of Sri Lanka: This ordinance, established in 1935 (Ministry of Justice, 1935) and amended multiple times, governs the	**Positives:** The ordinance imposes restrictions on the conversion of agricultural land to other uses, requiring permits and approvals from relevant authorities. This can help to prevent deforestation and land degradation, contributing to carbon sequestration and climate change mitigation.

	systematic development and alienation of state land in Sri Lanka. It includes provisions on land classification, allocation, and restrictions on land use to ensure sustainable development and prevent environmental degradation.	**Challenges**: Some provisions of the ordinance are outdated and do not reflect the current understanding of land use and environmental sustainability. The ordinance needs to be updated to incorporate modern concepts like climate-smart agriculture, ecosystem-based adaptation, and sustainable land management practices.
	Soil Conservation Act (The Ministry of Agriculture Development and Agrarian Services, 2009)**:** focuses on the conservation of soil resources, prevention, and mitigation of soil erosion, and protection of land against damage by floods, salinity, alkalinity, waterlogging, and drought. It aims to enhance soil productivity and restore degraded land.	**Positives:** The Act empowers the Minister of Agriculture to declare conservation areas where soil erosion or land degradation is a threat. This allows for the implementation of specific regulations and measures to protect these areas, contributing to carbon sequestration and climate change mitigation. The Act outlines various measures for soil conservation, such as the construction of terraces, bunds, and drains, as well as the planting of cover crops and trees. These measures can help to reduce soil erosion, improve water retention, and enhance soil fertility, contributing to sustainable agriculture and climate resilience. **Challenges:** Many farmers and landowners lack awareness of the importance of soil conservation and the available techniques and technologies. There is a need for more comprehensive awareness campaigns and capacity building programs to promote sustainable land management practices. The Act was enacted in 1951 and amended in 1996, and some of its provisions may be outdated and not aligned with current challenges and scientific understanding of soil conservation and climate change. A review and update of the Act is necessary to ensure its effectiveness in addressing contemporary issues. While the Act addresses soil erosion and land degradation, it does not explicitly address the specific challenges posed by climate change, such as changing rainfall patterns, increased temperatures, and extreme weather events. Integrating climate change adaptation strategies into soil conservation measures is crucial for ensuring the long-term resilience of agricultural systems.
Market-based instruments	**Payments for Ecosystem Services (PES)** (Kallesoe and Alwis, 2005)**:** PES is a mechanism where beneficiaries of ecosystem services, such as carbon sequestration, watershed protection, or biodiversity conservation, provide financial or other incentives to landowners or managers who maintain or enhance those services.	**Positives**: Several pilot PES projects have been implemented in Sri Lanka, primarily focusing on watershed protection and forest conservation. These projects have demonstrated the potential of PES to incentivize sustainable land management practices and contribute to climate change mitigation and adaptation. The concept of PES is gaining traction in Sri Lanka, with increasing awareness among government agencies, NGOs, and local communities about its potential benefits for both environmental conservation and economic development. **Challenges**: PES implementation in Sri Lanka is still in its early stages, and the number of projects and their scale

		remain limited. Scaling up PES schemes to achieve significant impact on GHG emissions and land-use change is a major challenge. The lack of a comprehensive legal and institutional framework for PES can hinder its widespread adoption and implementation. Clear guidelines and regulations are needed to ensure transparency, accountability, and fair distribution of benefits.
	Green Financing: Green financing refers to financial investments in projects and initiatives that promote environmental sustainability and climate action. In Sri Lanka (Central Bank of Sri Lanka, 2022b), this includes loans, grants, and other financial mechanisms designed to support sustainable agriculture and forestry practices, renewable energy in the AFOLU sector.	**Positives:** Several banks and financial institutions in Sri Lanka have introduced green credit lines specifically targeting sustainable agriculture and renewable energy projects. These credit lines offer favourable terms and conditions, such as lower interest rates and longer repayment periods, to incentivize investments in environmentally friendly projects. The Central Bank of Sri Lanka has developed a Green Bond Framework to facilitate the issuance of green bonds by the government and private sector entities. These bonds can be used to finance projects in the AFOLU sector that contribute to climate change mitigation and adaptation. Some initiatives provide financial support to smallholder farmers for adopting sustainable agricultural practices, such as organic farming and agroforestry. **Challenges:** Many farmers and small businesses in the AFOLU sector lack awareness of available green financing options and face challenges in accessing them due to limited financial literacy, collateral requirements, and complex application procedures. Financial institutions may perceive investments in the AFOLU sector as risky due to factors like climate change vulnerability, price volatility of agricultural commodities, and limited track record of successful projects. This can lead to higher interest rates or reluctance to lend to the sector.
Information instruments	**National Land Use Information System (NLUIS):** The NLUIS is a centralized database and platform designed to collect, manage, analyse, and disseminate land-use and land-cover (LULC) data in Sri Lanka. It aims to provide comprehensive and up-to-date information on land use patterns and changes, supporting evidence-based decision-making for sustainable land management and climate action (Sri Lanka Survery Department, n.d.)	**Positives**: The NLUIS has successfully compiled land-use data from various sources, including government agencies, surveys, and satellite imagery. This centralized database provides a valuable resource for understanding land-use patterns and trends, which is crucial for assessing the AFOLU sector's contribution to GHG emissions and identifying areas for mitigation and adaptation. The system enables the creation of detailed land-use maps and the analysis of land-use change over time. This information is essential for monitoring deforestation, forest degradation, and agricultural expansion, all of which are key drivers of GHG emissions in the AFOLU sector. **Challenges**: While the NLUIS has made significant progress in data collection, challenges remain in ensuring the accuracy and completeness of the data, particularly for certain regions and land-use categories. This can affect the reliability of the analysis and its usefulness for decision-making.

		Land use patterns can change rapidly, especially in areas undergoing rapid urbanisation or agricultural expansion. The NLUIS needs to be regularly updated to reflect these changes and provide timely information for decision-makers.

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6 Ukraine – Case Study

6.1 Big picture: Current national-sectoral decarbonisation status and prospects

With a total land area of 603,549 km², Ukraine is the second largest country in Europe located in Eastern Europe at the Black Sea (SSSU, 2023; WorldData.info, n.d.). The topography is rather flat except for the Crimean and Carpathian Mountains and the country is dominated by the Dnieper River and more than 73 thousand other, mostly transboundary rivers. Ukraine is a resource rich country with mineral resources in high concentrations and close proximity to each other (large reserves of coal, iron ore, natural gas, manganese, salt, oil, gold, lithium, aluminium, graphite, copper, sulphur, kaolin, peat, titanium, nickel, magnesium, timber, and mercury), as well as conventional and unconventional hydrocarbon resources (UNECE, 2023). The World Bank assess Ukraine as highly vulnerable to the impacts of climate change as increased temperatures, increasingly variable precipitation patterns, floods, heat waves and more intense and frequent droughts (World Bank Climate Change Knowledge Portal, n.d.). Boundaries of spring frost are expected to shift with expected impacts on the agriculture sector. Impacts on the amount and quality of water resources affect uses in the energy sector (UNECE 2023a).
Ukraine has a total population of 41.134 million (SSSU, 2023) with a low population density of about 68 persons per sq.km and experiencing continued negative population growth for more than two decades (World Bank Climate Change Knowledge Portal, n.d.). Several unforeseen "shocks" challenged, had and have an impact on the country, its people and economy.

- Collapse of the former Soviet Union in 1991 and subsequent economic transformation challenges,
- Recession following the economic crisis of 2008 ending a boom between the years 2000-2008,
- Unprovoked Russian aggression 2014/2024 and war.

Ukraine is classified as a lower middle-income country ranking 56th in the world in 2020 by the size of nominal GDP in absolute terms (Government of Ukraine, 2021). In 2023, gross domestic product (GDP) was USD 178.76 billion with 5.3% annual growth after 28.8 collapse in 2022 stemmed from Russian invasion and GDP per capita at USD 5181.4 (World Bank Group, 2024). The economy is dominated by industry and the agriculture sector (Government of Ukraine, 2021) being heavily impacted by the ongoing war. Estimated GDP losses in 2022 reflect a major disruption of economic activities. This includes damage to productive assets and infrastructure, logistical problems, labour force losses, ruined supply-demand chains, uncertainty and elevated risks (UNIDO, 2023).
Ukraine became independent in 1991 when the Soviet Union dissolved and declared neutrality. Since 2014 when Russia annexed Crimea, Ukraine is in a military conflict with Russia and in an ongoing war since the Russian invasion in February 2022. With the evolving military conflict and change in government in 2014, political orientation shifted towards the European Union (Association Agreement). Already in 2011, Ukraine became a contracting Party to the Energy Community Treaty involving commitments to reform legislative frameworks, in particular to enable private participation in the electricity and gas sectors (OECD, 2021).

In particular important for Ukraine's climate and decarbonisation policies is this EU alignment. Ukraine applied in 2022 for EU-Membership and has official EU candidate status. Accession negotiations opened in June 2024 (European Commission, n.d.). Replacing annual Association Implementation Reports, the European Commission provides annual enlargement reports on Ukraine to the European Council. Reporting includes an assessment of Ukraine's alignment of its laws with the EU acquis in six thematic clusters and 33 acquis chapters. Among those the level of preparation of Ukraine on the cluster "green agenda and sustainable connectivity" regarding transport policy, energy as well as environment and climate change (European Commission, 2023a and 2023b).

Policy formulation and Implementation
The Ministry of Environment Protection and Natural Resources (MEPR) is responsible state policy on environmental

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protection and climate change. It reports to the Cabinet of Ministers. Other ministries and agencies also have an impact on environmental protection and climate change in Ukraine: the Ministry of Energy, the Ministry of Communities, Territories and Infrastructure Development (MCTID), the Ministry of Agriculture, and the State Agency for Energy Efficiency and Energy Saving, which reports to the MCTID. The National Centre for GHG Emission Inventory compiles Ukraine's GHG inventory and reports to MEPR.

Greenhouse Gas Emissions

In 2021, Ukraine's GHG emissions, including land use, land use change and forestry (LULUCF), totalled 341.5 million tonnes of CO2 equivalent (Mt CO2e) – a huge decrease from 911.4 Mt CO2-eq in 1990 (Figure 1). CO2 accounted for around two-thirds of total GHG emissions in 2021; CH_4 for 21% and N_2O for 13% (MEPR 2023). The share of energy-related emissions was recorded at 64% of total GHG emissions in 2021. The industrial processes and product use (IPPU) were responsible for 18% of total GHG emissions, agriculture for 14%, and waste contributed only 4% to total GHG emissions (Figure 22). The major reduction achieved in GHG emissions is attributed to deindustrialisation of the economy and economic stagnation. Ukraine's carbon intensity, however, remains one of the highest in the world exceeding the global and European average levels, despite the recent trends in reducing the greenhouse gas emissions and indicating the need for investment to modernise its energy, industry, agriculture and transport sectors (Zanizdra, 2022). It has to be generally mentioned that access to data after 2021 is difficult as legal entities are not obliged to report to the SSSU since the invasion. Some data is classified by the government as confidential after Russia launched missiles attacks on energy infrastructure and therefore not publicly available. This report hence uses latest available data. Some analysis and ratings such as the Climate Action Tracker have suspended their rating for Ukraine "as the country defends itself from the unlawful Russian invasion".

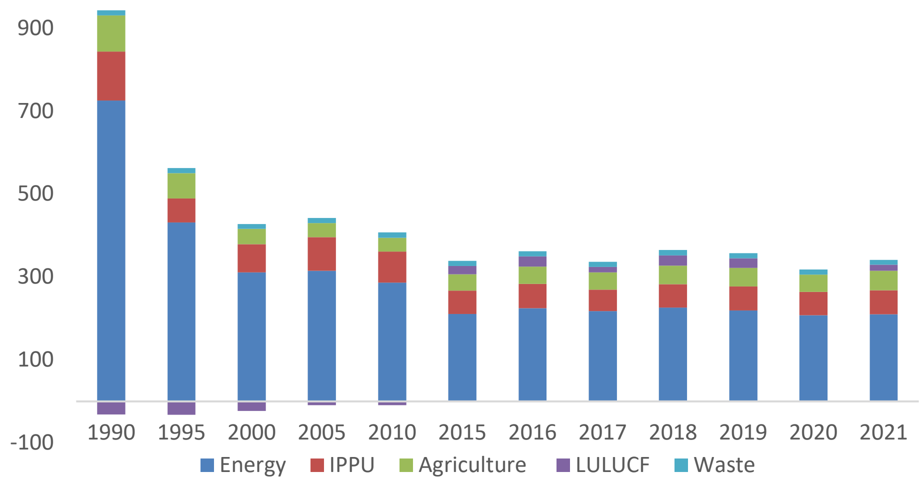

Figure 16: GHG emissions by sector in 1990-2021 (Mt CO2e)
Source: IEA, 2023

Ukraine managed to successfully decouple economic growth and greenhouse gas emissions. Although Ukraine's real GDP increased by 47% in 2021 over 2000, total GHG emissions decreased by 16% over this period.

The electricity and heat generation were responsible for almost half of CO2 emissions in 2020 but its emissions were 41% lower than in 2000 (Figure 23). The second-and third-highest emitters in 2020 were industry, which registered a decrease of 57% of CO2 emissions, and households, whose emissions dropped 61% over twenty years. Total emission from transport, which is only the fourth largest source of emissions in Ukraine, fell by 19% in 2020 over 2000 (IEA, 2023. Note: The IPCC and the IEA methodologies yield different estimation of CO2 emission by countries.).

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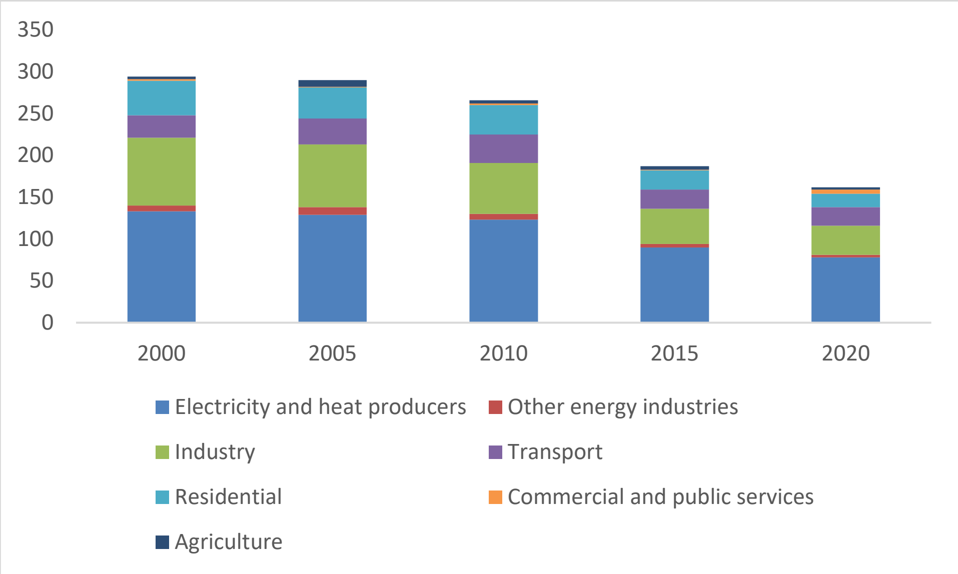

Figure 17: CO2 emissions by sector in Ukraine in 2000-2020 (Mt CO_2)
Source: IEA, 2023

Historically, removals in the Land-Use Change and Forestry sector were almost -40 Mt CO_2e in 1990 (Climate Watch, 2022). Removals were continuously decreasing thereafter and since 2011 the sector has become a net source due to national practices of cropland and grassland management and forestry (MEPR 2021 and 2023).
There were different drivers for CO2 emission decline in 2000-2020 (figure 24). Some emission decrease is attributed to significant population and industrial decline since the war with Russia began in 2014. Some of it stems from lower carbon and energy intensity of the economy over this period. The electricity generation also declined in Ukraine from 171 TWh in 2000 to 148 TWh in 2020 but carbon intensity of electricity generation also improved due to higher shares of nuclear and renewables over this period.

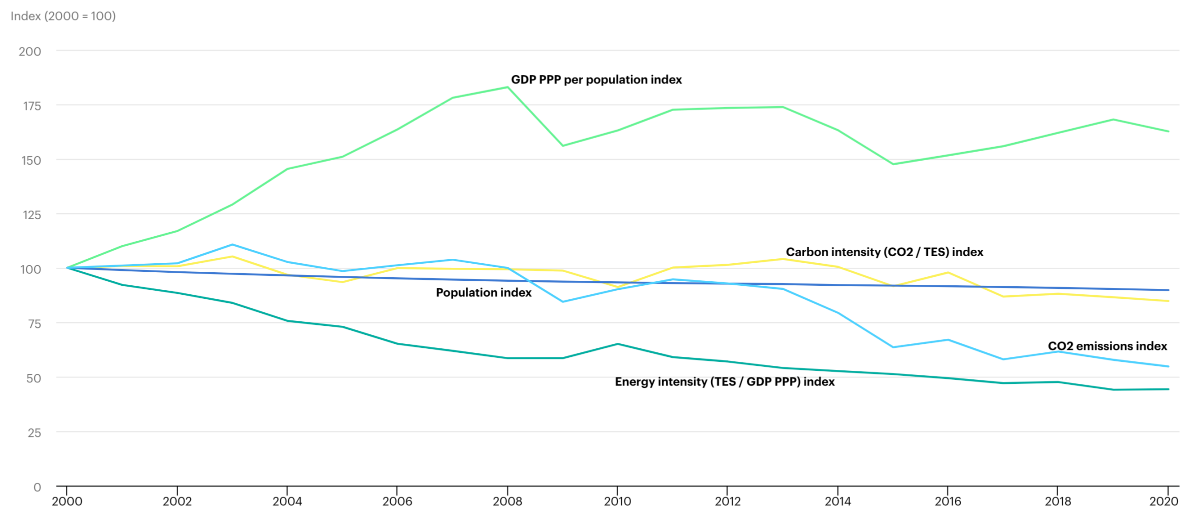

Figure 18: CO2 emissions drivers, Ukraine 2000-2020
Source: IEA, https://www.iea.org/countries/ukraine

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Ukraine ratified the Paris Agreement in September 2016 and in its first nationally determined contribution (NDC) pledged to reduce its net GHG emissions to 40% below the 1990 level by 2030, a target that has already been met. In July 2021, it submitted an updated first NDC to the UNFCCC with a commitment for an economy-wide net domestic reduction of 65 % of GHG emissions by 2030 compared to 1990 (Government of Ukraine, 2021a). The Government of Ukraine stresses that the NDC target includes GHG emissions and targets for its uncontrolled and occupied territories on the basis of expert assessments as detailed information on the economic activities and GHG emissions on those territories is not available. The updated NDC target covers all GHGs and the following sectors: energy; industrial processes and product use; agriculture; land use, land-use change and forestry and waste. Ukraine employed a TIMES-Ukraine integrated system modelling for analysing sectoral potentials on which the updated first NDC was based. The model analysis developed at the Institute of Economics and Forecasting of Ukraine's National Academy of Sciences.determined the climate change mitigation actions in electricity and heat production, industry, buildings, transport, agriculture, forestry, land use and land use change and waste management sectors (MEPR, 2021). Total investment needs were estimated at €102 bn, from which €93 bn had to be allocated to energy sectors and industrial processes (Ibid)). The documented emissions of 2021 show that targets have already been met in 2021 as they were 62.5% below 1990 levels including LULUCF and 64.8% excluding LULUCF (Government of Ukraine, 2023). The updated NDC of 2021, moreover included a net zero target for 2060 (Government of Ukraine, 2021a) and highlights that Ukraine has started to actively implement energy efficiency and environmental protection policies and promotes economic modernisation with key legislative and regulatory act and includes a list of strategies and plans already approved. However, compared to the modelled domestic pathways, the Climate Action Tracker rated Ukraine`s updated NDC target as highly insufficient (CAT, 2021).
Before the unprovoked Russian invasion, Ukraine planned various measures in the sectors, in particular retiring old coal-fired power plants, large renewables deployment, using biomass for heat production, increasing energy efficiency in buildings and reducing natural gas pipeline leaks (MEPR, 2021). Despite the devastation of war and economic breakdown, the Ukrainian Government pursues its transition to net zero in times of war. Approving the "Energy Strategy of Ukraine through 2050" in May 2023 it increased climate ambition aiming to meet the net-zero target ten years earlier in 2050 (Government of Ukraine 2023). Regarding sectoral decarbonisation, projections and planning of sector strategies and policies are difficult as Russia's war has caused massive damage and destruction in the Ukrainian energy, industry, transport, agriculture and building sectors.

