IAM COMPACT

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

29/07/2024

D4.4 Broad scenario logic – Update

WP4 – Modelling – Quantitative evidence in support of post-2030 Paris-compliant climate action

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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

This report will be used as guidance and harmonisation framework for modelling work in the 2nd modelling cycle of IAM COMPACT. It should, therefore, be used by all groups that conduct modelling work in IAM COMPACT. It also describes the harmonisation process that took place in the 1st modelling cycle after the submission of D4.3, and hence may be of use to readers wishing to track the modelling work undertaken in the project.

3. Short summary of results (<250 words)

This deliverable contains updates to and expansion of deliverable D4.3, *'Broad Scenario Logic'*. A broad scenario logic is understood as a set of assumptions and harmonised data that serve as a default background for different research questions in the project and the modelling studies that address those research questions. Each study supplements the broad scenario logic with a specific and more complete scenario protocol and, if necessary, can override any part of the broad scenario logic to address the given research question.

The deliverable expands on the first version of the logic (D4.3) by describing the harmonisation that took place in the 1st modelling cycle of IAM COMPACT after D4.3 was submitted, and by specifying updates and changes to the harmonisation data that was given in D4.3. The updated harmonisation data is intended for use in the 2nd modelling cycle. The deliverable also describes and discusses the results of a qualitative survey that was conducted with the participants in the 1st modelling cycle to elicit feedback and suggestions for changes to D4.3, and which motivated some of the changes made. Finally, it provides some clarifications on output formats and requirements for model results.

4. Evidence of accomplishment

This report.

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	
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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	
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THU – Tsinghua University	CN	
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Executive Summary

This deliverable contains updates to and expansion of deliverable D4.3, *'Broad Scenario Logic'*. A broad scenario logic is understood as a set of assumptions and harmonised data that serve as a default background for different research questions in the project and the modelling studies that address those research questions. Each study supplements the broad scenario logic with a specific and more complete scenario protocol, and, if necessary, can override any part of the broad scenario logic if needed to address the given research question or to be consistent with a specific modelling framework. Nevertheless, input data and assumptions should be harmonised between models as far as possible, and—when not inappropriate—between studies, in order to ensure a consistent starting point and enable comparison of results. Deviations from default harmonisation data should be reported explicitly by each modelling group along with model results, to ensure that this information is easily available to anyone who needs to analyse and compare results. The purpose of and methodology for harmonisation is discussed in depth in deliverable D4.3 and not repeated here.

The deliverable expands on D4.3 by describing harmonisation that took place in the 1st modelling cycle of IAM COMPACT after D4.3 was submitted, and by specifying updates and changes to the harmonisation data that was given in D4.3. The updated harmonisation data is intended for use in the 2nd modelling cycle.

The deliverable starts by describing harmonisation that was performed after D4.3 in the context of modelling studies in the 1st modelling cycle. Current policies and national climate targets were harmonised across studies to produce long-term emission pathways. Specific studies further added harmonisation of energy inputs, material inputs and technological parameters for the steel production for a study focused on the steel sector, and weighted average cost of capital for different technologies for a study focused on derisking clean energy technologies.

The deliverable then describes and discusses the results of a qualitative survey that was conducted with the participants in the 1st modelling cycle to elicit feedback and suggestions for changes to D4.3, and which motivated some of the changes made. The conclusion was that most recommendations from D4.3 should stay in place, but that certain 3rd-party data sets used for harmonisation should be updated to new versions that were released after D4.3, and that updated Shared Socioeconomic Pathways should be used for harmonising socioeconomic data and scenario projections. The possibility of further harmonisation of assumptions for the land-use sector was also discussed, but ultimately found not to be feasible within the frame of IAM COMPACT.

The most extensive section of the deliverable specifies updates and additions to the common harmonisation data from D4.3, for use in the 2nd modelling cycle. The most significant change is that GDP and demographic data (both historical and future) are now harmonised on the Shared Socioeconomic Pathways (SSPs) instead of a custom composite dataset, with SSP2 as the default scenario unless a research question suggests otherwise. A data set of current climate-relevant policies and national targets is also added, which was not part of D4.3. Apart from these changes, data for energy from the IEA, greenhouse gas emissions from the IEA, EDGAR and the Global Carbon Budget, as well as technology costs from the IEA are updated to the latest available year. There is also a small addition to the discussion of free alternatives to IEA's data, which now includes a free, less detailed version of the IEA World Energy Balances themselves ("World Energy Balances Highlights").

The deliverable ends with a few updates to the section on output formats and requirements from D4.3, including some clarifications about how to correctly use the IAMC format for model result files.

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1 Introduction

1.1 Purpose of deliverable D4.4

This deliverable is an update of deliverable D4.3 "Broad scenario logic". As in D4.3, a "broad scenario logic" is defined to be a set of question-agnostic, default input assumptions and output requirements that form a background for specific modelling exercises. It does **not** specify complete scenarios or assumptions needed to address specific research questions. Full scenario protocols and research question-specific data and assumptions are developed in the context of specific modelling studies or modelling tasks, and not reported here.