Implications of war

Russia's invasion of Ukraine in February 2022 resulted in tragically upended lives and casualties among civilian population. As of July 31, 2024, the Office of the UN High Commissioner for Human Rights recorded 35,160 civilian casualties in Ukraine: 11,520 killed and 23,640 injured (United Nations, 2024). One-third of Ukraine's population is estimated to be displaced due to Russia's invasion of the country.
The World Bank reports 29.1% GDP decline in 2022, and its estimates, recovery and reconstruction need across social, productive, and infrastructure sectors total at least $411bn by June 2023, which is more than 2 times the 2021 GDP of Ukraine (World Bank Group, 2023). KSE Institute documented only the total amount of damage to residential and non-residential real estate, other infrastructure amounted to more than $157.2 bn (at replacement cost) as of January 2024 (KSE, 2024).
Assessments of Ukrainian climate policy has been suspended by initiatives such as the Climate Action Tracker (CAT, 2022) or the Climate Change Performance Index (CPPI, 2024). (Green) recovery strategies and plans have been developed and discussed in international conferences not least with a view to sectoral decarbonisation strategies and policies, but amount and implementation depend on the end of war. Green recovery strategies and finance programs are discussed in a series of recovery conferences, for example the Ukraine Recovery Conference in June 2024 in Berlin (URC, 2024).
Not least, Russia's war in Ukraine also had an impact on global climate as a result of substantial GHG emission. The total GHG emissions attributable to 18 months of war are estimated at 150 Mt CO2-eq. (de Klerk et. al., 2023), which is more than the annual emission of highly industrialized Belgium (Figure 25). The estimate constitutes of warfare, fires caused by war, refugees, civil aviation, reconstruction needs and Nord Streams 1 and

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2 sabotage. The direct damage from the warfare are estimated at 37 Mt CO2-eq (ibid). They consist of fuel used at combat field, the use of carbon-intensive explosives, steel, and other materials, the increase in ammunition production, concrete as construction material used by Russians for fortifications construction. Additional GHG emissions are associated with the manufacturing of military equipment that has been destroyed and damaged during the war, as well as long-distance arms delivery.

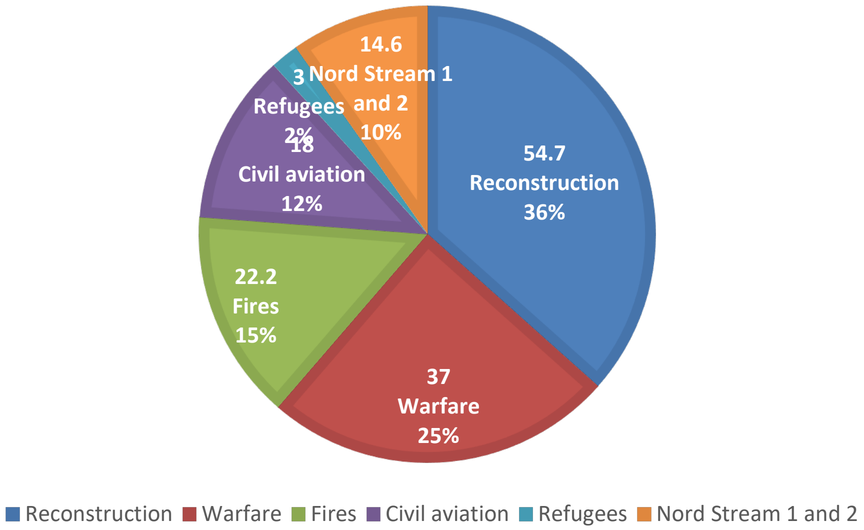

Figure 19: *Total GHG from the first 18 months of Russian invasion, Mt CO2-eq., %*
Source: de Klerk et. al., 2023

6.2 Industry

Current decarbonisation status and prospects
Ukraine`s economy is still one of the most energy intensive ones (figure 26). The industrial sector is dependent on gas (UNECE, 2023a) and contributes significantly to the economy and employment (nearly 2.2 million people excluding agroindustry and construction sector). In 2021, industrial manufacturing accounted for 10% of Ukraine's GDP. The majority of industrial enterprises are SMEs with less than 250 employees. Main activities of industry except agroindustry are the following:

- Manufacturing of basic metals and fabricated metal products,
- Mining and quarrying,
- Manufacturing of rubber and plastics products, as well as other non-metallic mineral products,
- Machine building.

Main exported industrial products in 2020 were iron ore and concentrates, flat-rolled products of iron, cast iron processing, ferro-alloys, and pipes made of cast iron and ferrous metals (UNIDO, 2023). Most important export goods were ferrous metals, electrical machinery and nuclear reactors, boilers and machinery.

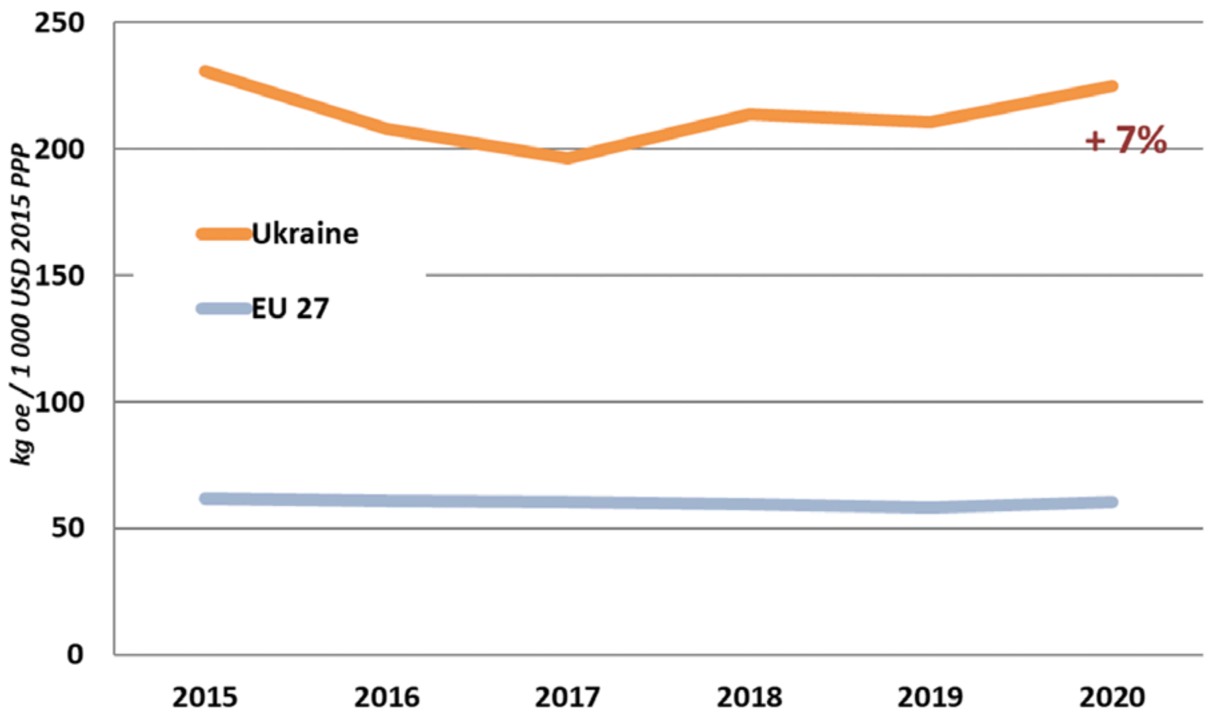

Figure 20: Energy intensity in Ukraine`s industry sector.
Source: (UNECE 2023)

The sector is characterized by energy intensive production and activities. Infrastructure is energy inefficient due to underinvestment over a long period. Industrial processes and product use are responsible for 18 percent of greenhouse gas emissions in Ukraine. Among industrial processes, metal production accounts for 66.7 percent, chemical industries for 17.48 percent and mineral products for 12.06 percent of greenhouse gas emissions from industrial processes and product use (MEPR, 2023). In 2021 – before the war, the most emission-intensive regions were Donetsk, Dnipropetrovsk, Zaporizhzhia and Ivano-Frankivsk (UNIDO, 2023). Outdated and inefficient production technologies remain in use across the entire region (Industrial Decarbonisation Accelerator, n.d.). Therefore, the industrial sector, especially Ukraine`s metal industries, have a large potential to rapidly reduce greenhouse gas emissions through energy efficiency measures, innovation and investment in new technology. In the National Economic Strategy up to 2030 (Government of Ukraine, 2021b) investment needs (foreign and domestic) of the industry sector were estimated at at least USD 20 billion by 2030 to modernise production facilities and reduce emissions. Moreover, investment needs of the mining sector were estimated at about USD 7 billion by 2030 to conduct geological exploration to expand its mineral resource base.

Implications of war

The war has the third largest impact on the industry of Ukraine infrastructure and housing in terms of total value of damages and asset losses. Total losses across commerce and industry amounted to USD 173.2 billion with total damage to facilities estimated at USD 15.6 billion, as of December 2023 (World Bank, et al., 2024). As of January 2024, the Kyiv School of Economics (KSE, 2024) assessed the total damage to the assets of enterprises at USD 13.1 billion and at least 426 large enterprises were damaged or destroyed since the beginning of the war. Total reconstruction and recovery needs for the commerce and industry sector were estimated at USD 20.8 billion over 10 years. In terms of emissions, in 2023, damage to industry and utilities is assessed as additional 14.4 Mt CO2-eq. of GHG emissions (KSE, 2023).

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6.2.1 National-sectoral mitigation enablers and barriers

The industrial sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in the Annex (Table 73) and are summarized below:

Geophysical feasibility: Regions with high potential for renewables (solar and wind) may emerge as exporters of hydrogen or become hubs for the production of green / blue iron or steel. However, currently areas with high potential are mainly in areas of military conflict so capacity of renewables and land (new sites) are constrained (Devlin et. al., 2024) and not safe until the end of war. The agriculture and forestry sector have a large potential to provide biomass for use as bioenergy (Was et al, 2022; Vasylyshyn et al., 2022). Regarding tri-generation / Combined Heat and Power, this is suitable for many industrial zones as they are characterized by high energy demands for electricity, heating, and cooling.

Environmental and ecological feasibility: There is a significant potential for resource conservation, waste reduction and pollution prevention through circular economy and the reduction of pollution and resource depletion can be achieved through RECP. A transformation towards green steel production has a potential for resource conservation, waste reduction and pollution reduction / prevention. Furthermore, Eco-Industrial Parks have significant potential for increasing resource efficiency, waste minimisation, pollution reduction and increasing environmental benefits (Ministry of Economic Development and Trade of Ukraine, n.d.). Finally, tri-generation can significantly improve energy efficiency and reduce emissions compared to separate generation of electricity, heating and particularly cooling.

Technological feasibility: RECP technologies and methodologies are available and adaptable. However, RECP Investment levels for new technologies and modified equipment remained small after establishment of RECP Center, indicating an untapped potential for more expensive technological solutions with higher impacts (EU4 Environment) for technical knowledge reasons. As well, circular economy principles and practices are increasingly adopted worldwide. As there is almost no waste-processing technology and no European-style landfills in Ukraine (Yevstihnieieva, 2022) this might be a barrier for the introduction of waste management technology and Circular Economy. Tri-generation technologies are mature and available. Eco-industrial park models and technologies are well established globally. Application in Ukraine is supported by the Government of Switzerland and UNIDO.

Economic feasibility: Circular Economy is an underdeveloped issue in Ukraine, but resource efficient cleaner production practices (RECP) are applicable in industrial processes and sectors in Ukraine. RECP and circular economy practices result in (long term) cost savings through resource optimisation and waste reduction. The increased use of biomass contributes to the reduction of Ukraine`s dependence on fossil fuels (natural gas) in the long run. However, as the focus in Ukraine is rather on waste management, waste reuse/recycling than on CE (UNIDO, 2023), a barrier to the adoption of circular economy models may be that they require significant changes in business practices. Regarding Eco-Industrial Parks, a barrier could be the need for coordinated planning and collaboration among multiple stakeholders which is required to set up these parks. Experience with implementation of "usual" Industrial Parks shows management and planning difficulties. Moreover, there might be a lack of available skilled labour in EIPs. A barrier to the decarbonisation of the industry sector is that the current instability/war has strong impact on investment decisions. Generally, a limited overall flow of investment into industrial energy efficiency improvements (Industrial Decarbonisation Accelerator, n.d.) is observed, enabler for improving energy efficiency would be policy incentives and market mechanisms that drive adoption of low carbon technologies. Another economic enabler for decarbonisation in industry could be the cost saving potential of tri-generation (Combined Heat and Power).

Sociocultural feasibility: Sustainable biomass supply chains and RECP practices offer a potential for job creation and improved working conditions. Eco-industrial parks offer community benefits. Raising awareness and

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fostering stakeholder engagement are crucial for the success of all initiatives. A lack of awareness /technical and financial capacity may hinder adoption of RECP practices. Moreover, limited awareness and knowledge on trigeneration and modern energy technologies among central and local authorities and district heating utilities (USAID ESP, 2024) is a barrier to implementation.

Institutional feasibility: The RECP Center of Ukraine was established with support of an EU Programme. but so far, there was a lack of Government incentive mechanisms for RECP (EU4 Environment, 2022) to unfold more impact. A further enabler could be a waste management information system, which should simplify the system of accounting and reporting, submission of declarations and implementation of permitting procedures that should be introduced after entry into force of the Waste Management Law in 2023 (WTO, 2023). But a barrier is that no modern waste management system was in place before the war (Lindskog, 2023) despite strategies and management plans. An enabling factor for decarbonisation of the industry sector is the amendment of Ukraine's Law on Industrial Parks regarding the EIP approach which is in the public consultation phase. (UNIDO, 2024) However, currently the lack of clear regulations, standards, enforcement, and monitoring mechanisms hinders the use of biomass, RECP roll out, eco-industrial park development, and circular economy practices in general. An EIP related national standard is under development since June 2024 (UNIDO, 2024) which might improve this. 6.9.1 (Quicklink to table on enablers and barriers)

6.2.2 Current status of national-sectoral policy

Ukraine has no formalized industrial strategy. An order of the Cabinet of Ministers of Ukraine on approval of the strategy for the development of the industrial complex of Ukraine for the period up to 2025 had been drafted in 2017 but not been approved (UNIDO, 2023). Industry chapters are integrated in other strategies such as the National Economic Strategy until 2030.

Governance and planning instruments: The objectives of economic and industrial development are described in the **National Economic Strategy until 2030** adopted in 2021. General goals are the establishment of a favourable environment for business development and investment, achievement of competitiveness in the international market, development of innovations and modernisation of economic sectors, development of human potential, and ensuring equal rights and opportunities for women and men in all spheres of society. Pollution and climate change related issues are not focus areas and the industry chapter does not directly mention emission reduction as priority. Implementation will be reviewed in 2024 and 2027. The **Strategy of Environmental Safety and Adaptation to Climate Change until 2030** approved in 2021 contains strategic goals including the reduction of industrial pollution, creation of an effective chemical safety system, ensuring the rational use of natural resources, as well as the creation of the legal and economic framework for the introduction of waste management systems (Government of Ukraine, 2021c; UNIDO, 2021). The **National Waste Management Strategy of 2017** is based on requirements of the EU Directive on Waste Management**:** It should regulate the area of waste management and the introduction of certain elements of circular economy (Environment, People, Law, 2022).

Regulatory instruments: In 2009, the **Law on Promotion of Biological Fuels Production and Use** was approved: The main objectives to be achieved by promotion of biofuels were to save fossil fuels, decrease dependency from energy imports, increase energy security, and decrease negative impacts on the environment caused by burning fossil fuels. The Law introduced a definition of biofuels and its types (bioethanol, biogas, biomass, biodiesel, etc.) and promotes companies` engagement in production and sale of biofuels. Biofuel types are subject to certification (except for products for own consumption). During the sale, the producer is obliged to present to the buyer documenting the quality of the fuel. Production of bioethanol can be conducted by licensed entities of which the Cabinet of Ministers keeps a registry. The **National Waste Management Plan until 2030** approved in 2019 should further develop and specify the National Waste Strategy. Implementation of the tasks

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and objectives of the plan would require further related and more specific legislation.