The recommended inputs and assumptions in the broad scenario logic are defaults, and both can be overridden if required to address a given research question or to ensure consistency with a given modelling framework. As far as possible, assumptions and input data should nevertheless be harmonised between models and across studies when not inappropriate, in order to reduce the number of possible sources of difference between model results, which in turn will increase comparability of results and make them more useful for cross-cutting analyses. The motivation for and approach to harmonisation are discussed in depth in deliverable D4.3 chapter 2 and subchapters 3.1 and 3.2, along with considerations for what aspects to harmonise in a broad scenario logic versus in individual modelling studies and are not repeated here.

This deliverable contains updates and changes relative to D4.3, as well as some content resulting from activities that took place after D4.3 was submitted but does not wholesale repeat content from D4.3 and refers to D4.3 for further detail in many places. As in D4.3, the main focus is on harmonisation of input and calibration data, and general assumptions that can be used as defaults across modelling studies in the coming 2nd modelling cycle to be conducted in the autumn of 2024.

1.2 Main changes since deliverable D4.3

Parts of the changes in this deliverable are based on a questionnaire sent to modelers. The questionnaire included mostly qualitative questions about how D4.3 was used in the 1st modelling cycle and suggestions for improvements in D4.4. Its conclusions are discussed in Chapter 3.

The main changes in this deliverable relative to D4.3 are:

- A short summary has been added of what harmonisation was added in the 1st modelling cycle after D4.3 was submitted (Chapter 2).
- Recommended GDP and population data and projections for harmonisation have been changed from a composite dataset in D4.3 to recommending the 2024 update of the Shared Socioeconomic Pathways (SSPs) in this deliverable (Section 4.3)
- A database of climate policies and targets have for use in harmonised policy scenarios has been added (Section 4.7). In the first modelling cycle, this was not contained in D4.3 but was added after D4.3 was submitted.
- Several other recommendations for harmonisation data sets have been updated to the latest versions, including energy and emissions data from the IEA, emissions data from EDGAR and the Global Carbon Budget, and a number of data sources for technology costs and parameters (Sections 4.4, 4.5 and 4.6).
- More detail has been added on requirements for output formats, along with a short description of validation and vetting procedures for result files.

1.3 Connection to project objectives and to other tasks

This deliverable provides updated harmonisation recommendations for all modelling studies, and as such connects to all other tasks in IAM COMPACT work packages 4 and 5. Through the specifications for output formats, validation and vetting, it also connects to task T3.6 and overlaps with the Milestone 7 report that was produced in connection with that task. While the deliverable provides a set of default, research question-independent assumptions to be used as a basis for study-specific scenarios, it does not provide full scenario protocols or specific assumptions designed to answer specific research questions. That is done within each modelling study, and described in deliverables that detail the results of those studies.

By providing a basis for modelling activities, the deliverable indirectly supports all objectives that are met through model activities that require some degree of harmonisation. Furthermore, it directly supports the following stated objectives for Work Package 4:

- "*Quantify the role of major sectors (including energy, water, transport, industry, and land use) in mitigation*": Quantifying the role of and therefore comparing emissions in different sectors in several cases require making use of multiple models and/or sector-specific models. D4.3 supports the use of multiple models by providing recommendations for harmonised data that can help ensure comparability of model results. The baseline assumptions for GDP and population in the harmonisation data further provides a necessary basis for any forward-looking modelling, including assessing the role of different sectors in mitigation scenarios. Finally, the added database of climate policies and targets (Section 4.7) is a necessary starting point for defining the mitigation pathways to be modelled, which is at the heart of any assessment of the roles played by different sectors.
- "*Provide evidence on national planning for the post-2030 period, in light of the Paris Agreement goals*": The database of policies and targets provided by this deliverable contributes a starting point for any modelling-based assessment of national climate actions that address the goals of the Paris Agreement.

By enhancing comparability between models and providing a transparent set of common inputs, the harmonisation data also directly supports the following overall project objectives (specific parts in **bold**):

- O1: *Supporting the assessment of global climate progress, needs, and feasibility, and the preparation of national policies for the post-2030 period, toward mid-century climate neutrality* ***based on comparable modelling activities,*** *between global and regional/national scenarios as well as* ***between IAMs and other models, in intercomparison exercises with extensive sectoral representation*** *(water, energy, transport, industry, AFOLU, etc.).*
- O6: ***Opening the 'black box' of scientific inputs, processes and outputs in line with the principles of open science ensuring the data used/produced are FAIR*** *(findable, accessible, interoperable, reusable),* ***documenting model*** *capabilities and* ***specifications*** *for expert and non-expert audiences, including open-source models among the project's model ensemble, providing open access to data and code produced (new modules, model integration, meta-analysis), transparently mapping outputs onto assumptions, and exploiting/expanding the I²AM PARIS open exchange platform with open databases, briefs, papers, and policy support toolboxes for each exercise.*

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2 Harmonisation added in modelling studies after D4.3

Some additional parameters were harmonised across the models after the submission of D4.3 based on different study requirements to ensure consistent interpretation of the modelling outcomes and reduce model variance.