Market-based instruments: Ukraine adopted a **Carbon Tax** covering CO2 emission from stationary sources in the industry, power and buildings sectors in 2011 with a marginal tax rate of €0.003/tCO2. The carbon tax is currently again at a low level at UAH10/tCO2 (around €0.25/tCO2 at December 2023 exchange rate) and remains one of the lowest carbon prices worldwide (Neuweg, 2023; World Bank, 2020). At this tax rate, the carbon tax cannot affect the production and consumption decision in the economy and consequently, cannot lead to substantial GHG emissions reductions. A weak motivating role of environmental taxes and low investment activity of industry are assessed as barriers not providing conditions for effective decarbonisation and digitalisation of the industrial complex (Zanisdra, 2022).

Information instruments

As part of the Europeans EaP Green programme UNIDO supported Ukraine in setting up a Resource Efficient and Cleaner Production Centre (RECPC) in 2013. RECPC supported more than 170 companies to improve resource efficiency and environmental performance. Despite RECPC there appears little attention for saving opportunity (material flows, circular economy). Investment levels for new technologies and modified equipment remained small, indicating an untapped potential for more expensive solutions with higher impacts. Incentive mechanisms are lacking (EU4Environment, 2022.).

The next table lists the individual policies and measures. Further information, including a brief of the policies, can be found in the Annex (Table 74).

Table 49: Ukraine`s policy package (industry sector)

Type of instrument	Status
Governance and planning instruments	National Economic Strategy for the period up to 2030 Strategy of Environmental Safety and Adaptation to Climate Change until 2030 (2021). National Waste Management Plan until 2030 (2019)
Regulatory instruments	Law on Promotion of Biological Fuels Production and Use (2009) Law on waste management reform (2022) replacing law on waste adopted 1998 Law on Alternative Fuels (2000, amended 2009 and 2012)
Market-based instruments	Carbon Tax (2011) Tax Code: Excise Tax
Information instruments	RECPC established (2013)

6.2.3 How to strengthen national-sectoral climate policy

Challenges for the industry sector are the reduction of carbon consumption and energy consumption per unit of output, and the modernisation of industrial enterprises with the best available technologies. Challenges for heat supply are to increase heat production from biofuels by 30%, and to modernise central heating systems. Challenges for waste management are to implement best practices in the waste management hierarchy, and to utilise methane from solid and liquid waste.

Ukraine`s Net Zero Scenario projects that negative emissions from power and heat through carbon capture and storage and direct air capture could offset remaining emissions from industry to achieve Net Zero by 2050 (Institute for Economic Forecasting, 2023).

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As it has been assessed that the Ukraine Carbon Tax is ineffective in strengthening energy efficiency and reducing carbon emissions (Breuning, 2021) efforts to introduce a range of measures to achieve emission reduction goals call for a revision of Ukraine's carbon pricing strategy. A successful transition towards effective carbon pricing should include a gradual increase of carbon tax with revenue allocation to support vulnerable customers and industrial energy efficiency measures and a speed up of the introduction of Ukrainian ETS and consider its linkage to EU's ETS to ensure the tax revenue from steel and power industries stays in Ukraine instead of flowing to the EU after CBAM introduction: The absence of an effective carbon pricing is an important barrier on the path towards net-zero. Ukraine is planning to establish a national ETS in 2025, in line with its obligations under the Ukraine-EU Association Agreement. Ukraine adopted a framework law in 2019 on measurement, reporting and verification (MRV), which is one of the initial steps required to set up an ETS but other progress in establishing ETS is limited so far. An additional element Ukraine's policymakers should consider when choosing an optimal carbon pricing solution is the EU Carbon Border Adjust Mechanism (CBAM), which will first apply to sectors that could already be covered by Ukraine's ETS: iron and steel, aluminium, cement, fertilisers and electricity. Imports from these sectors would be subjected to a border carbon tax unless a carbon tax was paid on them in Ukraine. According to a KSE study, iron and steel and electricity exports would be affected the most by the CBAM (KSE, n.d.). Thus, the annual exports losses from steel industry will amount to €513-739 m while annual losses of electricity exporters are estimated at €108-125 m. Given the substantial emission reduction by Ukraine over 1990 and extensive damages to both steel and electricity produces from the war, Ukraine needs to ask for a grant period of CBAM implementation which can be used to establish and link the ETS-Ukraine with the ETS-EU.

Regarding Ukraine`s metal producing industry, decarbonisation of iron and steel production has a large greenhouse gas reduction potential based on retrofitting of existing facilities for partial fuel switching to biomass or hydrogen, or carbon management. Achieving very low and zero emissions in steel production can be accomplished through high-capture CCS or direct hydrogen utilisation, resource efficiency and material substitution, process integration and optimisation.

6.3 Energy

Current decarbonisation status and prospects

The energy mix of Ukraine relies on fossil fuels and energy imports. In 2020 before the war, fossil fuels (coal, crude oil, oil products and natural gas) accounted for 70% of the total primary energy supply. Nuclear energy accounted for 23 % of total primary energy supply and provided the base load and more than half of total electricity generation (in 2021). Renewables (wind and solar) accounted for 7 % of total primary energy supply including almost 5% bioenergy from waste (UNECE, 2023a). In comparison, in the energy mix in the year 2000, renewables did not play any role, and bioenergy was on a low level (figure 27).

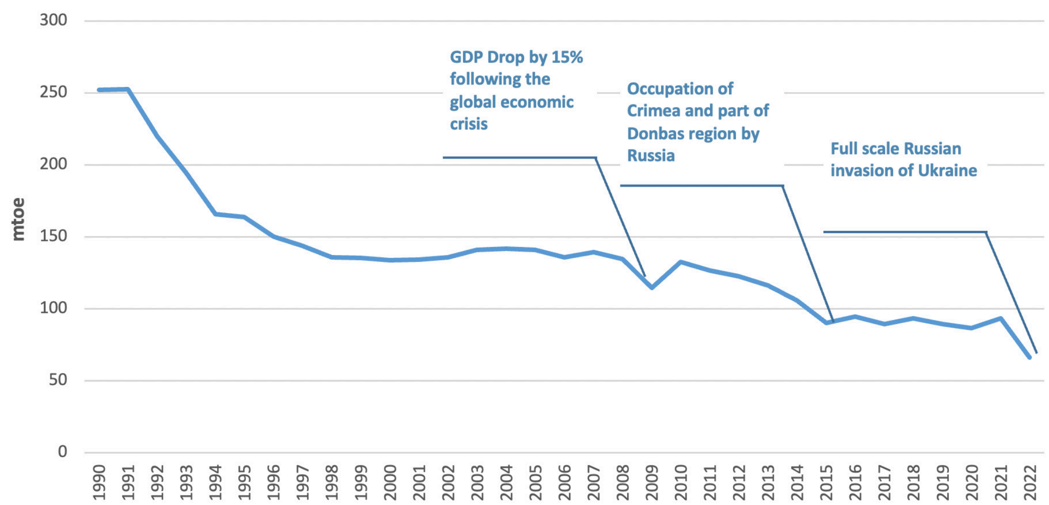

Figure 21: Total primary energy supply (mtoe). Ukraine 1999-2022

Source: (UNECE 2023)

In the National Economic Strategy up to 2030 (Government of Ukraine, 2021b) investment needs (foreign and domestic) of the energy sector were estimated at least as USD 25 billion by 2030 to replace generating capacity and modernise the energy infrastructure.

Decarbonisation could lead to a doubling of electricity demand, which could be supplied by solar and wind generation increasing their share from 12% in 2020 to appr. 80% in 2050 (UNECE, 2023a). Nuclear, hydropower and bioenergy would complement these sources. The estimated potential Ukraine´s bioenergy sector is very large compared to current, 2021 volumes of production, with benefits regarding decentralisation of energy supply ensuring independence from natural gas and reducing dependence on other types of fuel (UNECE et.al., 2023): For example, biomethane/biogas development potential has been estimated as 1719 ktoe biomethane in 2035 compared to 125 ktoe biogas in 2021. The estimated potential of solid biomass is 10.1 Mtoe in 2035 compared to 4.2 Mtoe in 2021 (ibid).

Implications of war

Russia's unprovoked invasion also poses a huge challenge for a resilience of Ukrainian energy sector. The availability of power and heat for civilians is being compromised by Russian attacks on critical energy infrastructure and other targets. The largest source of war related GHG emissions stems from civilian infrastructure damages and its post-war reconstruction needs. The destruction of Nova Kakhovka dam by Russian military forces to empty the reservoir and resulting the downstream flood is an act of ecocide for which Russia should be accounted for in line with the international law. Total GHG emissions from this sector are estimated at 54.7 Mt CO2-eq. and continue increasing with war. From October 2022 to March 2023 Russia launched 33 extensive attacks with more than 1000 missiles and kamikaze drones targeting primarily electricity generation and grid facilities and other energy assets. In 2022, about 50% of Ukraine's generating capacities and transformer substations had been damaged or occupied. Renewable energy has also been affected as up to 40% of solar and 90% of wind electricity generation was lost (Ministry of Energy of Ukraine, 2023b). The emissions from the sabotage of the Nord Stream 1 and 2 pipelines on 26 September 2022 is estimated at 14.6 Mt CO2-eq. (de Klerk, 2023).

Amid the continuous attacks on energy infrastructure and energy security, the Bioenergy Association of Ukraine appealed the World Biogas Association (WBA) for help in supporting the urgent need for decentralised energy solutions on the basis of bioenergy, biogas represents a key technology to achieve this. WBA has agreed the request and called on their members and the international biogas community to help supply Ukraine with surplus and second-hand anaerobic digestion (AD) and biogas systems (WBA, 2024).

6.3.1 National-sectoral mitigation enablers and barriers

There are many enablers that support climate and decarbonisation policies in the energy sector but the sector also faces numerous barriers that hinder climate mitigation options. The enablers and barriers are categorized and explained in more detail in the Annex (Table 75) and are summarized below:

Geophysical feasibility: Ukraine starts from an energy sector based on coal, (imported) natural gas and nuclear. It has large domestic natural gas reservoirs. Ukraine has an abundant untapped potential for renewable energy. Solar, wind have increased but are still on a lower level in the energy mix (UNECE, 2023). There is suitable terrain for additional hydropower and geothermal energy potential has almost not been exploited (Demchuk and Liventseva, 2023). There is a large potential for bioenergy from agriculture waste. Increasing the share of renewables is accompanied by risks from the intermittent nature of solar and wind energy. Under the current conditions of war, potentials cannot be exploited in east and south regions of Ukraine.

Environmental and ecological feasibility: Decarbonizing Ukraine's energy sector has a high potential of reducing Ukraine`s energy sector greenhouse gas emissions and other pollutants related to mining activities (coal). There might be environmental impacts of intensified domestic natural gas extraction or new (larger) hydropower projects.
Technological feasibility: Globally, mature renewables technologies are available but grid stability, transmission infrastructure in Ukraine might by bottlenecks to greater solar PV integration (Bilek et. al., 2024). Battery technology is a research focus globally. Globally, expertise in biomass power generation is growing. The currently underutilized extensive natural gas transmission system and underground storage facilities can potentially store the entire existing potential of biomethane production in Ukraine (up to 10 billion m3 per year) (UNECE, 2023b). Low level of policy support for research, development and demonstration (RD&D) for bioenergy related novel technologies is a barrier for wider deployment. There is proven technology for natural gas power plants. Mature technologies for energy-efficient appliances, lighting, and building design are available.

Economic feasibility: Diversification of the energy mix increases energy security and has the potential to decrease dependence on imports. There are decreasing costs of renewable energy technologies having a potential for long-term cost savings. Implementation of energy efficiency measures reduces energy cost in the medium and long-term. Market structure, high upfront investment cost, tax rates on biofuels, subsidy structure, and a lack of incentives generally are economic barriers (Bilek et. al., 2024). Regarding nuclear fuel, Ukraine aimed to reduce its dependence on Russian nuclear fuel switching to US fuel (Szulecki and Overland, 2023).

Sociocultural feasibility: Diversification results in new jobs but net balance with job losses must be assessed. Trust issues regarding large scale introduction of solar PV and prejudice against bioenergy (food security) might be a barrier for acceptance.

Institutional feasibility: There is a number of regulations and initiatives for renewable energy development (feed in tariff etc.) and energy efficiency but enforcement level appears low. FiT remains only for households. In legislation, it was replaced by auctions and contracts for difference. Auctions on large capacities were promised but delayed since 2020. The first auctions were promised for the fall of 2024.The bioenergy sector has a high potential for growth, but a supportive regulatory environment is essential to attract investment and to support existing businesses. Complex procurement procedures for investments in renewables and related technologies like energy storages by SOE and imperfect competition and private participation at the heat supply market are barriers for diversification.

6.9.2 (Quicklink to table on enablers and barriers)

6.3.2 Current status of national-sectoral policy

The energy sector in Ukraine has been transformed to some extent in the past and is "under attack" in the ongoing war. The current National Energy Policy can be described as strategically driving transformation but having to safeguard daily business and consistent implementation. There are two key pillars: ensure energy security (short-term), and sustainability by diversifying the energy mix and reducing dependence on fossil fuel resources (mid-/longterm).

Governance and planning instruments: Ukraine has a considerable tradition of developing energy sector related government strategies and plans. In 2017, the **Energy Strategy of Ukraine (ESU) 2035** was approved but an assessment showed limited effects (Zachmann et. al., 2019). The **Energy Strategy of Ukraine until 2050** approved in 2023 is an energy roadmap focusing on the development of nuclear and renewable power generation capacity and on the modernisation and automatisation of transmission and distribution systems, in order to achieve carbon neutrality in the energy sector by 2050. Ukraine aims to strengthen energy security and the sustainability of its energy system and wants to join the unified energy system of Ukraine (UES) to the

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European network of electricity transmission system operators (ENTSO-E). Ukraine announced to achieve climate neutrality by 2050, ten years earlier then announced in its updated NDC in 2021. As updated in the **Ukraine Plan** (2024) it outlined green recovery projections and investment needs. In June 2024, the **National Energy and Climate Plan (NECP)** was approved. The NECP defines key targets for 2030, reaffirming the updated NDC targets and net zero for 2050 and adding specific sub-targets. It has been prepared in about one year and approved under conditions of war and was driven by the EU accession process. Focus areas are decarbonisation, energy efficiency, energy security, internal energy market (electricity, gas including bioenergy and oil) as well as research, innovation and competitiveness. For each focus area, it identifies existing, additional, and planned policies and measures and summarizes these in an 6 page overview table on policies and measures.

Regulatory instruments: Feed in and incentive tariffs have been enforced to promote renewables. The **Feed in Tariff for electricity producers from RES (2008)** promoted investments for power generation through non-conventional sources of fuel using non-fossil technologies and granted the green FIT to investors until end of 2029. However, it was effective only for projects implemented until 2020. Auctions for new capacities are delayed but may be introduced as required secondary legislation was adopted in 2023-2024. The **Incentive tariff for heat energy from RES (2017)** grants investors implementing gas substitution projects a legislatively fixed tariff for heat. Basic biofuel regulation has been approved in 2008.

Market-based instruments: Ukraine`s Tax Code can be mentioned, for example the Excise Tax on Electricity. Energy taxes account for a high share of environmentally related tax revenue. Apart from the carbon tax covered in the industry section, this results mainly from the excise tax on electricity. A challenge is that tax revenue fluctuates, therefore it difficult as basis for expenditure for renewables support measures.

Information instruments: The NECP list several measures, for example a **Modernisation of educational programs** to address skills gap in the green transition and renewable energy sector.
The next table (table 69) lists these policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies where available, can be found in the Annex (Table 76).

Table 50: Ukraine`s policy package (energy sector)

Type of instrument	Status
Governance and planning instruments	National Energy and Climate Plan of Ukraine covering the period 2025-2030 (approved June 2024) Ukraine Plan (2024) Clean Energy Roadmap (2023)
Regulatory instruments	Feed in tariff for electricity producers from RES (2008), secondary legislation 2023/24 Incentive tariff for heat energy from RES (2017) Law on Promotion of Biological Fuels Production and Use (2009)
Market-based instruments	Carbon Tax (2011) Tax Code: Excise Tax on Electricity
Information instruments	Educational programs address skills gaps in the green transition and renewable energy sector

6.3.3 How to strengthen national-sectoral climate policy

In its updated NDC, Ukraine the Government of Ukraine, 2021 listed as success factors for the energy sector transformation and for achieving the NDC (Government of Ukraine, 2021):

- Implementation of the National plan on reduction of emissions from large combustion plants;
- Integration of the unified energy system of Ukraine into the energy system of continental Europe (ENTSO-

E);
- Construction of up to 2 GW of peak and semi-peak shunting heat generation and 0.5 GW of frequency control support systems;
- Generation of nuclear energy in the amount of not less than 50% of the primary energy supply, taking into account the need to build new power units and maintaining independence from Russian nuclear fuel;
- Maintaining the transit of natural gas through the territory of Ukraine in the amount of 40-55 billion m^3 per year and preventing the completion of the Nord Stream 2 project as such, which poses a threat to the energy security of Ukraine and the EU;
- Overcoming energy poverty of consumers;
- Significant increase in the share of electricity and heat production from renewable sources;
- Full-scale implementation of a program on just transition of coal regions.
-

These and other goals are the basis for scenarios and related strategic policies and measures. Despite all war challenges, Ukraine presented its vision of the path to achieve net zero emissions by 2050 at COP28 (Ministry of Energy of Ukraine, 2023a). The vision is based on decarbonisation, massive renewables development, deployment of new technologies as hydrogen, small-modular reactors (SMR) and green steel, and energy efficiency. The modelling through 2030 and 2050 was performed by the US Net Zero Initiative and the Institute for Economic Forecasting employing the TIMES-UA model used for modeling, for example the first NDC of Ukraine and other energy and climate related government strategies and plans. TIMES-UA is a linear optimization energy system model providing a bottom-up technology-rich representation of the energy system of Ukraine for the longterm estimation of the energy dynamics (ibid). The Government of Ukraine called the presentation Net Zero Strategy until 2050. Specific challenges for the energy (power) sector are to increase solar and wind power to 30% in electricity generation mix by 2030, deploy ultra-flexible gas generation and electricity storages capacities, reduce the use of coal-fired power plants, and gradually close coal mines while implementing programmes to transform coal regions including programmes for workers (just transition).
The reference (business-as-usual) scenario assumes no changes in policies and development of economy and energy sector as compared to 2020. In this scenario coal continues to play an important role in energy supply through 2050. The Net Zero Base Scenario assumes the achievement of net zero emission by 2050 and is supposed to be based on the base case scenario of the Energy Strategy of Ukraine through 2050. Finally, the Net Zero Intense Scenario reflects the vision of the Office of the President of the post-war recovery presented at the Ukraine Recovery Conference London in 2023 and contains massive adoption of new technologies like green steel and hydrogen.

equivalent (Mtoe)

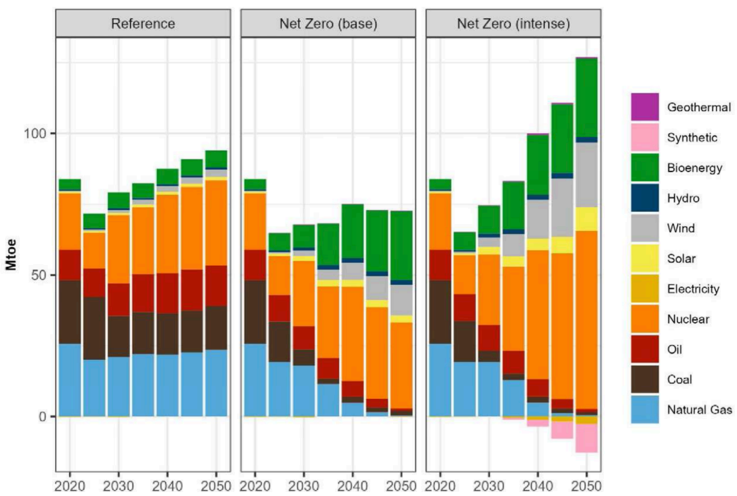

Figure 27_1: Total Primary Energy Supply (TPES) in 2020-2050 by scenario, million tonnes of oil equivalent (Mtoe)

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Source: *Ministry of Energy of Ukraine, 2023a.*

In the net zero scenarios there is rapid phasing out of coal by 2035 and very fast deployment of variable renewables (solar and wind), bioenergy and nuclear. In the Net Zero Intense Scenario the TPES in 2050 is much bigger than in two other scenarios due to large exports of green steel and hydrogen.

Electrification plays a key role in decarbonisation of energy demand, so electricity production grows considerably in Net Zero Scenarios (figure 27_2). Wind and solar will account for the most production increase. In the Net Zero Intense Scenario the wind is responsible for over 250 TWh in 2050 compared to 156 TWh of total electricity generation in 2020. Although the wind offshore and onshore potential is substantial in Southern Ukraine, the war over South of Ukraine with Russia increases the risks of such investments in the region, which in turn substantially increase the costs of investments in wind generation.

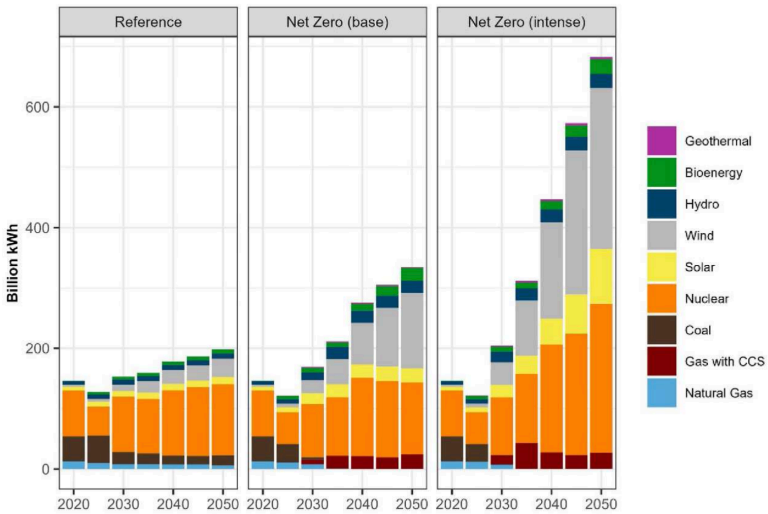

Figure 27_2: Electricity generation by scenario in 2020-2050, TWh
Source: *Ministry of Energy of Ukraine, 2023a.*

The power and heat sectors are projected to be net negative by 2040. Negative emissions from power and heat through carbon capture and storage and direct air could offset the remaining emission from industry and energy supply achieving net zero by 2050. The timeline of total emission decline is very similar between Net Zero Base and Intense scenario as both of them must meet the 2050 net zero target.
Regarding specific sector policies, existing regulation such as the Carbon Tax of 2011 has to be improved by setting an effective tax rate, the announced ETS has to be adopted and implemented, many other regulation as for example envisaged in Ukraine`s National Economic and Climate Plan would have to be implemented in a shorter time than usual, as time from announcement of a strategic objective to implementation of specific regulation appears to be very long. Several policies to exploit potentials depend on the end of war.

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6.4 Transport

6.4.1 Current decarbonisation status and prospects

Greenhous gas emissions in the transport sector include emissions from fuel combustion in all transport modes. In 2021, emissions amounted to amounted to 33.67 Mt of CO2e which is 70 % decrease compared to 1990 levels (figure 28) but a 5.82 % increase compared to 2020. The by far largest share of total transport related emissions was contributed by road transport with 24.98 Mt of CO2e (74.2 %) and the second largest share came from other types of transportation with 7.99 Mt of CO2e (23.74%) including emissions from combustion of natural gas by drives of gas pumping units of compressor stations of main gas pipelines, machinery for agriculture work, as well as activities of off-road vehicles. Other transport modes had marginal shares: railways 0.42 Mt of CO2e, civil aviation 0.19 Mt of CO2e, and waterway transport 0.08 Mt of CO2e (MEPR, 2023). Other information on modal split such as shares of non-motorized transport or public transport is not available.

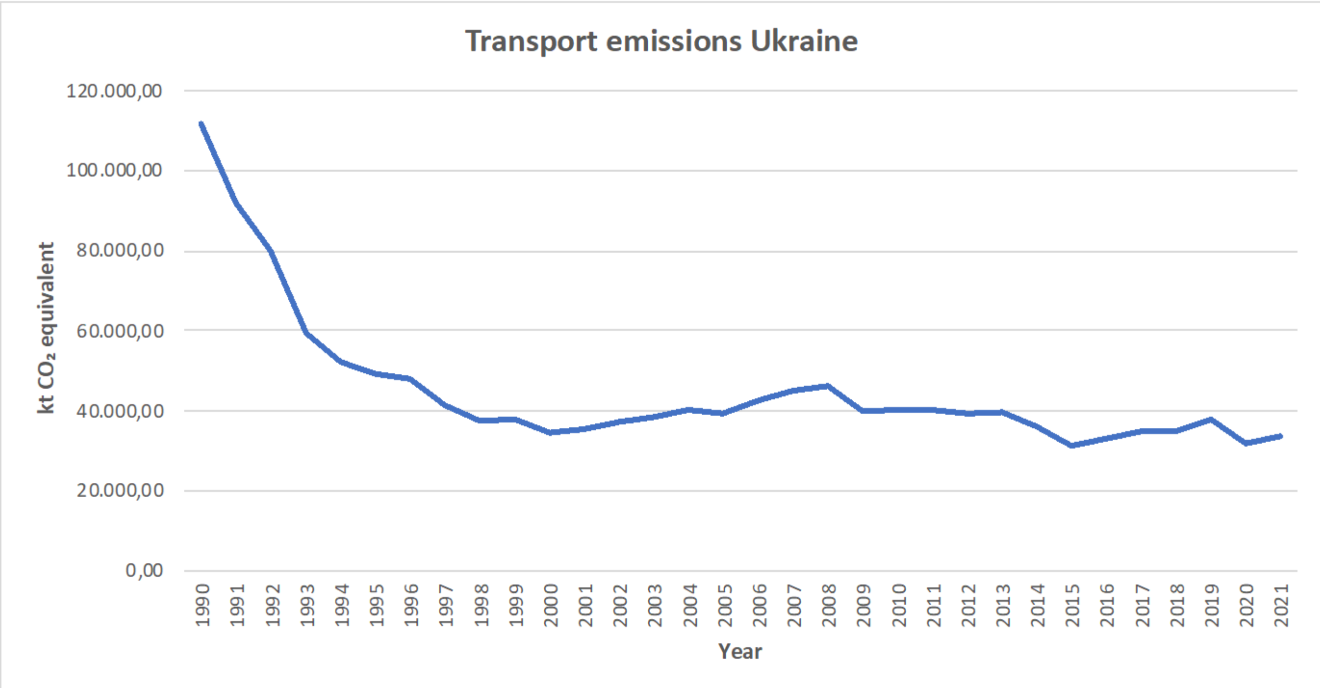

Figure 22: Transport Emissions Ukraine(kt CO2e), 1990-2021.
Source: Own compilation of time series data (UNFCCC, 2024).

Regarding pollution related to transport, Ukraine, ranked 8th in Europe and 43rd in the world among the countries with the most polluted air in 2020, According to experts, the country's annual losses from environmental pollution by vehicles are estimated at 2.5 billion euros. This situation is caused, first of all, by the aging of vehicles, because the average age of the car fleet in Ukraine is 22.7 years, which is two times higher than the average in the countries of EU (11.5 years). Therefore, the carbon trace of road transport in Ukraine has been assessed as being "terrible" (Abuselidse et. al., 2023).

Prospects for emission reduction are high as Ukraine supports the European objectives for sustainable and smart mobility, it has significant potential for rail and inland water transport, an intends in the near future to redistribute transport traffic between transport modes, in particular road and rail transport (ibid).

Implications of war

Transport infrastructure and the vehicle fleet suffered significant damage: Already at the end of 2022, was estimated at USD 28.5 billion (KSE, 2022) and assessed as additional 14.3 Mt CO2-eq. of GHG emissions. Civilian

transport infrastructure is a target for Russian military attacks. After about half a year of war, 25,000 km highways, 500 km railways, 315 bridges, and 111 railway stations were destroyed. Losses due to destroyed public transport reached USD 657 million and for private vehicles damage amounted to USD 1.7 billion USD or about 200,000 cars (UNECE, 2023). The closure of the Siberian airspace by Russia to Western airlines and the closure of Ukraine's airspace to commercial traffic increased the distance of air routes between Europe and Asia and as estimated increased the global GHG emissions by 18.0 Mt CO2-eq (de Klerk, 2023).
National-sectoral mitigation enablers and barriers
The transport sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in the Annex (Table 77) and summarized below:

Geophysical feasibility: In Ukraine, there are suitable climate conditions and terrain for walking and cycling in many areas (non-motorized transportation). Rivers and canals offer additional potential for sustainable inland water transport (Alekseievska et.al., 2023). Ukraine's existing road and rail infrastructure can be improved and expanded when not damaged and has to be reconstructed where destroyed.

Environmental and ecological feasibility: As pollution from road transport and traffic amounts are high, reduction in congestion, air pollution, and GHG emissions through sustainable transport modes including walking and cycling could be enables for decarbonisation in the transport sector. Additional potential environmental impacts of new infrastructure construction, reconstruction could be barriers. Experiences worldwide demonstrate that non-motorized ways are feasible as a zero-emission transport mode. A shift to public transport has benefits for the reduction of congestion, air pollution, and greenhouse gas emissions. In-land water transport has potential for lower emissions compared to road transport. On the other hand, increased In-land water transport may have negative impacts on aquatic ecosystems and water quality. Again, the increase in numbers of electric and hybrid vehicles has the potential for significant reductions in air pollution and GHG emissions from road transport. But it must be considered that electric vehicles require decarbonized electricity supply to maximise environmental benefits. Improved vehicle fleet efficiency leads to reduced fuel consumption and emissions from existing vehicles.

Technological feasibility: Technologies for intelligent transport systems, traffic management and electric mobility are globally available. Existing rail infrastructure can be upgraded for freight transport. Technologies for intermodal transport (e.g., containerisation) are available. Electric and hybrid vehicle technology is mature and available. But limited charging infrastructure is a barrier. Regarding retrofitting potentials, high upfront investment costs for technology upgrades may be barriers. In addition, concerns about limited range of electric vehicles and concerns about battery life exist. As another cost, factor, cost of retrofitting older vehicles with fuel-efficient technologies can be substantial. Even before war, main and regional routes deteriorated and the share of tracks to be repaired and modernized is more than 40 % with increasing tendency (Abuselidse et. al., 2023) without including damages from war.

Economic feasibility: Introduction of taxes to promote public transport can generate substantial revenue for the government. Improved transport efficiency can reduce fuel costs and travel time, boosting economic productivity. Improved public transport can lead to lower operating costs and fares compared to private vehicles. Potential for job creation in the public transport sector. Lower operating costs for electric vehicles due to lower fuel and maintenance costs. Low cost of non-motorized transport in urban areas. The lower costs are confronted with high cost of infrastructure repair, modernisation and optimisation as there is a need for investment in rail infrastructure (e.g. high share of non-electrified rail transport). High upfront costs of electric vehicles are comparatively high. Not least, the modal shift might require subsidies to maintain affordability of public transport.

Sociocultural feasibility: The potential for improved accessibility, safety, and comfort for passengers associated with an improved transport sector is an enabler for decarbonizing the transport sector. There is a growing global trend towards electric mobility. But at the same time there is a lack of awareness and familiarity with electric vehicles. Resistance to change travel habits and preferences is also widespread just as a negative perception of public transport (e.g., overcrowding, unreliability, personal safety). Air pollution and safety are of concern in using non-motorised transport, particularly in urban areas and non-motorised modes promote physical health (Panasiuk, 2022). However, acceptance and use of bicycles as a primary transport mode remain limited in Ukraine (ibid) because of cultural preference for motorized transport and infrastructure gaps. Finally, there appears to be limited awareness and demand for inland water transport.

Institutional feasibility: Government incentives and policies can promote the electric vehicle market. Existing tax and regulatory mechanisms can be adapted to promote public transport and transport mode optimisation. But there is a priority for road and rail transport and a lack of political will and commitment to prioritize public transport. Moreover, Ukraine's inland waterways currently play a secondary role/ are secondary priority in the country's transportation system. several reforms needed to create sustainable logistic system with green inland water transport (Alekseievska et. al., 2023).
6.9.3 (Quicklink to table on enablers and barriers)

6.4.2 Current status of national-sectoral policy

Governance and planning instruments: In 2018, Ukraine has adopted a **National Transport Strategy of Ukraine until 2030** (Government of Ukraine, 2018). It describes the vision of government on priorities for transport policy and a framework for the modernisation of the transport sector in Ukraine. It has four priority areas and contains a problem analysis, task description and expected results for each of the priority areas. However, objective related to sustainable transport such as decarbonisation measures, greenhouse gas emission reduction is not an explicit focus, the electrification of the sector appears not a priority, and electric vehicles are not prominently mentioned. Criticism focuses on the very low speed of legal and institutional adjustments and reforms related to the strategy but admitted that this is affected by Russia's military aggression (European Commission 2023b). The **National Energy and Climate Plan** (2024) has a specific focus on decarbonisation, includes transport objectives, as well as existing and planned transport measures.

Regulatory instruments: There are a number of regulations that address the transport sector such as the Law "On **Amendments to the Customs Code** of Ukraine (2020). The law aims to stimulate the development of the electric transport industry in Ukraine".

Market-based instruments: The **Law "On Amendments to of the Tax Code of Ukraine and some legislative acts of Ukraine on stimulating the development of electric transport in Ukraine**" (2020) has the objective to stimulate the use of electric vehicles and charging stations/infrastructure in order to support an annual increase of the electric vehicle fleet in Ukraine of 3% as forecasted in preparing Ukraine`s updated NDC (Abuselidse et. al., 2023). It provides for fiscal incentives that should increase the interest in electric car ownership. At the same time, because of VAT exemptions, no customs duty is levied on imports of electric vehicles to stimulate imports (Government of Ukraine, 2024). There are mixed interpretations of the effectiveness: Some estimate the result is not sufficient to achieve decarbonisation goals in transport (Abuselidse et. al., 2023) However, the Government estimated the incentives as successful. Although effectiveness of tax benefits was not directly evaluated, the number of electric cars increased ten time between 2018 and 2023 from 7,439 units to 72,435 units (Government of Ukraine, 2024)

The next table lists these policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies where available, can be found in the Annex (Table 78).

Table 51: Ukraine's policy package (transport sector)

Type of instrument	Status
Governance and planning instruments	National Energy and Climate Plan (2024) National Transport Strategy of Ukraine until 2030 (2018)
Regulatory instruments	Law "On Amendments to the Customs Code of Ukraine (2020)
Market-based instruments	Law "On Amendments to of the Tax Code of Ukraine and some legislative acts of Ukraine on stimulating the development of electric transport in Ukraine”
Information instruments	--

6.4.3 How to strengthen national-sectoral climate policy

Challenges for the transport sector are to increase the share of electric cars to 15% of annual car registrations by 2030, increase the share of biofuel use, develop low-carbon public transport, and support non-motorized transport to increase their share in the modal split. A particular role in decarbonizing the transport sector and reducing greenhouse gas emissions plays the shift from road to rail transport and its optimisation (Abuselidse et. al., 2023). Elements of this optimisation strategy would involve reforms of the tariff regulation of railway transportation, overcoming deficiencies of locomotive traction (e.g. via revies of planned purchases of locomotives), modernisation of rail infrastructure (e.g. electrification of all tracks), in combination with the optimisation of the structure of road transport (e.g. by implementing a legal framework for traffic optimisation). This strategy is projected to reduce carbon emissions of the transport sector according to objectives of Ukraine’s updated NDC.

6.5 Buildings

6.5.1 Current decarbonisation status and prospects

With 28 %, the residential buildings sector is the second largest final energy consumer in Ukraine (UNECE, 2023). Households are the major users of natural gas. Energy efficiency is low but high potential remains largely untapped due to limited investments. A high demand in residential heating is combined with inefficient building infrastructure leading to high energy intensity in the buildings sector (figure 29). Therefore, the residential sector accounts for a large part of the energy related emissions in Ukraine, in 2018, the buildings sector accounted for approximately 8% of Ukraine's total GHG emissions. Dating back to the Soviet Union before 1991, the building stock needs to be modernized as energy consumption per square meter of most buildings is high, three times higher than modern class B energy-efficient buildings. In the National Economic Strategy up to 2030 (Government of Ukraine, 2021b) total investment needs, foreign and domestic, of the buildings sector were estimated at USD 120 billion by 2030 to renovate 100 per cent of the entire stock of old housing.