As part of the first policy response mechanism cycle, global assessment was done to assess the long-term emission pathways considering pre-COP26 2030 NDCs (Nationally Determined Contributions) and current policies and resulting warming pathways(de Ven, Arenas, Sampedro, & Mittal, 2024; Mittal & de Ven, 2024). For this study, in addition to the socioeconomic drivers including population and gross domestic productioncapita, current policies and emissions targets communicated by different countries in their national determined contribution and long-term strategies submitted to the UNFCCC were also harmonised between three integrated assessment models, i.e., GCAM, PROMETHEUS and TIAM-Grantham. The models differ in the level of policy implementation due to technological and sectoral granularity, which differs across the models used.

In another study focusing on the European steel sector, representation of steel production technologies (including system boundaries, energy and material inputs, technology costs, TRL and earliest availability, specific co2 emissions), regional steel demand and (global) scrap availability were harmonised between GCAM, TIAM and WISEE EDM-I to the largest extent possible in additions to other harmonisation done in the above mentioned study (see D4.7 for details). This was done to understand the impacts of steel trade restrictions between the EU and other regions on steel transformation pathways in the EU in terms of cost, final energy demand, and emissions. The harmonised data regarding steel technologies can be found in the D4.7 Appendix. In another study that focuses on the implications of derisking clean energy technologies and risking fossil fuels-based technologies, empirical estimates of the weighted average cost of capital (WACC) for different technologies were harmonised in two global integrated assessment model and one electricity system model (see D5.6 Annex D section 4 for the details). The historical WACC values by region and technologies were taken from (Calcaterra, (2024)&;IRENA, (2022). The future trajectory of the WACC values varies based on the scenario narratives.

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3 Use of D4.3 and feedback for D4.4

The main purpose of deliverable D4.4 is to improve on D4.3 and provide updated and improved specifications for harmonisation and reporting of results in the 2nd modelling cycle of the IAM COMPACT project. To achieve this, a survey was conducted with the participants in the 1st modelling cycle to map how D4.3 was used by modellers in the 1st modelling cycle, and to collect feedback and requests for improvements. This chapter summarizes the results and how they are addressed in D4.4.

3.1 Survey of 1st modelling cycle participants

A survey was sent to all modelling groups in February 2024, with questions about how D4.3 was used in the 1st modelling cycle, and how D4.4 should improve on it. The purpose was to make D4.4 as useful for the modelling cycle as possible, not to evaluate D4.3 per se. For this reason, all questions were qualitative, and in most cases required entering free-form text responses into text boxes.

The main groups of questions were:

1. **Classifier questions:** Which model(s) the respondents used and which modelling studies they participated in.
2. **Use of deliverable D4.3:** What parts of the harmonisation data or other recommendations were used, how and for what purposes
3. **Feedback on the content of D4.3:** What aspects of D4.3 the respondents found particularly useful, what parts should be improved or expanded on, and what parts were considered superfluous.
4. **Other requests and suggestions for D4.4:** What harmonisation data would be most important to update, whether there were any concerns about updating particular parts of the harmonisation data, and any feedback or suggestions for D4.4 not covered in any of the questions.

The survey was sent to all modelling groups in the IAM COMPACT project. 9 respondents from the same number of different institutions responded to the survey. These respondents represented 11 different models (CLEWs, EnergyPLAN, GCAM, MARIO, MEDEAS, MENA-EDS, OSeMOSYS, PROMETHEUS, the TEEM modelling ensemble, WILIAM, and China MAPLE). All 7 studies from the 1st modelling cycle were represented except for study 5 ("What is the contribution of earlier stage technologies if they undergo rapid cost reductions?").

3.2 Results: Use of D4.3 in 1st modelling cycle

All respondents responded that they used the harmonisation recommendations from D4.3 in their modelling work in some form, except for the group representing the EnergyPLAN model. The latter is understandable and expected, given that the EnergyPLAN model is not an IAM, but a detailed energy system model that operates at high temporal resolution, and in most cases would need to be harmonised through inputs received from other models with broader sectoral coverage. One model (China MAPLE, a country-specific model) only made use of the recommendations for outputs, not harmonisation data or other input recommendations.

Out of the 7 groups that reported having made use of the recommended harmonisation data, the following number made use of each group of data:

- **Socioeconomic data** (population and/or GDP data and projection): 4 groups
- **Emissions data** (historical)**:** 4 groups, 1 of which only made use of alternative emissions data from the CEDS database
- **Energy data** (historical)**:** 1 group
- **Technology data** (costs and/or performance parameters): 3 groups

All of the 7 groups except one reported using regional data in some form, as opposed to only global data.