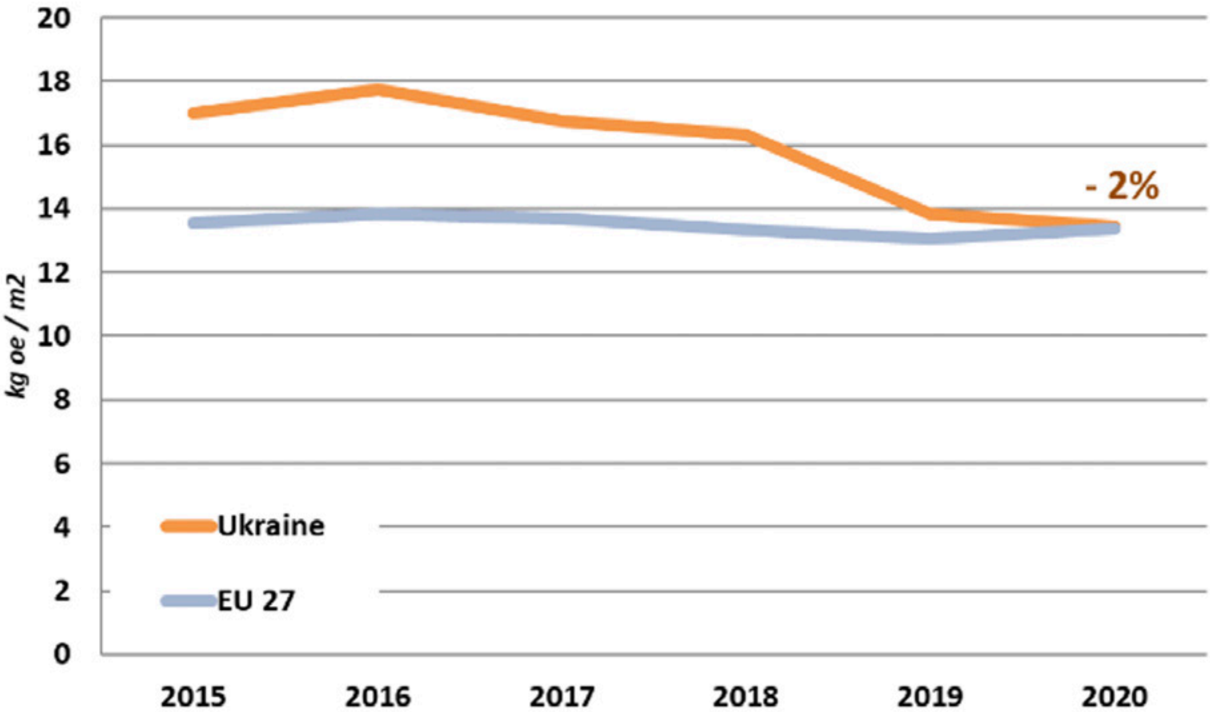

Figure 23: Energy intensity in Ukraine`s residential buildings sector.
Source: (UNECE 2023)

Implications of war

A main barrier for decarbonisation policies in the buildings sector is the ongoing war. According to the Third Rapid Damage and Needs Assessment by the World Bank (World Bank et al., 2024) the sector's damages and estimated recovery needs are the highest across all sectors. Thus, the costs of damages in the housing sector are estimated at US$55.9 billion while the recovery needs for the housing sector are estimated at US$80.3 billion across the long term (2024–2033) (ibid). Building reconstruction is estimated to lead to 25.9 Mt CO2-eq.

6.5.2 National-sectoral mitigation enablers and barriers

More generally, the building sector faces numerous barriers that hinder climate mitigation options, but also enablers exist that support climate action. The enablers and barriers are categorized and explained in more detail in the Annex (Table 79) and are summarized below:

Geophysical feasibility: Ukraine has a larger potential for biomass energy as a fuel source for heating and hot water services in the municipal sector (UNDP, 2016). The High solar potential could also be utilised for solar PV in buildings. Measures to promote sufficiency, energy efficient building construction/renovations, as well as low carbon heating and cooling reduce natural resource consumption (fossil fuels, metal ores, minerals) associated with final energy consumption. Advanced construction methods and reuse of building materials can reduce consumption of raw materials although most sustainable building technologies are not limited by materials. Installation of green roofs reduce heat gains and losses. Globally, new sustainable insulation materials have been developed and are available.

Environmental and ecological feasibility: Sufficiency and energy measures in buildings that reduce fossil fuel demand can improve both air quality and biodiversity. The decarbonisation in the buildings sector has a potential to generate co-benefits in health, energy affordability and jobs (OECD, 2022). Many opportunities are available for green infrastructure techniques that have an positive environmental effect (green roofs, rainwater harvesting, gray water management). A switch to more efficient appliances could result in negative impacts from increased resource use, which can be mitigated by avoiding premature replacement and maximising the recycling of old appliances.

Technological feasibility: Many advanced construction methods are widespread in developed countries. Insulation technologies are generally well-developed. Sustainable heating and cooling technologies are globally available. There might be additional challenges to the power grid system due to the increasing electrification of heating (and cooling). There are risks of limited adoption of sustainable practices due to cost, lack of awareness, and pressure to rebuild, as well as shortages of skilled workers for energy retrofits and e.g. heat pumps installation.

Economic feasibility: Opportunities for cost savings through energy-efficient design (passive design strategies) and renewable energy integration. Demand-side management measures (e.g., sensors, controls, energy consumption feedback measures) are mature and usually cost-effective. Utility-scale solar PV, and the accelerated installation of small-scale distributed solar PV in the residential sector and public buildings (schools and hospitals) have already significantly increased system resilience (Bilek et. al., 2024). Barriers result from high upfront costs and longer payback time to invest in building energy efficiency measures, renewable energy technologies, and low-embodied carbon materials. As well, financial mechanisms and incentives are limited.

Sociocultural feasibility: Build-back-better principle is a strong motivation and guiding principle although there is a lack of information and knowledge about building energy efficiency and low carbon heating/cooling options and a lack of awareness about the benefits of sustainable buildings.

Institutional feasibility: Generally high priority and promotion of renewable energy systems by government and coordination between national and sub-national governance levels is necessary. There is a lack of comprehensive data on building energy performance and emissions. There are no government policies being developed to promote sustainable urban planning.

6.9.4 (Quicklink to table on enablers and barriers)

6.5.3 Current status of national-sectoral policy

A comprehensive policy strategy for the decarbonisation of the building sector has not been approved in Ukraine. **Governance and planning instruments**: There is **no explicit government strategy** for decarbonisation of the buildings sector. Objectives regarding the development of the residential / buildings sectors are contained in a number of energy focused strategies and plans. However, in December 2023, the government adopted and approved specific policy measures and instruments aiming at hitting the set in the document targets for

decarbonisation, in particular net zero energy consumption in the sector by 2050 (MITCD, 2023c). The implementation of the STMB is divided into three stages. At the first stage in 2024-2030, the government sets the ambitious targets for total energy consumption decrease in the sector. It plans to modernise more than 3 million buildings at the first stage and projects potential annual savings at 66.7 TWh and 2.9 TWh for heating and electricity respectively which would enable to reach around €3 bn annual savings. The total annual decrease of the total final energy consumption of the buildings is projected at 5.9 Mtoe by 2030, 12.8 Mtoe by 2040, and 18.4 Mtoe in the ambitious scenario assuming Ukraine will be on track to hit the net-zero target for buildings by 2050. To monitor the progress over approved targets in STMB, the Cabinet of Ministers of Ukraine (CMU) also approved the Operational Plan of Measures for the Implementation of the STMB in 2024-26 (MITCD, 2023a). The strategic goals in the plan are the following: keep the high priority of the policy of increasing the energy efficiency of buildings at the state and local level, ensure complex and integrated approaches to thermal modernisation, overcoming energy poverty, create the market-playing filed for large-scale thermal modernisation of buildings, accelerating the pace of deep thermal modernisation of public buildings, sustainable and targeted financing of thermal modernisation, development of human capacity, digitalisation and innovations. Each of these goals is assigned a list of detailed measures with deadlines for an effective monitoring of the STMB implementation.
In December 2023, the CMU also approved the Concept of the State Targeted Economic Program to Support Thermal Modernisation of Buildings until 2030 (STEPSTMB, MITCD, 2023b). The document aims at increasing the number of thermal modernisation projects of residential buildings and public buildings, increasing the number of buildings with close to zero energy consumption, which will contribute to strengthening Ukraine's energy independence and resilience. The STEPSTMB defines the list of possible incentives for population, public and private entities to speed up the energy efficiency improvement in the building sector in 2024-2026. The costs of of STEPSTMB financing is estimated at UAH 172.9-934.3 billion.

Regulatory instruments: Ukraine has adopted laws to implement the EU Energy Performance of Buildings Directive and align them with the Energy Efficiency Directive, promoting nationwide modernisation of buildings, replacement of low-efficiency boilers, substitution of fossil-fired heating systems and nationwide reconstruction of residential buildings.

Market-based instruments: Programmes such as the **Energy Efficiency Fund (EEF)** or the **Warm Loans Programme** have been established to drive financing towards more efficient buildings envelopes and buildings technical systems. The EEF-law defines the legal, economic, and organisational foundations for the establishment and operation of the Energy Efficiency Fund. The objective is to support energy efficiency and energy savings initiatives and introduce incentive and support measures for energy efficiency improvements and energy saving in buildings. It is aligned to the national plan for energy efficiency, objectives to reduce CO2 emissions under the Paris agreement, and upholding Ukraine's international obligations in the area of energy efficiency**.** Has been assessed as effective instrument (European Commission, 2023a).

Information instruments: With the order 'On approval **of Technical Regulation on energy labelling of energy consumer products**' (2022) a framework has been developed for energy labelling, providing consumers with information about their energy consumption and allowing them to make informed choices (Government of Ukraine, 2024). The label is in line with the EU energy label scheme. It aims to raise consumer awareness about energy efficiency. Suppliers and distributors of appliances must ensure that products have label related information (level of efficiency of energy consumption) and product information sheets. Suppliers must ensure accuracy and provide technical documentation. The label has been amended for a broader product scope.
The next table (table 71) lists the individual policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies, can be found in the Annex (table 80).

Table 52: Ukraine's policy package (buildings sector)

Type of instrument	Status

Governance and planning instruments	Long-term Strategy of Thermal Modernisation of Buildings (STMB) until 2050 Operational Plan of Measures for the Implementation of the STMB in 2024-26 Concept of the State Targeted Economic Program to Support Thermal Modernisation of Buildings until 2030
Regulatory instruments	Several laws to implement the EU Energy Performance of Buildings Directive and align them with the Energy Efficiency Directive
Market-based instruments	Energy Efficiency Fund (EEF) Warm Loans Programme
Information instruments	Technical Regulation on energy labelling of energy consumer products' (2022)

6.5.4 How to strengthen national-sectoral climate policy

Challenges for the buildings sector are to thermally modernise 1.3% of Ukraine's total buildings annually, install high-efficiency boilers, replace fossil energy sources with renewable ones, and to construct new buildings that have close to zero energy consumption.

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6.6 AFOLU

6.6.1 Current decarbonisation status and prospects

Out of the 60 million ha of land in Ukraine, 42.7 million ha (70,8 %) is agriculture land and of that 33 million ha is arable land. 14% is used for agriculture. About 16% is covered by forests. The main agricultural products in Ukraine are oil seeds and crops. Agriculture, forest and fishery production contributed to about 7.4% of Ukraine`s GDP in 2023 (Worldbank Group, n.d.) and the sector employs 14 % of the population (USAID, 2022). In 2019, agriculture value added per agricultural land hectare was USD 355 (KSE Institute, 2021). Accounting for 41% of total exports, agriculture products were Ukraine`s most important exports in 2021 and the country played a critical role for the global supply of oilseeds and grains (USAID, 2022).

In 2021, the share of the agriculture sector in total GHG emissions without LULUCF was 14.4 %. The major emission sources were agricultural soils (80.0 % of the total emissions) and enteric fermentation (15% of the total emissions). Compared to 1990, emissions decreased by 45.9 % but compared to 2020, emissions increased by 12.8 % mostly due to emissions in agricultural soils. The LULUCF sector includes both emissions and removals of carbon dioxide, as well as emissions of CH4, and N2O. In 2021, the LULUCF sector was a net source of emissions with 14.2 Mt CO2e compared to net removals of 31.4 Mt CO2e 1990. The main reason was a change in agriculture management system on croplands resulting in a change from 4.6 Mt CO2e of removals in 1990 to 48.3 Mt CO2e of emissions in 2021. The forest sector experienced a shift from deforestation trends during 1996–2000 to reforestation between 2000 and 2020 (in Ukraine-controlled territories). This trend reversal appears to be the result of amendments and enhancements in national forest management legislation (Shumilo et. al., 2023). In the National Economic Strategy up to 2030 (Government of Ukraine, 2021b) investment needs (foreign and domestic) of the agriculture sector were estimated at around USD 50 billion by 2030 in total to achieve good land conditions, develop agrotechnology and stimulate R&D. In the forest sector, cost for achieving the NDC goals were assessed as EUR 3 billion over 2021-2030 (MEPR, 2021).

Implications of war

Fires in forest areas in close proximity to the frontline are also a significant source of GHG emissions leading to additional 22.2 Mt CO2e emissions during the first 18 months of war (de Klerk et al., 2023).

National-sectoral mitigation enablers and barriers

The enablers and barriers are categorized and explained in more detail in the Annex (table 81) and are summarized below:

Geophysical feasibility: Ukraine has diverse climatic zones and soil types and is famous for a large share of rich black soil. There is potential for expanding renewable energy generation areas (solar, biogas). The vulnerability to climate change impacts (droughts, floods) can affect reforestation efforts, crop yields and livestock production.

Environmental and ecological feasibility: Reforestation and afforestation can improve soil health, biodiversity, and water resources. Natural forests act as carbon sinks and provide ecosystem services. Sustainable agricultural practices (e.g., agroforestry, organic farming) can also improve soil health, water quality, and biodiversity. Intensive agriculture practices can lead to soil erosion, water pollution, and loss of biodiversity. Deforestation (in occupied regions) can worsen environmental degradation.

Technological feasibility: Due to the current energy crisis, there is growing interest in renewable energy applications for agriculture (e.g., solar-powered irrigation pumps, biogas digesters). At the same time, a lack of awareness and technical capacity among farmers can hinder the uptake in sustainable agricultural practices.

Economic feasibility: Forest-based industries can provide income and employment opportunities. Carbon credits and payments for ecosystem services can incentivize sustainable forestry practices. Improved productivity and reduced input costs can be realized through efficient resource management and there are number of competing economic interests in land use such as energy generation, agriculture, and tourism that maybe a barrier to the decarbonisation od the AFOLU sector the same holds for high investment costs for technology adoption and infrastructure development to adapt sustainable agriculture practices.

Sociocultural feasibility: (not applied here)

Institutional feasibility: There are policies and institutions for forest conservation and management.

6.9.5 (Quicklink to table on enablers and barriers)

6.6.2 Current status of national-sectoral policy

Governance and planning instruments: The **NECP** focuses on agriculture and some forest measures. Criticism on a draft of the NECP focuses on the non-representation of LULUCF sector as no data was provided in the sections on "Current situation and projections based on existing policies and measures" and "Impact assessment of planned policies and measures" (Ecoaction, 2024). As the LULUCF sector has the potential for net removals, it plays a key role in achieving climate neutrality Apart from forests, absorption and carbon storage can result from cropland, steppe and grassland, wetlands, settlements, and other land. Therefore, these land uses should be addressed with measures to strengthen the removal capacity by preserving existing natural carbon stocks (in soils and ecosystems), increasing carbon stocks through ecosystem restoration, soil protection measures, restoration of degraded lands, implementation of sustainable agricultural practices. The **Strategy of Agriculture and Rural development of Ukraine until 2030** (Ministry of Ministry of Agrarian Policy and Food of Ukraine, 2024) aims at providing a clear definition of priorities and the creation of favorable conditions for the development of agriculture and rural areas in Ukraine.

Regulatory instruments: **Law "On Approval of the Concept of the National Target Program for Land Use and Protection".** The Objective is the reduction of soil degradation and related the reduction of greenhouse gases. Expected results are to reduce agricultural development (by 5%) and ploughed land (by 10%), to optimise the structure of the agricultural landscape; to increase the productivity of agricultural land (by 40-50%) through the rational use of organic, organo-mineral and mineral fertilizers and chemical meliorants on acidic and saline soils. Increase the area of land with natural landscapes to a level sufficient to preserve landscape and biological diversity (up to 10.5% of the total area of the country), conserve degraded, unproductive and technologically polluted land (Ecoaction, 2024). As the NECP includes a goal for increasing the area of arable land from which crops will be harvested until 2050 this contradict other declared goals such as to reduce the area of arable land by removing slopes. The **National Program for the Formation of the National Ecological Network of Ukraine for 2000–2015 (2020)** organsises participation in the Emerald network aiming at the creation of special sites for biodiversity and endangered species conservation, implementation of EU environmental-protecti (on legislation, and policies harmonized across the global network (Shumilo et. al., 2023)

Market-based instruments: (not covered here)

Information instruments: The **National Forest Inventory of Ukraine (2006)** provides statistically substantiated information on quantitative and qualitative indicators of the state and dynamics of forests, their resource potential for the needs of the state administration, strategic planning of forestry, state forestry cadastre, environmental monitoring, international reporting on forests.

The next table (table 72) lists these policies and measures. Further information, including a brief description and an assessment of the effectiveness of the policies where available, can be found in the Annex (table 82)

Table 53: Ukraine's policy package (AFOLU sector)

Type of instrument	Status
Governance and planning instruments	National Energy and Climate Plan (2024) Strategy of Agriculture and Rural development of Ukraine until 2030
Regulatory instruments	Law "On Approval of the Concept of the National Target Program for Land Use and Protection" National Program for the Formation of the National Ecological Network of Ukraine for 2000–2015 (2020)
Market-based instruments	--
Information instruments	National Forest Inventory of Ukraine (2006)

6.6.3 How to strengthen national-sectoral climate policy

Challenges for the agriculture sector are to increase the use of minimal- or zero-tillage technologies, a transition to fertilisers with slow nutrient release, to increase the share of organic land to 3% by 2030 and to increase biogas production and use. This is planned to be achieved by current policy formulations aimed at promoting sustainable agriculture and environmentally conscious farming. Measures should include modernizing agriculture practices, using renewable energy, reducing water usage, and improving value addition and waste management in both crop and livestock sector. Challenges for the forestry sector are to increase forested areas and make a transition towards sustainable forest use. According to the updated NDC and the related analysis report, Ukraine aims to reduce the GHG emissions in the LULUCF sector by 9.4 % and plans to achieve a greenhouse gas emission sequestration in the sector of 9 million tonnes of CO2-eq. The share of forested should increase to 18% (MEPR, 2021). Systemic reforms of the forest industry's governance, an improved regulatory framework, increased transparency and control over logging, and a complete inventory of the forest fund are needed.

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6.7 Conclusion

Russia's unprovoked war in Ukraine has caused massive damage and destruction. It created and still creates huge economic and environmental challenges in Ukraine. The first 18 months of war resulted in an additional 150 Mt CO2e GHG emissions, which may increase considerably as duration of the war is uncertain (De Klerk et. al., 2023). The ongoing war also increases the costs of project financing for Ukraine making investments in renewables and other climate neutral technologies unprofitable. It focuses the priority of the government on military and social support at the expense of education, health, or climate mitigation measures.

At the same time, the Russian invasion marked a breakout of the past for Ukraine. The resilience of the energy sector in particular and economy as a whole now depends on whether Ukraine will be able to make its electricity sector a more distributed one. It can be done through investments in distributed renewable sources, digitalisation of the grid and increasing energy efficiency in all sectors.

Ukraine demonstrated very good strategic planning and ambitious target setting to meet its pledges to the Paris Agreement and now plans to achieve the net-zero by 2050 ten years earlier than initially agreed. It submitted its first updated NDC to the UNFCCC in 2021, approved the integrated National Energy and Climate Plan up to 2030 in June 2024, and presented its vision of net-zero by 2050 at COP28.

The progress towards net-zero GHG emission requires simultaneous action on several fronts. The NECP includes a 6-page overview table of existing and planned policies and measures focusing on decarbonisation, energy efficiency, energy security, internal energy market (electricity, gas including bioenergy and oil) as well as research, innovation and competitiveness in different sectors. However, implementation of specific regulations is often criticized as slow and not ambitious enough. The transport and buildings sectors, heavily affected by war, have been less addressed in the past then energy, industry and agriculture but are central for recovery plans. Finally, the Ukraine's ability to meet its 2050 net-zero target depends on whether it can access financing from developed countries, the private sector, international financial institutions, and other donors for climate modernisation projects. Therefore, the creation of market-playing field is a pre-requisite of the successful transition.

The absence of effective carbon pricing is an important barrier on the path towards net-zero. The current carbon tax is very low to impact production and consumption decision within the economy and the plan to establish Ukrainian ETS in 2025 in line with its obligations under the Ukraine-EU Association and Enlargement Agreements may be delayed by the unprovoked Russian war. At the same time an effective carbon tax along with an ETS and phasing out energy subsidies will enable Ukraine to create an effective energy pricing mechanism including pricing the externalities. The introduction of the domestic carbon pricing would also enable to lower the impact of CBAM introduction by the EU, which aimed at ensuring that ambitions climate actions in the EU does not lead to climate leakage.

6.8 Bibliography

- Abuselidze, G.; Levchenko, N.; Shyshkanova, G.; Platonov, O.; and L. Iuschenkov, 2024. Policy of Decarbonisation of the Transport Sector of the Economy of Ukraine: Problems and Perspectives. *Ecological Chemistry and Engineering* S. 30. 517-540. 10.2478/eces-2023-0046.
- Alekseievska, H., KolosokK, E., and O. Hryhorenko, 2023. POTENTIAL OF UKRAINE'S INLAND WATER TRANSPORT AS A FACTOR OF SUSTAINABLE DEVELOPMENT. *Economic Innovations*, *25*(3(88), 35-49. https://doi.org/https://doi.org/10.31520/ei.2023.25.3(88).35-49
- Bilek, P.; Stubbe, R. and H. Weser, 2024. A Solar Marshall Plan for Ukraine. Empowering Ukraine`s Brighter Future: Bottlenecks, and key Policy Reform Needed to Boost Solar PV Deployment. Policy Paper. Berlin: Berlin Economics. https://www.greenpeace.de/publikationen/20240607-greenpeace-report-BE-solar-marshallplan-ukraine-encv.pdf.
- Breuing, Julia, 2021. A revision of Ukraine's Carbon Tax. Low Carbon Ukraine Policy Note May 2 2021. https://www.lowcarbonukraine.com/wp-content/uploads/A-Revision-of-Ukraines-Carbon-Tax.pdf
- Climate Action Tracker, 2021. Ukraine, Update 13 December 2021. https://climateactiontracker.org/countries/ukraine/2021-12-13/
- Climate Action Tracker, 2022. Ukraine, Update 4 March 2022. https://climateactiontracker.org/countries/ukraine/
- Climate Change Performance Index, 2024. Ukraine. https://ccpi.org/country/ukr/.
- Climate Watch Historical GHG Emissions, 2022. Washington, DC: World Resouces Institute. Available online at: https://www.climatewatchdata.org/ghg-emissions. https://en.ecoaction.org.ua/wp-content/uploads/2023/12/20231201_ClimateDamageWarUkraine18monthsEN_1.pdf
- De Klerk, L.; Shlapak, M.; Shmurak, A.; Gassan-zade, O.; Mykhalenko, O.; Korthuis, A.; Zasiadko, Y.; Andrusevych, A.; and I. Horodyskyy, 2023. Climate Damage Caused by Russia`s War in Ukraine.
- Demchuk, Y. V. and H. A. Liventseva, 2023. Geothermal Overview of Ukraine. *Mining Geology and Geoecology*, 1 (6). DOI:10.59911/mgg.2786-7994.2023.1(6).287850
- Devlin, A.; Mykhnenko, V.; Zagoruichyk, A.; Salmon, N. and M. Soldak, 2024. Techno-economic optimisation of steel supply chains in the clean energy transition: A case study of post-war Ukraine. Journal of Cleaner Production, 466, 142675. https://doi.org/10.1016/j.jclepro.2024.142675.
- Ecoaction, 2024. Ecoaction Comments on draft NECP 2024. https://en.ecoaction.org.ua/wp-content/uploads/2024/06/Ecoaction_comments_NECP2024s.pdf.
- Energy Community, 2024. Ukraine approves National Energy and Climate Plan as EU Accession Negotiations Begin. Energy Community News 25.96.2024, https://www.energy-community.org/news/Energy-Community-News/2024/06/25b.html.
- Environment, People, Law, 2022. Compliance of the public policy of Ukraine in the area of waste management with the priorities and goals of the European Green Deal. https://epl.org.ua/wp-content/uploads/2022/01/Circular_economy_ENG.pdf
- EU-Ukraine Civil Society Platform, 2018. REPORT of the UA CSP "Climate change in the context of Paris Agreement commitments: challenges and cooperation opportunities for EU and Ukraine", https://www.eesc.europa.eu/sites/default/files/files/6th_csp_ua_climate_change_eng.docx. Accessed 04/07/2024.
- European Commission, n.d. https://neighbourhood-enlargement.ec.europa.eu/european-neighbourhood-policy/countries-region/ukraine_en#eu-ukraine-relations, accessed 01.07.2024

Funded by
the European Union

- European Commission, 2023a. Commission Staff Working Document. Analytical Report following the Communication from the Commission to the European Parliament, the European Council and the Council Commission Opinion on Ukraine's application for membership of the European Union. SWD(2023) 30 final. https://neighbourhood-enlargement.ec.europa.eu/system/files/2023-02/SWD_2023_30_Ukraine.pdf
- European Commission, 2023b. Commission Staff Working Document. Ukraine 2023 Report. SWD(2023) 699 final. https://neighbourhood-enlargement.ec.europa.eu/system/files/2023-11/SWD_2023_699%20Ukraine%20report.pdf
- EU4Environment, 2022. Boosting Circular Economy in Ukraine through Resource Efficient and Cleaner Production. https://www.eu4environment.org/app/uploads/2022/04/Boosting-Circular-Economy-in-Ukraine-through-Resource-Efficient-and-Cleaner-Production.pdf.
- Eyl-Mazzega, M.-A. and C. Mathieu, 2019. Developing a National Energy and Climate Plan for Ukraine. https://www.lowcarbonukraine.com/wp-content/uploads/updated_LCU_PP02_2019-03_en.pdf
- Government of Ukraine, 2017. UKRAINE 2050 LOW EMISSION DEVELOPMENT STRATEGY. https://unfccc.int/sites/default/files/resource/Ukraine_LEDS_en.pdf.
- Government of Ukraine, 2018a
- Government of Ukraine, 2018b. National Transport Strategy of Ukraine. https://cdn.climatepolicyradar.org/navigator/UKR/2018/national-transport-strategy-of-ukraine-until-2030_e1c7acb2a21b4f88f0be5ef29b03bbb0.pdf (machine translated)
- Government of Ukraine, 2021a. Updated Nationally Determined Contribution of Ukraine to the Paris Agreement. https://unfccc.int/sites/default/files/NDC/2022-06/Ukraine%20NDC_July%2031.pdf
- Government of Ukraine, 2021b. National Economic Strategy for the Period up to 2030 approved by the Resolution of the Cabinet of Ministers of Ukraine No 179, 3 March 2021. https://cdn.climatepolicyradar.org/navigator/UKR/2021/decree-179-2021-approving-the-national-economic-strategy-for-the-period-up-to-2030_dfb24a820409f62274fe22fe993e75a1.pdf (machine translated).
- Government of Ukraine, 2021c. СТРАТЕГІЯ екологічної безпеки та адаптації до зміни клімату на період до 2030 року (Strategy of Environmental Safety and Adaptation to Climate Change until 2030). https://zakon.rada.gov.ua/laws/show/1363-2021-%D1%80#n17.
- Government of Ukraine, 2023. Order of 24 February 2023 No. 176-r On approval of the Strategy for the Development of Industrial Parks for 2023-2030. https://www.kmu.gov.ua/npas/pro-skhvalennia-stratehii-rozvytku-industrialnykh-par-a176r (machine translated).
- Government of Ukraine, 2024. National Energy and Climate Plan (NECP) for the period up to 2030. https://me.gov.ua/Documents/Detail?lang=uk-UA&id=f7088035-142e-4912-9aa0-6fe2def80c1b&title=ProektNatsionalnogoPlanuZEnergetikiTaKlimatuUkraini2025-2030 (machine translated)
- Henderson, B.; Frank, S.; Havlik, P. and H. Valin, 2021. Policy strategies and challenges for climate change mitigation in the Agriculture, Forestry and Other Land Use (AFOLU) sector, OECD Food, Agriculture and Fisheries Papers, No. 149, OECD Publishing, Paris. http://dx.doi.org/10.1787/47b3493b-en
- Industrial Decarbonization Accelerator, n.d. Ukraine. https://www.industrialenergyaccelerator.org/where-we-work/ukraine/.
- IEA, 2020. Ukraine energy profile, IEA, Paris https://www.iea.org/reports/ukraine-energy-profile.
- IRENA, 2023. Energy Transition Outlook 2023. https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2023.

Funded by
the European Union

- Kaufmann. D. and Kraay, A., 2023. Worldwide Governance Indicators, 2023 Update. www.govindicators.org, Accessed on 10/05/2024.
- KSE Institute, unpublished. Study of the impact on the Ukrainian economy as a result of the implementation of the CBAM by the European Union, unpublished draft December 2022.
- KSE Institute, 2021. Strategy for the development of land relations in Ukraine. White Paper. https://kse.ua/wp-content/uploads/2021/05/Land-strategy_Engl.pdf
- KSE Institute, 2022. As of November 2022, the total amount of losses, caused to the infrastructure of Ukraine, increased to almost $136 billion. https://kse.ua/about-the-school/news/as-of-november-2022-the-total-amount-of-losses-caused-to-the-infrastructure-of-ukraine-increased-to-almost-136-billion/.
- KSE Institute, 2024. Report on damages and losses to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of January 2024 https://kse.ua/wp-content/uploads/2024/05/Eng_01.01.24_Damages_Report.pdf.
- Lindskog, T., 2023. The Present State of the Circular Economy in Ukraine. https://www.circularinnovationlab.com/post/the-present-state-of-the-circular-economy-in-ukraine
- Low Carbon Ukraine, 2019. Ukraine: Key Objectives, Strategic Questions and Options. Low Carbon Ukraine Policy Paper 2/2019. https://www.lowcarbonukraine.com/wp-content/uploads/updated_LCU_PP02_2019-03_en.pdf
- Ministry of Economic Development and Trade of Ukraine, n.d. Batumi Initiative on Green Economy (BIG-E). Actions by Ukraine. https://www.greenpolicyplatform.org/sites/default/files/downloads/big-e//Ukraine_BIG-E_Roadmap%20of%20the%20development%20of%20an%20eco-industrial%20parks%20model.pdf
- Ministry of Energy of Ukraine, 2023a. Clean Energy Roadmap. From Reconstruction to Decarbonization in Ukraine. Report for COP28. https://www.pnnl.gov/sites/default/files/media/file/Ukraine%20NZW%20COP28%20report%202023.pdf
- Ministry of Energy of Ukraine, 2023b. Ukraine lost 90% of wind and 40% of solar electricity generation in 2022. https://www.weareukraine.info/ukraine-lost-90-of-wind-and-40-of-solar-electricity-generation-in-2022/, Accessed on 24/07/2024.
- Ministry of Environmental Protection and Natural Resources of Ukraine (MEPR), 2021. Analytical Review of the Updated Ukraine`s Nationally Determined Contrribution to the Paris Agreement. https://mepr.gov.ua/wp-content/uploads/2023/07/Analitychnyj-oglyad-NVV-lypen-2021.pdf (machine translated with deepl).

- Ministry of Environmental Protection and Natural Resources of Ukraine (MEPR), 2021. Analytical Review of the Updated Ukraine`s Nationally Determined Contrribution to the Paris Agreement. https://mepr.gov.ua/wp-content/uploads/2023/07/Analitychnyj-oglyad-NVV-lypen-2021.pdf (machine translated with deepl).

- Ministry of Environmental Protection and Natural Resources of Ukraine (MEPR), 2023. National Inventory Report (NIR), https://unfccc.int/documents/628276.
- Ministry of Infrastructure, Territories and Communities Development 2023a. Operational Plan of Measures for the Implementation of the STMB in 2024-26, available in Ukrainian at https://mtu.gov.ua/documents/2389.html
- Ministry of Infrastructure, Territories and Communities Development 2023b. Concept of the State Targeted Economic Program to Support Thermal Modernization of Buildings until 2030, available in Ukrainian at https://mtu.gov.ua/documents/2389.html

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- Ministry of Infrastructure, Territories and Communities Development (MITCD), 2023c. Long-term Strategy of Thermal Modernisation of Buildings (STMB) until 2050, available in Ukrainian at https://mtu.gov.ua/files/%D0%A1%D1%82%D1%80%D0%B0%D1%82%D0%B5%D0%B3%D1%96%D1%8F_0901.pdf , https://mtu.gov.ua/documents/2389.html (own English translation).
- Neuweg, I., et al., 2023. Review of environmental taxation and environmental expenditure in Ukraine, *OECD Environment Working Papers*, No. 231, OECD Publishing, Paris, https://doi.org/10.1787/921319bc-en.
- OECD, 2021. OECD Energy Investment Policy Review of Ukraine, OECD Publishing, Paris, https://doi.org/10.1787/6e6e58c6-en.
- Panasiuk, A., 2022. Exploring the Barriers to Urban Cycling Adoption in the City of Kyiv. Masterthesis. https://kse.ua/wp-content/uploads/2024/01/Andrii-Panasiuk_113093_assignsubmission_file_KSE_Master-thesis_Panasiuk_v.2.pdf
- Shumilo, L., Skakun, S., Gore, M.L. *et al*. Conservation policies and management in the Ukrainian Emerald Network have maintained reforestation rate despite the war. *Commun Earth Environ* **4**, 443 (2023). https://doi.org/10.1038/s43247-023-01099-4.
- SSSU State Statistical Service of Ukraine, 2023. https://www.ukrstat.gov.ua/druk/publicat/kat_u/2023/zb/10/zb_dov_22.pdf
- Szulecki, K. and Overland, I., 2023. Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine. *Nat Energy* 8, 413–421 (2023). https://doi.org/10.1038/s41560-023-01228-5
- UNDP, 2016. Development and Commercialization of Bioenergy Technologies in the Municipal Sector in Ukraine. https://www.undp.org/sites/g/files/zskgke326/files/migration/ua/f29ae1e4e878ad66781c6841928b5a589fc92999846b22627f4313ca62b48638.pdf.
- UNECE, 2023a. Rebuilding Ukraine with a Resilient, Carbon-Neutral Energy System. Geneva: United Nations. https://unece.org/sustainable-energy/publications/rebuilding-ukraine-resilient-carbon-neutral-energy-system.
- UNECE, 2023b. Multi-stakeholder Dialogue - Untapped Bioenergy Potential of Ukraine: Comprehensive View of Proper Use. Issues of Energy Security and Food Security. https://unece.org/sustainable-energy/events/multi-stakeholder-dialogue-untapped-bioenergy-potential-ukraine.
- UNECE, UNEP, FAO, 2023. Policy Recommendations, Existing Barriers and Possible Solutions to Support Biofuels Market Development in Ukraine (draft for discussion). Summary as seen from the market stakeholders point–of-view for the Ukrainian Government & International Donors. https://unece.org/sites/default/files/2023-03/Draft%20for%20Discussion%20on%20Policy%20Recommendations.pdf.
- UNFCCC, 2024. Greenhouse Gas Inventory Data. Detailed data by Party. https://di.unfccc.int/detailed_data_by_party.
- UNIDO, 2023. Rapid Industrial Diagnostic Study. https://www.unido.org/sites/default/files/unido-publications/2023-10/UNIDO%20rapid%20industrial%20diagnostic%20study_Ukraine_Feb%202023.pdf
- United Nations, 2023. Briefing Security Council on Attacks against Ukrainian Village, City Centre, Senior Official Stresses Member States Must Show Commitment to UN Charter. https://press.un.org/en/2023/sc15434.doc.htm.