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3.3 Results: Feedback and wishes for D4.4

The responses to the survey largely did not reveal a need to add additional content, with a few exceptions noted below. They also clearly indicated that no parts should be removed. One group commented that the technology performance parameters were perhaps not needed in as much detail and were in any case difficult to harmonise across models, but at least two other groups responded that they did indeed use these parameters.

3 of the 7 groups that responded to questions about the harmonisation data requested that the data in D4.4 be made as up to date as possible, while no groups recommended *not* to update any data. However, one group responded that some (not specified) parts of the updated data might not be used due to the difficulty or recalibrating their model. Discussions after the survey further highlighted the challenge of recalibrating, in particular for the land-use sector (see below). Updating projections for technology costs and performance was seen as particularly important by one respondent, and in conversations after the survey several groups welcomed updating the socioeconomic data/projections to revised SSPs.

One respondent requested explicit emissions factors as part of the harmonisation data, which was required by their model rather than emissions directly. D4.3 specified to use default emission factors from the 2006 IPCC guidelines for national greenhouse gas inventories, but did not provide these factors directly.

One other group also suggested harmonising land-use parameters more generally rather than just emissions from land-use change.

3.4 How the feedback is addressed in D4.4

In D4.4, we update the socioeconomic harmonisation data to use the revised Shared Socioeconomic Pathways (SSPs) rather than the custom and partly outdated dataset used in D4.3, and update as many data sets as possible to their latest versions when updates have been made available in the past year (see Chapter 4 for details).

Although several datasets have been updated, we acknowledge that recalibrating models with the new data can in some cases be challenging, and that the extra value provided by doing so may not justify the effort required in all cases. The participants in each modelling study should therefore discuss and agree on which parts of the updated data should indeed be updated and which are better left the same as in the 1st modelling cycle. This issue is discussed further in Section 4.5.2.

In order to address the need for explicit emission factors, we make a database of emission factors from the IPCC guidelines available on the IAM COMPACT SharePoint. This database contains far more detail than is likely to be necessary for any given model, but due to the possibly different needs of each model, the database is made available unmodified and in full (see Section 4.5.4 for details).

In response to the suggestion to harmonise land-use parameters (as opposed to just checking modelled land-use change emissions against the range in the Global Carbon Budget, as in D4.3), a comprehensive discussion took place to probe what free parameters different models used as inputs or calibration for the land-use sector, to what extent they could be adjusted, and what level of effort that would require. The discussion was conducted partly in online meetings and partly by email during March and April 2024. The conclusion from this discussion was that the models that represented the land use sector endogenously had quite different approaches and used different inputs, and that there was little to no room for harmonising any parameters without a recalibration effort that would be far beyond the capacity of this project. As such, it was decided not to attempt any harmonisation of land-use parameters in D4.4 beyond the land-use change emissions data that was already included in D4.3.

4 Updates and changes to harmonisation

As in chapter 3 of deliverable D4.3, this chapter specifies data to be used for harmonisation in modelling studies for the second modelling cycle and explains the reasons for the changes where applicable.

In most cases, a full discussion is included only when there are changes relative to D4.3 chapter 3. Where there is no change, simple updates or changes to specific details, we specify the changes if any and refer to D4.3 for a detailed specification and discussion of the data.

As in D4.3, the provided harmonisation data should be considered as defaults, that can and should be overridden if required in the context of a specific modelling study or research question. It is up to those in charge of each modelling study to decide which variables should be overridden, how strictly modellers should adhere to the provided harmonisation data, and whether specific variables do not need to be harmonised. Modellers should nevertheless make a concerted effort to harmonise variables that in most cases should be the same in all studies, and that are likely to greatly affect comparability between studies unless there is good reason for results not to be comparable. This includes in particular historical and future population data, historical GDP figures as well as future GDP figures in studies that do not involve alternate GDP trajectories, and historical GHG emissions and energy production/consumption.

All studies and models should report what harmonisation data was used for calibration or for other inputs, both what data was recommended for each study as a whole and what data was actually used by each individual model. This should be reported regardless of whether the recommendations from this chapter were used unaltered or different or modified data were chosen. A custom Excel template should be used for this reporting and uploaded to the IAM COMPACT project SharePoint. Instructions are given in Section 5.3.

4.1 Summary of harmonisation data

NB! Whenever possible, modellers should use the data files that have been shared on the IAM COMPACT SharePoint rather than obtaining it directly from the primary source, or reusing equivalent-looking data used earlier model runs. This is desirable in order to avoid mistakes, including cases where modelers believe that previously used data are equivalent to the recommended harmonisation data but in fact are not. If modellers use different data sources than the provided data files due to various constraints or existing data pipelines, it is important that they compare the numbers they use to those in the data files and confirm that they are equivalent.