Funded by
the European Union

- United Nations, 2024. Ukraine: protection of civilians in armed conflict, July 2024 update. https://ukraine.un.org/sites/default/files/2024-08/Ukraine%20-%20protection%20of%20civilians%20in%20armed%20conflict%20%28July%202024%29_ENG.pdf
- United Nations Industrial Development Organisation (UNIDO), 2024. Ukraine`s IP Law Amendments Featuring EIP Approach Enter Public Discussion Phase. https://geipp-ukraine.org/wp-content/uploads/2024/07/EN-Draft-news-Draft-Law-implementation-of-EIP-concept-22-07-24.pdf
- USDA, 2022. Ukraine Agricultural Production and Trade. https://fas.usda.gov/sites/default/files/2022-04/Ukraine-Factsheet-April2022.pdf.
- USAID Energy Security Project, (2024). Trigeneration Capacity to Enhance the Efficiency of District Heating. https://energysecurityua.org/news/trigeneration-capacity-to-enhance-the-efficiency-of-district-heating/.
- Vasylyshyn, R.; Lakyda, I.; Yurchuk, Y.; Lakyda, M.; Melnyk, O. and R. Bondarchuk, 2022. Energy potential of woody biomass in Ukraine's forests and prospects for its utilization as an alternative energy source. IOP Conf. Ser.: *Earth Environ. Sci.* 1042 012010. DOI 10.1088/1755-1315/1042/1/012010
- Was, A.; Sulewski, P.; Gerasymchuk, N.; Stepasyuk, L.; Krupin, V.; Titenko, Z.; Pogodzinska, K., 2022. The Potential of Ukrainian Agriculture’s Biomass to Generate Renewable Energy in the Context of Climate and Political Challenges—The Case of the Kyiv Region. *Energies* 2022, 15, 6547. https://doi.org/10.3390/en15186547.
- World Bank Climate Change Knowledge Portal, n.d. https://climateknowledgeportal.worldbank.org/country/ukraine, accessed 25/06/2024.
- World Bank Group, n.d., Data. https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=UA
- World Bank Group, 2023. Boosting Project Delivery Capacity in Key Ukrainian Institutions. Press Release June 22 2023, https://www.worldbank.org/en/news/press-release/2023/06/22/boosting-project-delivery-capacity-in-key-ukrainian-institutions , Accessed 17/12/2023.
- World Bank Group, 2024. World Development Indicators, https://databank.worldbank.org/source/world-development-indicators (data extracted August 20, 2024).
- The World Bank, the Government of Ukraine, the European Union, the United Nations, 2024. UKRAINE Third Rapid Damage and Needs Assessment (RDNA3) February 2022–December 2023, https://ukraine.un.org/sites/default/files/2024-02/UA%20RDNA3%20report%20EN.pdf
- World Biogas Association (WBA), 2024. Bioenergy Association of Ukraine Requests Urgent Support from International Biogas Community. https://www.worldbiogasassociation.org/bioenergy-association-ukraine-requests-urgent-biogas-infrastructure-aid/
- WorldData.info, n.d. Ukraine, retrieved on 10/05/2024 https://www.worlddata.info/europe/ukraine/index.php.
- World Trade Organization, 2023. Notification G/TBT/N/UKR/251. https://eping.wto.org/en/Search/Index?&viewData=G%2FTBT%2FN%2FUKR%2F251.
- Yevstihnieieva, O., 2022. Reform Index Focus: Waste Management Reform. What will change in Ukraine? https://voxukraine.org/en/waste-management-reform.
- Zachmann, G.; Nitsovych, R.; Serebrennikov, B.; Radeke, J.; Meißner, F.; and C. Stiewe, 2019. Review of the Energy Strategy: Lessons learnt from implementation. Low Carbon Ukraine Policy Note 2019.7. https://www.lowcarbonukraine.com/en/energy-strategy-2035-lessons-learnt-from-implementation/
- Zanizdra, M. Y., 2022. Carbon intensity of the Ukrainian industry: current state and foresight. Economy of Industry, 1(97). https://doi.org/10.15407/econindustry2022.01.061.(Full text translated with Google).

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6.9 Annex

6.9.1 Industry

6.9.1.1 National-sectoral mitigation enablers and barriers

Table 73: Overview of enablers and barriers (industry sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Biomass resources available (e.g. agricultural residue, forests) to establish sustainable biomass supply for industries in Ukraine (Was et.al, 2022, Vasylyshyn et.al. , 2022). Trigeneration / Combined heat and Power is suitable for many industrial zones as they are with high energy demands for electricity, heating, and cooling. Regions with high potential for renewables (solar and wind) may emerge as exporters of hydrogen or become hubs for the production of green / blue iron or steel.	Green steel production dependent on availability of low carbon/ renewable energy, solar wind capacities, nuclear. Capacity might be constrained (Devlin et. al., 2024 Availability of space for new green steelmaking sites nearby high-quality renewables
Environmental-ecological feasibility	Reduction in pollution and resource depletion can be achieved through RECP. Industrial Eco Industrial Parks have significant potential for increasing resource efficiency, waste minimisation, pollution reduction and increasing environmental benefits (Ministry of Economic Development and Trade of Ukraine, n.d.). Significant potential for resource conservation, waste reduction and pollution prevention through circular economy. Tri-generation can significantly improve energy efficiency and reduce emissions compared to separate generation of electricity, heating and particularly cooling. Green steel production has a potential for resource conservation, waste reduction and pollution reduction / prevention	
Technological feasibility	RECP technologies and methodologies are available and adaptable. Eco-industrial park models and technologies are well established globally. Application in Ukraine is supported by the Government of Switzerland and UNIDO Circular economy principles and practices are increasingly adopted worldwide. Tri-generation technologies are mature and available.	RECP Investment levels for new technologies and modified equipment remained small after establishment of RECP Center, indicating an untapped potential for more expensive technological solutions with higher impacts (EU4 Environment) Almost no waste-processing technology and no European-style landfills in Ukraine (Yevstihnieieva, 2022)
Economic feasibility	Sustainable biomass can reduce dependence on fossil fuels (natural gas) in the long run.	Little attention for saving opportunity (material flows) of RECP.

	RECP and circular economy practices bring (long term) cost savings through resource optimisation and waste reduction. Resource efficient cleaner production practices (RECP) are applicable in industrial processes and sectors in Ukraine. Tri-generation can reduce energy costs. Policy incentives and market mechanisms can drive adoption of low carbon technologies improving energy efficiency.	Require coordinated planning and collaboration among multiple stakeholders to adopt eco-industrial parks. Experience with implementation of IPs shows management and planning difficulties Availability of skilled labour in EIPs Current instability/war has impact on investment decisions. Adoption of circular economy models may require significant changes in business practices. Currently CE focus on waste reuse/recycling only (UNIDO, 2023). Generally, limited overall flow of investment into industrial energy efficiency improvements (Industrial Decarbonisation Accelerator, n.d.)
Sociocultural feasibility	Sustainable biomass supply chains and RECP practices offer potential job creation and improved working conditions. Eco-industrial parks offer community benefits. Raising awareness and fostering stakeholder engagement are crucial for the success of all initiatives.	Lack of awareness /technical and financial capacity may hinder adoption of RECP practices. Limited awareness and knowledge on trigeneration and modern energy technologies among central and local authorities and district heating utilities (USAID ESP, 2024)
Institutional feasibility	RECP Center established through EU Programme. Amendment of Ukraine`s Law on Industrial Parks regarding the EIP approach is in public consulation phase. (UNIDO, 2024) A waste management information system, which should simplify the system of accounting and reporting, submission of declarations and implementation of permitting procedures should be introduced after entry into force of Waste Management Law in 2023 (WTO, 2023)	Lack of Government incentive mechanisms for RECP(EU4 Environment) No modern waste management system in place in Ukraine before war (Lindskog, 2023). Lack of clear regulations, standards, enforcement, and monitoring mechanisms hinder use of biomass , RECP roll out, eco-industrial park development, circular economy practices. EIP related national standard is under development since June 2024 (UNIDO, 2024)

6.9.1.2 Current status of national-sectoral climate policy

Table 54: Ukraine Overview of policies and measures (industry sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Economic Strategy for the period up to 2030** (Government of Ukraine, 2021b) approved by Decree 179/2021: The Strategy aims to ensure the appropriate level of welfare, self-realisation,	**Positives:** The Strategy contains the net zero goal for 2060 as reported in Ukraine`s updated NDC. Mission contains reference to SDGs. Decarbonisation is one element of the guidelines, principles and values in economic policy. Efficieny objectives in several sectors. **Challenges:** Focus is on growth and attraction of foreign investment. The climate and SDG components of the strategy would have to be implemented by regulation. Unclear how Net Zero should be achieved, no focus of greenhouse gas mitigation, no climate mitigation and adaptation sections. Strategy mentions inconsistent

	security, rights and freedoms of every citizen of Ukraine through innovative economic growth.	policies and incomplete reforms in the past. The agriculture section mentions climate change only as reason for better irrigartion efforts (adaptation), industry mentions high energy intensity in context decreasing competitiveness.
	Strategy of Environmental Safety and Adaptation to Climate Change until 2030 (2021).	**Positives:** Strategic goals include the reduction of industrial pollution, creation of an effective chemical safety system, ensuring the rational use of natural resources, as well as the creation of the legal and economic framework for the introduction of waste management systems (Government of Ukraine, 2021c; UNIDO, 2021)
	National Waste Management Strategy (2017) Strategy based on requirement of EU Directive on Waste Management	**Positives:** Strategy that should regulate the area of waste management and the introduction of certain elements of circular economy. (Environment, People, Law, 2022) **Challenges:** Implementation of the tasks and objectives of these strategies and programs is impossible without further relevant legislation.
Regulatory instruments	**National Waste Management Plan until 2030** (2019)	**Positives:** Should further develop and specify National Waste Strategy **Challenges:** Implementation of the tasks and objectives of the plan needs further relevant legislation.
	Development of **corporate investments** in the purchase of climate technologies and renewable energy solutions	
	Law on waste management reform (2022) replacing law on waste adopted 1998	**Positives:** Objective is to improve the waste management system, determine the legal, organisational, economic and control mechanisms. Measures should prevent or reduce waste generation, mitigate the negative impacts from waste management, and facilitate reuse and recovery as secondary raw materials and energy resources. Entered into force in July 2023 **Challenges:** Due to delays of the parliament in adopting the draft Law of Ukraine "On Waste Management" other necessary legislative changes were also delayd and could not be implemented (Environment, People, Law, 2022)
	Law on Alternative Fuels (2000, amended 2009 and 2012): Framework for financial mechanisms to stimulate	**Positive:** Objectives were to save energy resources and reduce dependence on imports, to reduce environmental impacts by using various kinds of waste as raw material for the production of alternative fuels. Support for developing scientific and technical basis of production of alternative fuels, support for entrepreneurship. It aims to prevent the creation of monopolies of alternative fuels.

	biofuels and other alternative fuels	Amendments to introduce biofuel blending mandates and to introduce a steady increase in biofuels share of the fuel mix to 20% of the total amount of fuel consumption in 2020. **Challenges:**
Market-based instruments	**Carbon Tax 2011**	**Positives:** Tax was already introduced in 2011. **Challenges**: Marginal tax rate at the beginning (EUR 0.003 /tCO2) and was gradually increased thereafter by a rate not much higher than inflation. In 2019 a larger increase was implemented but with a carbon tax of EUR 0.33 /tCO2, Ukraine still had one of the lowest carbon prices worldwide (Neuweg, 2023; World Bank, 2020) and currently it is down to around €0.25/tCO2 in December 2023. It has been shown that the Carbon Tax was ineffective in strengthening energy efficiency and reducing carbon emissions (Breuning, 2021). Efforts to introduce a range of measures to achieve emission reduction goals call for a revision of Ukraine's carbon pricing strategy
	Tax Code: Excise Tax on fuel produced domestically and imported	**Positives:** Energy taxes account for a high share of environmentally related tax revenue. (Neuweg, 2023) **Challenges:** Revenue fluctuates, therefore difficult as basis for expenditure for renewables support measures.
Information instruments	**Resource Efficient and Cleaner Production Centre (RECPC) established in 2013**	**Positives:** RECPC supported more than 170 companies to improve resource efficiency and environmental performance. **Challenges:** Despite the operation of the RECPC still there appears little attention for saving opportunity (material flows, circular economy). Investment levels for new technologies and modified equipment remained small, indicating an untapped potential for more expensive solutions with higher impacts. Incentive mechanisms are lacking (EU4Environment, 2022.).

6.9.2 Energy

6.9.2.1 National-sectoral mitigation enablers and barriers

Table 75: Overview of enablers and barriers (energy sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Abundant untapped renewable energy potential (solar, wind, hydropower) suitable terrain for hydropower, potential for bioenergy from agricultural waste. High availability of natural gas resources in the region (e.g. Dnipro-Donetsk region in the east, the Carpathian region in the west, and the Black Sea-Sea of Azov region in the south) to be used in e.g. oil power stations converted to use natural gas. High Potential for hydropower	Intermittent nature of solar and wind energy. Regions with high potentials in war zone.

	Potential for geothermal energy in three regions (Transcarpathian (west), Steppe Crimea (south) and Dnipro-Donetsk basin (east). Total geothermal potential estimated at $438*10^6$ kWh p/ year. Annual technically achievable energy potential of geothermal energy equivalent to 8,4 Mtoe, use can save around 10 bcm of natural gas. (Demchuk and Liventseva, 2023).	
Environmental-ecological feasibility	Reduced GHG emissions and air pollution of solar and wind compared to fossil fuels. Potential for carbon neutrality, energy savings (in all sector), and diversification of energy mix to reduce dependence on gas.	Environmental impacts of intensified natural gas extraction Potential environmental impacts of new hydropower Mine closure might violate hydrological regime and lead to flooding of soil surface; release of methane from closed mines to the surface. (Government of Ukraine, 2018a)
Technological feasibility	Mature technologies for solar PV, wind, and hydro generally available including a growing expertise in biomass power generation. Battery technology as R&D focus globally Mature technologies for energy-efficient appliances, lighting, and building design are available. Proven technology for natural gas power plants. Underutilized extensive natural gas transmission system and underground storage facilities can potentially store the entire existing potential of biomethane production in Ukraine (up to 10 billion m3 per year) (UNECE, 2023b)	Policy support for research, development and demonstration (RD&D) for bioenergy related novel technologies. Grid stability, transmission infrastructure as bottleneck to greater solar PV integration (Bilek et. al., 2024)..
Economic feasibility	Generally decreasing costs of renewable energy technologies. Potential for long-term cost savings and energy security (also for energy efficiency measures). Increased energy security with diversified fuel sources and decreased dependence on foreign energy sources / imports Bioenergy production promotes decentralisation, create new jobs, and generate funds for local budgets instead of making payments for imported natural gas (UNECE, 2023b)	High tax rates for biofuels, lack of incentives. Upfront investment costs for renewable energy projects. Structure of the wholesale market, (price caps, high levels of debt across the electricity system, including those on the renewable and balancing markets, inadequate incentives for investors and fundamental barriers (Bilek et. al., 2024) Residential electricity and natural gas price subsidies, price caps in electricity markets
Sociocultural feasibility	Acceptance may increase because of new jobs	Prejudice that the development of bioenerfy sector could affect food security. To ensure the environmental, social and economic benefits of bioenergy are maximised,

		regulations and certificates would have to be introduced, and partnerships promoted to ensure sustainability of biomass feedstock and the entire supply chain. Trust issues regarding Solar PV (Bilek et. al., 2024).
Institutional feasibility	There is a number of regulations and initiatives for renewable energy development (feed in tariff etc) and energy efficiency.	FiT remains only for households. In legislation, it was replaced by auctions and contracts for difference. Auctions on large capacities were promised but delayed since 2020. The first auctions were promised for the fall of 2024. Lack of biofuel legislation, regulation (UNECE et.al., 2023) Bioenergy would need policy support in the form of biofuel blending quotas, mandates and obligations; grants, subsidies and tax rebates for bioenergy projects (Irena, 2023) Corporate governance of state-owned enterprises (SOE) must be improved Complex procurement procedures for investments in renewables and related technologies like energy storages by SOE Competition and private participation at the heat supply market must be ensured.

6.9.2.2 Current status of national-sectoral climate policy

Table 76: Overview of policies and measures (energy sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Energy and Climate Plan (NECP) of Ukraine covering the period 2025-2030:** Comprehensive strategy aimed at coordinating energy and climate policies to ensure sustainable development and economic recovery of Ukraine. Approved by Cabinet of Ministers June 2024.	**Positives:** The NECP defines key targets for 2030, reaffirming the updated NDC targets and adding specific sub-targets. Has been approved under conditions of war, driven by EU accession process. A broad stakeholder Consultation took place to discuss the draft plan. Focus is on decarbonisation, energy efficiency, energy security, internal energy market (electricity, gas including bioenergy and oil) as well as research, innovation and competitiveness. Identifies for each focus area existing, additional, and planned policies and measures. **Challenges:** Critical need for funding, investment needs estimated at a total of USD 41.5 billion (Energy Community, 2024). Challenges have to be solved resulting from contradictory government decisions in the past, e.g. on carbon tax rate, coal mining. For example, in 2020, the Cabinet of Ministers adopted an order prioritising coal use in Ukraine's power sector to strengthen the domestic coal industry in 2023 it affirms to phase out from state owned coal power plants. Generally, the NECP identifies as main problems: 1. Continuation of the war and the need to take into account its consequences,

		uncertainty regarding the scale of destruction and the pace of recovery. Therefore, uncertainty on pace and success of implementing, specific policies and measures. Need for continuous monitoring of the NECP implementation and continuous high-level discussions on adapting to changing circumstances. 2. Economic downturn, associated energy poverty might lead to political unwillingness to apply energy pricing instruments. 3. Weakened capacity of state institutions to simultaneously manage crises in the conditions of war, fulfill key functions in implementing NECP related policies and measures, and considering the challenge of their reform in accordance with EU legislation. 4. Accumulated significant debt in the natural gas and electricity supply chains.
	Energy Strategy 2050 (Approved April 2023). Framework strategy focuses on the development of nuclear and renewable power generation capacity and on the modernisation of the energy infrastructure.	**Positives:** focuses on the sector development in order to achieve carbon neutrality in the energy sector by 2050. Ukraine aims to strengthen energy security and the sustainability of its energy system and wants to join the unified energy system of Ukraine (UES) to the European network of electricity transmission system operators (ENTSO-E). Addresses barriers such as grid stability and automatisation of transmission and distribution systems. Strategy is based on sector pathways. **Challenges:** Many uncertainties regarding implementation because of war damages and duration of war. Has been complemented by several recovery plans such as the **Ukraine Plan** projecting priorities investment needs and uncertainties.
	National Economic Strategy for the period up to 2030 (Government of Ukraine, 2021b) approved by Decree 179/2021: The Strategy aims to ensure the appropriate level of welfare, self-realisation, security, rights and freedoms of every citizen of Ukraine through innovative economic growth.	**Positives:** The Strategy contains the net zero goal for 2060 as reported in Ukraine\`s updated NDC. Mission contains reference to SDGs. Decarbonisation is one element of the guidelines, principles and values in economic policy. Efficieny objectives in several sectors. **Challenges:** Focus is on growth and attraction of foreign investment. The climate and SDG components of the strategy would have to be implemented by regulation. Unclear how Net Zero should be achieved, no focus of greenhouse gas mitigation, no climate mitigation and adaptation sections. Strategy mentions inconsistent policies and incomplete reforms in the past. Agriculture section mentions climate change only as reason for better irrigartion efforts (adaptation), industry mentions high energy intensity in context decreasing competitiveness.
Regulatory instruments	**Feed in tariff for electricity producers from RES (2008):** Regulatory framework to promote investments for the generation of power through non-conventional sources of fuel (renewables)	**Positives:** The framework promotes investments for power generation through non-conventional sources of fuel using non-fossil technologies. Ukraine agreed to grant the green FIT to investors until end of 2029. The regulations set green FITs in euros at one of the highest levels in the world, with an annual decrease until 2030. Exchange risks is passed to the government. **Challenges:** After fixed FITs for power plants commissioned until 2013, the green FITs were reduced gradually until 2017. Between 2017 and 2020 the FITs were more significantly reduced due to increasingly payment obligations due to success of the measure and