The following data have been changed or added relative to D4.3:

- GDP and demographic data switched to using SSPs (version 3.0.1), with SSP2 as default
- Added database of policies and climate targets
- Added the IEA "World Energy Balances Highlights" as a free alternative for energy data, but the full IEA World Energy Balances are still the recommended data source

The following data use the same sources as before, but have been updated to a newer version:

- Energy data updated to the July 2024 version of the IEA World Energy Balances
- Emissions of energy-related CO_2, CH_4 and N_2O emissions updated to the July 2024 version of the IEA Greenhouse Gas Emissions from Energy dataset
- Emissions of other greenhouse gases from energy and of all gases from industrial processes and product use (IPPU) updated to version 8.0 of EDGAR
- CO_2 emissions from land-use change updated to the 2023 release of the Global Carbon Budget
- Technology costs and other parameters from the IEA World Energy Outlook updated to the 2023 version

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Table 1: Summary of all recommended harmonisations. See deliverable D4.3 chapter 3 for the full discussion of all original recommendations, and the subsequent subchapters of chapter 4 in this deliverable for discussion of the updates to the recommendations.

Topic	Variable	Context	Recommended data
Socioeconomics	**Population**	All regions, historical and future	The "Historical Reference" scenario for historical data, by default SSP2 for future data, but other SSPs if more appropriate for a given modelling study. This is different from the dataset recommended in D4.3.(IIASA, 2024)
	GDP	All regions, historical and future	The "Historical Reference" scenario for historical data, by default SSP2 for future data, but other SSPs if more appropriate for a given modelling study. Use data from the model OECD Env-Growth. This is different from the dataset recommended in D4.3.(IIASA, 2024)
Techno-economics	**Technology costs (for reference scenarios)**[1]	EU27 and comparable countries[2]	Should be decided case-by-case, but most suitable option is likely to be technology costs from the EU Reference Scenario 2020 (De Vita et al., 2021)
		Other regions, power-sector technologies	No firm recommendation at this point. Most suitable option is likely to be cost assumptions from IEA's World Energy Outlook 2023 (IEA, 2023). Alternatives include technology costs from TIAM database as used in PARIS REINFORCE or using the costs from the EU Reference Scenario 2020 in regions where this is appropriate, possibly adapting the costs levels if feasible.
		Other regions, non-power technologies	No firm recommendations at this point. Options include the TIAM database (see above) or adapting costs from the EU Reference Scenario 2020.

[1] The appropriate choice of technology costs will often depend strongly on the research question. It can potentially also vary by model for models that employ learning curves, and resulting differences in technology costs could be a desired part of model diversity. The tentative recommendations here only apply to cases where the research question does not prescribe any particular assumptions about energy technology costs, but where a "neutral" technology scenario with harmonised energy costs is desired.

[2] "Comparable countries" here refers to non-EU European countries that are similar enough in terms of energy and trade policies and other economic and technological factors that one can assume the same technology cost levels as in the EU, in the context of a given scenario and research question. Whether using EU cost levels is appropriate for a given country must be decided by research question leaders on a case-by-case basis.

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Topic	Variable	Context	Recommended data
	Fossil fuel prices	Historical prices	Regional prices from IEA datasets(IEA, 2024). If participating modellers do not have access to proprietary IEA data, data for some years and regions can be extracted from the freely available World Energy Outlook 2023 report, or if global benchmarks are sufficient, some of these are available for free from the World Bank "pink sheet" (World Bank, 2023).
		Price projections	Regional price forecasts from the World Energy Outlook 2023 extended dataset(IEA, 2023), requires subscription. Participating modellers who do not have a license can extract some prices visually from charts in the World Energy Outlook 2023 report. For long-term EU-specific exercises that do not need short-term trends, price projections from the EU Reference Scenario 2020 may be used.
Energy	**Energy production and consumption**	Historical data[3]	IEA World Energy Balances. For users who do not have a license for the full energy balances and do not require detailed product and sector breakdowns, the free IEA World Energy Balances Highlights can be an alternative.(International Energy Agency, 2023c, 2023d)
Emissions	**Energy-related[4] CO_2, CH_4, N_2O**	Historical data	IEA Greenhouse Gas Emissions from Energy dataset(International Energy Agency, 2023a), if modellers have or can acquire access. Alternatively use EDGAR v8.0, which is consistent with IEA but with less detailed sector breakdowns and no disaggregation of fuel types(Join Research Centre, 2023). Emissions can also be calculated from energy consumption data using default Tier 1 emission factors from the 2006 IPCC guidelines for GHG inventories, which are consistent with IEA emission factors.

[3] No harmonised data is proposed for future energy consumption. This is assumed in most cases to be research-question specific and/or modelled endogenously.
[4] NB! The recommended datasets use the 1996 IPCC Guidelines for GHG inventories to define the boundary between energy-sector and

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Topic	Variable	Context	Recommended data
	IPPU CO_2 from cement	Historical data	Production data and emission factors from Andrew (2018). Updated data available on Zenodo.
	F-gases and non-energy CO_2, CH_4, N_2O	Historical data	EDGAR v8.0
	Other emissions	Historical data	CEDS(Hoesly & Smith, 2024)
	Land-use change emissions	Historical data	No firm recommendation on harmonised data, but should check that used or generated data falls within the range spanned by 3 bookkeeping models in the Global Carbon Budget 2023. Use an average of the three models if a single harmonised dataset is required and no other constraints are implied by the research question. See D4.3 subsection 3.7.5.3 for what to do when alignment with national inventories is required. (Friedlingstein et al., 2023)
	All emissions	Infilling of historical and future emissions	Use Silicone software package to infill missing emission components, if required by the modelling exercise (e.g., for climate impact assessment) (Lamboll, Nicholls, Kikstra, Meinshausen, & Rogelj, 2020)
Policies	**Climate policies and targets**	Current policies	Custom database of climate policies and national targets; see IAM COMPACT SharePoint and (de Ven et al., 2024; Mittal & de Ven, 2024). This is a new dataset and harmonisation category not included in D4.3.

4.2 Data availability

Harmonisation data is made available on the IAM COMPACT project SharePoint, in the folder "Harmonisation data" under the main D4.4 folder, as far as licensing conditions permit. Essentially all data is available there, with the major exception of the full energy balances and greenhouse gas emissions data sets from the International

industrial-process and product-use (IPPU) emissions, not the newer 2006 guidelines (although the emission *factors* used are consistent with the 2006 guidelines). The IEA also provides a dataset where emissions are categorised in accordance with the 2006 guidelines, but with less granular breakdowns of energy types and sectors. EDGAR does not provide any data using the 2006 sector boundaries.

Energy Agency (IEA).

The database of climate policies and targets is additionally publicly available in the iam-compact community on Zenodo (de Ven et al., 2024; Mittal & de Ven, 2024)

Although most of the other data sets (apart from those from the IEA) can be freely used for academic purposes, specific license conditions prevent almost all of them from being reshared in full on an open platform. For this reason, the data is not made available on Zenodo or other public platforms, but references are given (either in this deliverable or in D4.3) to the original sources where the data in most cases can be obtained for free.

4.3 GDP and population

NB! For harmonising socioeconomic variables, it is especially important that modellers 1) use the data provided on the IAM COMPACT SharePoint to ensure that up to date and correct data is being used; 2) use the same currency base year for GDP as provided in the data as far as possible; and 3) consult with CICERO before combining the provided GDP numbers with other data or other variables to ensure the PPP conversions are handled correctly, especially if different base years are involved. Details are elaborated at the end of this section.

4.3.1 Recommended harmonisation: Updated Shared Socioeconomic Pathways (2024)

GDP, population, and demographic variables such as age distributions and education levels should be harmonised the values in the Shared Socioeconomic Pathways (SSPs), in release 3.0.1 published in March 2024. If further updates are released before modelling starts in the 2nd modelling cycle, those updates may be used instead. At the time of writing, an extension that provides urbanisation rates is in final review. The final version of this extension should be used if it is released in time for the 2nd modelling cycle, otherwise the latest review version (review phase 3) may be used.

Numbers from SSP2 "Middle of the road" should be used by default, but in the planning of each study, it should be considered whether the research questions involve a narrative for which other SSP scenarios would be more appropriate. For example, in a study that explores the effects of a breakdown in global trade or increased levels of conflict, SSP3 might be a more consistent choice. It should still also be considered whether the individual study needs such an alternative demographic scenario strongly enough to outweigh the advantages of harmonisation across studies.

For GDP, the SSPs provide two different sets of projections for each pathway, one produced by the OECD (with the model identifier "OECD ENV-Growth 2023" in the Model column) and one produced by IIASA (named "IIASA GDP 2023" in the Model column). Only the OECD scenario should be used, both given that the OECD numbers were widely used as the default by users of the previous SSP release, and because the OECD also provide the historical GDP data.

An Excel file with data for each SSP scenario as well as historical reference (SSP release 3.0.1) is available to project participants in subfolder "Harmonisation data / GDP and population" under the D4.4 folder on the IAM COMPACT SharePoint. The data that should be used for harmonisation is found in the Excel file named "IAM COMPACT D4.4 GDP and demographics harmonisation data.xlsx", which has been modified relative to the original SSP data file by removing the IIASA GDP time series, and joining the historical data (the "Historical Reference" scenario from the original file) and the SSP2 scenario numbers into contiguous time series, identified as "IAM COMPACT D4.4" in the "Scenario" column. Other SSP trajectories are retained as they are, with their respective names in the "Scenario" column, and start in 2020, as in the original SSP file. Note that not all demographic variables are available in the "Historical Reference" data set, and the corresponding variables in the joined "IAM COMPACT D4.4" scenario therefore only have data from 2020

Due to licensing restrictions, the full dataset can not be reshared publicly, and is therefore not available on Zenodo. Readers without access to the IAM COMPACT SharePoint can view or download the data from IIASA's

SSP Scenario Explorer[5] by registering for a free account or logging in as a guest user. After logging in, go to the "Downloads" page[6] and choose the file "SSP basic drivers 3.0.1 full".