		substantially increased installed capacity of RES from 2010 to 2019 (OECD, 2021). So, it was effective only for projects implemented until 2020. Auctions for new capacities are delayed but may be introduced as required secondary legislation was adopted in 2023-2024.
	Incentive tariff for heat energy from RES (2017).	**Positives**: Investors implementing gas substitution projects receive a legislatively fixed tariff for heat from alternative sources at 90% of the tariff for heat from gas for the needs of budgetary institutions and the population. Thus, they have guarantees of return on their investments.
	Law on Promotion of Biological Fuels Production and Use (2009) Main objectives are to save fossil fuels, decrease dependency from energy imports, increase energy security; and decrease the negative impact on the environment caused by burning fossil fuels.	**Positives**: Four objectives should be achieved by promotion of biofuels The law introduces a definition of biofuels and its types (bioethanol, biogas, biomass, biodiesel, etc.). Companies can engage in production and sale of biofuels. Biofuel types designed for sale as market products are subject to certification (except for products for own consumption). During the sale, the producer is obliged to present to the buyer documentation confirming the quality of the fuel. Production of bioethanol can be conducted by licensed entities of which the Cabinet of Ministers keeps a registry. **Challenges**: Low enforcement, registry still not operable.
Market-based instruments	**Tax Code**: Excise Tax on Electricity	**Positives:** Energy taxes account for a high share of environmentally related tax revenue. Apart from the carbon tax covered in the industry section, this results mainly from the excise taxes on electricity (Neuweg, 2023) **Challenges:** Revenue fluctuates, therefore difficult as basis for expenditure for renewables support measures.
		Positives: **Challenges**:.
Information instruments	Modernisation of **educational programs** to address skills gap in the green transition and renewable energy sector	

6.9.3 Transport

6.9.3.1 National-sectoral mitigation enablers and barriers

Table 77: Overview of enablers and barriers (transport sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Existing road and rail infrastructure can be improved and expanded when not damaged and has to be reconstructed where destroyed. Suitable climate and terrain for walking and cycling in many areas.	

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	Rivers and canals offer potential for sustainable inland water transport (Alekseievska et.al., 2023).	
Environmental-ecological feasibility	Reduction in congestion, air pollution, and GHG emissions through sustainable transport modes including walking and cycling. Feasibility of non-motorised ways as a zero-emission transport mode. Reduction in congestion, air pollution, and GHG emissions through a shift to public transport. In-land water transport has potential for lower emissions compared to road transport. Electric and hybrid vehicles have the potential for significant reductions in air pollution and GHG emissions from road transport. Improved vehicle fleet efficiency leads to reduced fuel consumption and emissions from existing vehicles.	Potential environmental impacts of new infrastructure construction, reconstruction. Increased In-land water transport may have negative impacts on aquatic ecosystems and water quality. Electric vehicles (EVs) require decarbonized electricity supply to maximise environmental benefits.
Technological feasibility	Technologies for intelligent transport systems, traffic management and electric mobility are globally available. Existing rail infrastructure can be upgraded for freight transport. Technologies for intermodal transport (e.g., containerisation) are available. Electric and hybrid vehicle technology is mature and available.	High upfront investment costs for technology upgrades. Even before war, main and regional routes deterioriated and the share of tracks to be repaired and modernized is more than 40 % with increasing tendency (Abuselidse et. al., 2023) without including damages from war. Limited charging infrastructure. Concerns about limited range of electric vehicles and concerns about battery life. Cost of retrofitting older vehicles with fuel-efficient technologies can be substantial.
Economic feasibility	Introduction of taxes to promote public transport can generate substantial revenue for the government. Improved transport efficiency can reduce fuel costs and travel time, boosting economic productivity. Improved public transport can lead to lower operating costs and fares compared to private vehicles. Potential for job creation in the public transport sector. Lower operating costs for electric vehicles due to lower fuel and maintenance costs. Low cost of non-motorized transport in urban areas	High cost of infrastructure repair, modernisation and optimisation. Need for investment in rail infrastructure. High upfront costs of electric vehicles Modal shift might require subsidies to maintain affordability of public transport.
Sociocultural feasibility	Potential for improved accessibility, safety, and comfort for passengers with improved transport sector.	Acceptance and use of bicycles as a primary transport mode remain limited (Panasiuk, 2022)

	Rapid Transit modes can increase accessibility and convenience for urban residents. Growing global trend towards electric mobility. Air pollution and safety are of concern in using non-motorised transport, particularly in urban areas. Non-motorised modes promote physical health (Panasiuk, 2022).	because of cultural preference for motorized transport and infrastructure gaps. Resistance to change travel habits and preferences. Negative perception of public transport (e.g., overcrowding, unreliability, personal safety). Limited awareness and demand for inland water transport. Lack of awareness and familiarity with electric vehicles.
Institutional feasibility	Existing tax and regulatory mechanisms can be adapted to promote public transport and transport mode optimisation. Government incentives and policies can promote electric vehicle market.	Ukraine's inland waterways currently play a secondary role/ are secondary prority in the country's transportation system. several reforms needed to create sustainable logistic system with green inland water transport (Alekseievska et. al., 2023) Lack of political will and commitment to prioritize public transport.

6.9.3.2 Current status of national-sectoral climate policy

Table 78: Overview of policies and measures (transport sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Economic and Climate Plan (2024):** Transport objectives, existing and planned measures are included in the decarbonisation cluster of the NECP.	**Positives:** The NECP includes list of sectoral regulation regarding electric vehicles, charging infrastructure, public transports and some government assessment of results (success of policy) of existing policies and expected results of additional policies
	National Transport Strategy (2018b): Vision of government on priorities for transport policy and framework for the modernisation of the transport sector in Ukraine	**Positives:** Single strategy for the transport sector, not subsumed to other priorities. It explains the government's strategic approach to the transport sector development. Four priority areas are 1. Competitive and efficient transport system, 2. Innovative development of the transport industry and global investment projects. 3. Safe, clean and energy-efficient transport. 4. Seamless mobility and interregional integration **Challenges:** Speed of legal and institutional adjustments and reforms related to the strategy remains very slow and is affected by Russia's military aggression (European Commission 2023b). Decarbonisation and greenhous gas emission reduction is not an explicit focus, the electrification of the sector is not a priority, electric vehicles are not prominently mentioned. Rather a macro perspective.

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Regulatory instruments	**National Transport Action Plan 2021-2024** (cited in EU Commission, 2023b)	
	Law "On **Amendments to the Customs Code** of Ukraine to stimulate development of the electric transport industry in Ukraine" (2020)	**Challenges:** Same criticism and Government assessment as for the Tax code amendment.
Market-based instruments	**Law "On Amendments to of the Tax Code of Ukraine and some legislative acts of Ukraine on stimulating the development of electric transport in Ukraine" (2020)**	**Positives**: Objective to stimulate the use of electric vehicles and charging stations/infrastrusture to support an annual increase of the electric vehicle fleet of 3% as forecasted in preparing Ukraine`s updated NDC (Abuselidse et. al., 2023) Fiscal Incentives should increase interest in electric car ownership. At the same time, no customs duty is levied on imports of electric vehicles (Government of Ukraine, 2024) as VAT exemption on the import of electrical vehicles was extended until 31 December 2022. **Challenges**: Is estimated to be not sufficient to achieve decarbonisation goals in transport (Abuselidse et. al., 2023) However, the Government estimated the incentives as successful. Although effectiveness of tax benefits was not directly evaluated, the number of electric cars increased ten time between 2018 and 2023 from 7,439 units to 72,435 units (Government of Ukraine, 2024)
Information instruments		

6.9.4 Buildings

6.9.4.1 National-sectoral mitigation enablers and barriers

Table 79: Overview of enablers and barriers (building sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Ukraine has a larger potential for biomass energy as a fuel source for heating and hot water services in the municipal sector (UNDP, 2016) High solar potential could be utilised for solar PV at buildings Measures to promote sufficiency, energy efficient building construction/renovations, as well as low carbon heating and cooling reduce natural resource consumption (fossil fuels, metal ores, minerals) associated with final energy consumption Advanced construction methods and reuse of building materials can reduce consumption of raw materials but most sustainable building	

	technologies are not limited by materials (Cabeza et al., 2022a) Green roofs reduce heat gains and losses New sustainable insulation materials have been developed and are available	
Environmental-ecological feasibility	Sufficiency and building energy measures that reduce fossil fuel demand can improve air quality and biodiversity Decarbonisation in the buildings sector has potential to generate co-benefits in health, energy affordability and jobs. (OECD, 2022) Many opportunities available for green infrastructure techniques that have an positive environmental effect (green roofs, rainwater harvesting, gray water management).	switch to more efficient appliances could result in negative impacts from increased resource use, which can be mitigated by avoiding premature replacement and maximising the recycling of old appliances
Technological feasibility	Many advanced construction methods are widespread in developed countries Insulation technologies are generally well-developed, while transparent insulation materials and phase change materials need further R&D Sustainable heating and cooling technologies are widely implemented at all scales	Challenges to the power grid system due to the increasing electrification of heating and cooling Limited adoption of sustainable practices due to cost, lack of awareness, and pressure to rebuild. Shortage of skilled workers for energy retrofits and heat pumps installation
Economic feasibility	Ample opportunities are there for cost savings through energy-efficient design (passive design strategies) and renewable energy integration. Demand-side management measures (e.g., sensors, controls, energy consumption feedback measures) are mature and usually cost-effective. Utility-scale solar PV, and the accelerated installation of small-scale distributed solar PV in the residential sector and public buildings (most notably schools and hospitals) have significantly increased system resilience (Bilek et. al.,2024)	High upfront costs and longer payback time to invest in building energy efficiency measures, renewable energy technologies, and low-embodied carbon materials Financial mechanisms and incentives are limited
Sociocultural feasibility	Due to the ongoing energy crisis and high energy bills, there is growing attention on the public of sustainable living and green building concepts. Build back better principle as motivation and guiding principle	Lack of information and knowledge about building energy efficiency and low carbon heating/cooling options. Lack of awareness about the benefits of sustainable buildings.

Institutional feasibility	Generally high priority and promotion of renewable energy systems by government, aim to increase share of renewables.	Coordination between national and sub-national governance levels necessary.. Lack of comprehensive data on building energy performance and emissions. No government policies are being developed to promote sustainable urban planning.

6.9.4.2 Current status of national-sectoral climate policy

Table 80: Overview of policies and measures (building sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	There is no explicit strategy for decarbonisation of the buildings sector. Objective regarding the development of the residential /buildings sectors are contained in a number of energy focused strategies and plans.	
Regulatory instruments	Minimum **energy performance requirements** of buildings	
	Law on Energy Efficiency Fund (2017): The Law defines the legal, economic, and organisational foundations for the establishment and operation of the Energy Efficiency Fund	**Positives:** The objective is to support energy efficiency and energy savings initiatives and introduce incentive and support measures for energy efficiency improvements and energy saving in buildings. It is aligned to the national plan for energy efficiency, objectives to reduce CO2 emissions under the Paris agreement, and upholding Ukraine's international obligations in the area of energy efficiency**. Has been assessed as effective instrument (European Commission, 2023a).** Since its fullscale launch between September 2019 and July 2022, thermal renovations have been fully or almost fully completed in over 200 multi-apartment buildings, and more than 650 projects are in preparation. The EEF has been one of the few effective state institutions which continued providing support to beneficiaries in 2022 even after the outbreak of the war. organisational and technical capacity of the state market surveillance body needs be strengthened. At present, there is no legislation to incentivise investments in high-efficiency combined heat and power generation. Regulations to help improve the efficiency of district heating systems, especially of heat distribution networks, could further strengthen the framework for modernisation.
Market-based instruments		
Information instruments	Order 'On approval **of Technical Regulation on energy**	**Positives**: Label in line with EU energy label scheme. Programme aims to raised consumer awareness about energy

	labelling of energy consumer products' (2022) framework for energy labelling, providing consumers with information about their energy consumption and allowing them to make informed choices (Government of Ukraine, 2024).	efficiency. Suppliers and distributors of appliances have to ensure that products have label related information (level of efficiency of energy consumption) and product information sheets Suppliers must ensure their accuracy and provide technical documentation. Amended for broader product scope, .

6.9.5 AFOLU

6.9.5.1 National-sectoral mitigation enablers and barriers

Table 81: Overview of enablers and barriers (AFOLU sector)

Dimension	Enablers	Barriers
Geophysical feasibility	Diverse climatic zones and soil types, large share of rich black soil. There is potential for expanding renewable energy generation areas (solar, biogas).	The vulnerability to climate change impacts (droughts, floods) can affect reforestation efforts, crop yields and livestock production.
Environmental-ecological feasibility	Reforestation and afforestation can improve soil health, biodiversity, and water resources. Natural forests act as carbon sinks and provide ecosystem services. Sustainable agricultural practices (e.g., agroforestry, organic farming) can improve soil health, water quality, and biodiversity.	Intensive agriculture practices can lead to soil erosion, water pollution, and loss of biodiversity. Deforestation (in occupied regions) can worsen environmental degradation.
Technological feasibility	Due to current energy crisis, there is growing interest in renewable energy applications for agriculture (e.g., solar-powered irrigation pumps, biogas digesters).	Lack of awareness and technical capacity among farmers can hinder the uptake in sustainable agricultural practices.
Economic feasibility	Forest-based industries can provide income and employment opportunities. Carbon credits and payments for ecosystem services can incentivize sustainable forestry practices. Improved productivity and reduced input costs can be realised through efficient resource management and technology adoption.	There are number of competing economic interests in land use such as energy generation, agriculture, and tourism. High investment costs for technology adoption and infrastructure development to adapt sustainable agriculture practices.
Sociocultural feasibility		
Institutional feasibility	There are existing policies and institutions for forest conservation and management.	

6.9.5.2 Current status of national-sectoral climate policy

Table 82: Overview of policies and measures (AFOLU sector)

Type of instrument	Status / Is the policy in place?	What are challenges for issue this policy or enforce this policy?
Governance and planning instruments	**National Energy and Climate Plan (2024)**	**Positives**: The **NECP** focuses on agriculture and some forest measures. **Challenges**: Criticism on a draft of the NECP focuses on the non-representation of LULUCF sector as no data was provided in the sections on "Current situation and projections based on existing policies and measures" and "Impact assessment of planned policies and measures" (Ecoaction, 2024). As the LULUCF sector has the potential for net removals, it plays a key role in achieving climate neutrality Apart from forests, absorption and carbon storage can result from cropland, steppe and grassland, wetlands, settlements, and other land. Therefore, these land uses should be addressed with measures to strenghthen the removal capacity by preserving existing natural carbon stocks (in soils and ecosystems), increasing carbon stocks through ecosystem restoration, soil protection measures, restoration of degraded lands, implementation of sustainable agricultural practices.
	Strategy of Agriculture and Rural development of Ukraine until 2030 (Ministry of Ministry of Agrarian Policy and Food of Ukraine, 2024) The strategy aims at providing a clear definition of priorities and the creation of favorable conditions for the development of agriculture and rural areas in Ukraine.	**Positives:** The strategy has seven goals: sregthen institutional capacity, achieve food security, ensure the sustainability of the agricultural sector by m climate oriented agriculture, aintaining a stable and fair income of producers and by increasing their competitiveness, effective use of land (demining, land reform), modernisation of the agriculture sector, and creation of conditions for the development of rural areas. **Challenges:** Incomplete reforms, e.g. the land reform that is on the agenda since the 1990s .
	National Program for the Formation of the National Ecological Network of Ukraine for 2000–2015 (2020): Organsises participation in the Emerald network aiming at the creation of special sites for biodiversity and endangered species conservation, implementation of EU environmental-protecti (on legislation, and policies harmonized across the global network (Shumilo et. al., 2023)	**Positives:** Ukraine achieved a total reforestation area of 11.17 ± 1.45 th. ha at the dedicated sites before the beginning of the conflict and 17 ± 1.74 th. ha from 2000 to 2020 on the Ukraine-controlled territories. **Challenges:** Deforestation rates of territories under Russian control with similar bio-physical characteristics36 and the same war-related vulnerability factors indicate that the separation of ecosystems from environmental-protection institutions and policies through the occupation of territory led to dramatic degradation of the environment and loss of ecosystem sustainability
	Law "On Approval of the Concept of the National Target	**Positives:** Objective is the reduction of soil degradation and related the reduction of greenhouse gases. Expected results

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Regulatory instruments	**Program for Land Use and Protection"**	are to reduce agricultural development (by 5%) and ploughed land (by 10%), to optimise the structure of the agricultural landscape; to increase the productivity of agricultural land (by 40-50%) through the rational use of organic, organo-mineral and mineral fertilizers and chemical meliorants on acidic and saline soils. Increase the area of land with natural landscapes to a level sufficient to preserve landscape and biological diversity (up to 10.5% of the total area of the country), conserve degraded, unproductive and technologically polluted land (Ecoaction, 2024). **Challenges:** As the frameeork strategy NECP includes a goal for increasing the area of arable land from which crops will be harvested until 2050 this contradicts other declared goals such as to reduce the area of arable land by removing slopes.
Information instruments	**National Forest Inventory of Ukraine (2006)**	**Positives**: Provides statistically substantiated information on quantitative and qualitative indicators of the state and dynamics of forests, their resource potential for the needs of the state administration, strategic planning of forestry, state forestry cadastre, environmental monitoring, international reporting on forests.

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