4.3.2 Caveat about currency base years and PPP weights

If the GDP numbers in the harmonised dataset are combined with other economic data from different sources, it is important to ensure that the numbers are in fact compatible and expressed in consistent units. In particular, modellers need to correctly handle differences in currency base years (or deflators in the case of quantities denominated in nominal rather than constant-price currency values) and to check that how they use the GDP numbers is consistent with the fact that the national GDP numbers are expressed in terms of purchasing power parity (PPP) rather than currency market exchange rates (MER).

If in doubt about how to use or adapt the harmonised GDP values consistently, modellers should contact the authors of this deliverable for guidance.

In the following we give some background for these caveats:

The GDP numbers in the harmonised dataset (SSP revision 3.0.1) are provided in terms of purchasing power parity (PPP), as the variable "GDP|PPP". The unit used is international dollars, with 2017 as the base year for the dollar value. In simplified terms, this means that for each country, the numbers seek to represent how many US dollars the economic output of that country would be worth using US price levels in 2017, rather than simply measuring the country's GDP using local currency in a given year and converting it to US dollars in the same year using currency-market exchange rates.

Since GDP PPP corrects for different price levels in different countries, it is a better measure for comparing economic activity within different countries than using market exchange rates, and therefore also more appropriate as a driver of emissions and for calculating emission and energy intensities. Further, since constant US market prices in 2017 are used as the basis for the calculation, the change from one year to the next should be a better reflection of real economic growth, which at least in principle corrects for both inflation/deflation and currency value fluctuations.

Other economic data from other sources may have been calculated using currency market exchange rates rather than purchasing power parity. If modelers combine the GDP PPP numbers with numbers for, e.g., energy or emission intensity, per-capita value-added or similar measures, it is therefore vital to check that that data indeed is expressed in purchasing power parity.

Less obviously, even if the data from other sources is compatible with using GDP PPP, modelers should be aware that those sources may have used other PPP values. Adjusting for different price levels in different countries is inherently complex, and different sources may therefore report significantly different values for GDP PPP and derived figures.

The risk of inconsistent PPP values is made greater if data with a different currency base year than 2021 are used. In principle, to convert GDP PPP from 2017 international dollars to dollar values for some other year, one can simply multiply by the relative deflator for the US dollar in the target year relative to 2021, since GDP PPP expresses the purchasing power of a country's GDP in the United States. However, if a different data source uses GDP PPP values with a different currency base year than 2017, it is a strong hint that it uses a different set of PPP weights from the one used in the harmonised data set (i.e., in the 2024 SSPs). This further means that the other source most likely has somewhat different real GDP values from the harmonised data, and that the difference will vary by country and potentially by year.

[5] https://data.ece.iiasa.ac.at/ssp/
[6] https://data.ece.iiasa.ac.at/ssp/#/downloads

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4.3.3 Rationale for change in socioeconomic harmonisation data

The recommendation to use updated SSPs is a significant change from the recommendation D4.3 and the first modelling cycle. There, a custom-made merged dataset from several sources was used. The reason was that the most recent version of the SSPs at the time was from 2018, with most numbers having been produced prior to 2013, and therefore significantly out of date. In particular, they did not reflect changes in projections for both global population and differences in regional population changes, nor changed economic prospects in the previous decade. At the time of writing in 2023, real historical population numbers had already grown significantly faster than all SSPs, and historical GDP values were significantly lower than all SSPs even after correcting for the COVID19 pandemic.

Unfortunately, no more recent scenario projections were available that included both GDP and population at both global and regional/national levels, with both historical data and projections through the end of the 21st century. A merged dataset for historical and future GDP and populations was therefore created by using more up to date population projections from EuroStat, the OECD and the U.N., and GDP data and projections from the IMF, OECD, the EU Ageing Report, and extensions with SSP2 growth rates from the previous SSP release (2.0) where no other sources had data.

See chapter 3.4 of D4.3 for further discussion of the shortcomings of the previous SSPs, and a detailed description of the merged socioeconomic dataset that was made for the 1st modelling cycle.

With the version 3 release in 2024, the SSPs are now equally or more up to date than the sources used for the custom data set in D4.3. Given that the SSPs are designed to be based on internally consistent assumptions and coherent narratives for future pathways, they also avoid the main pitfalls of the D4.3 dataset, and are therefore a much more appropriate choice for harmonisation in the second modelling cycle.

See Figure 1 for a comparison of total population and GDP PPP from the previous and updated SSP2, the custom dataset from D4.3, and historical data; and Figure 2 for a comparison of global and EU27 population projections in old and new SSPs. A description of the most important differences is given in the caption.

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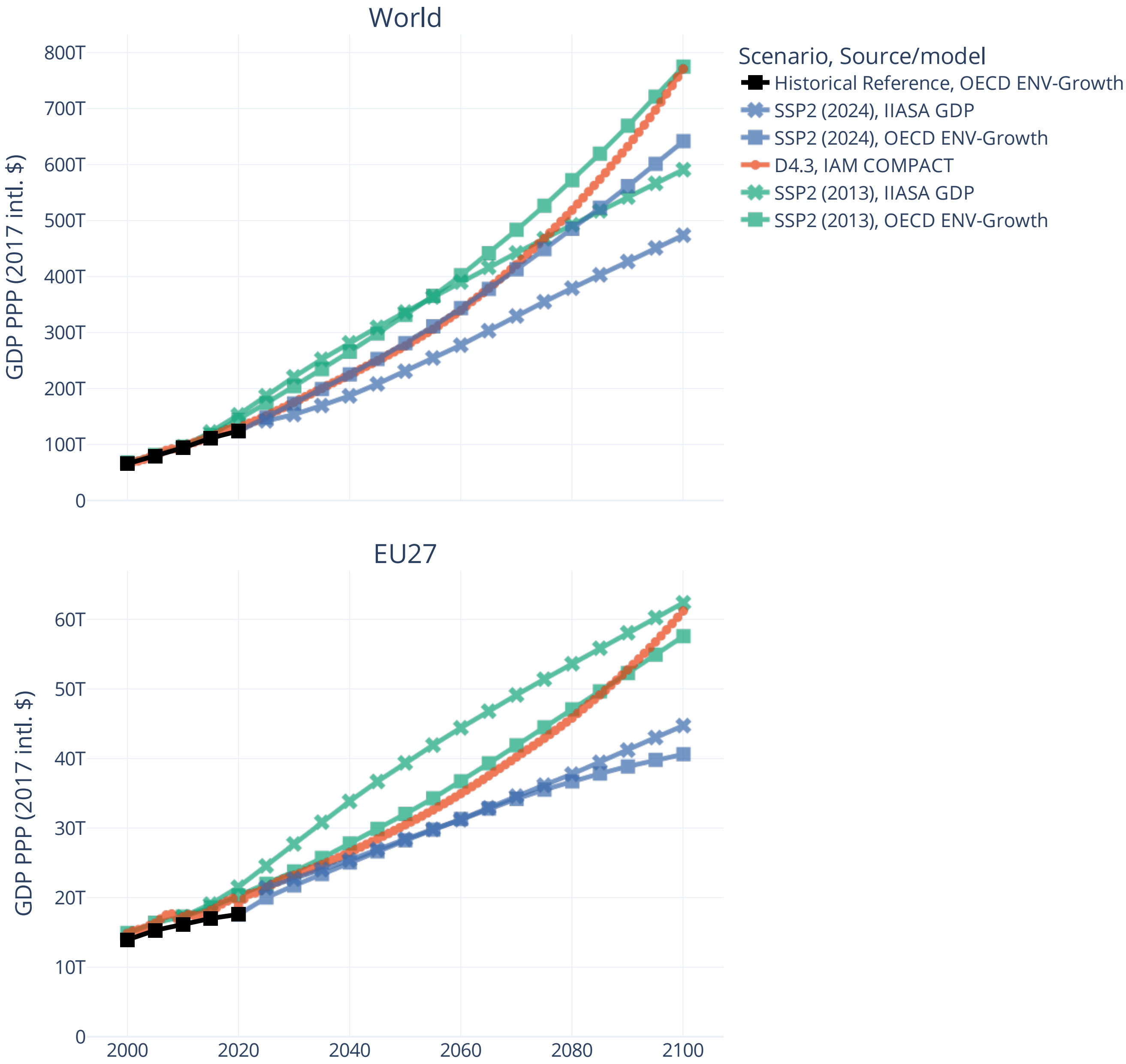

Figure 1: Comparison of GDP (global and EU27) for old (2013) and updated (2024) SSPs, and harmonisation data used in D4.3 and the 1st modelling cycle. Note that SSP 2013 GDP PPP figures are originally in 2005 international dollars, and have been scaled to 2017 international dollars. The recommendation for the 2nd modelling cycle is to use GDP numbers from SSP2, from the OECD ENV-Growth model (see rationale in the body text), along with the Historical Reference data from the same source. The D4.3 data used IMF and OECD projections for as long as they were available, and is therefore initially similar to the updated SSP2. However, it diverges towards the end of the century because it extended these projections with per-capita growth rates from the old SSP2 scenario multiplied by population numbers from UN projections (UN 2022 World Population Prospects).

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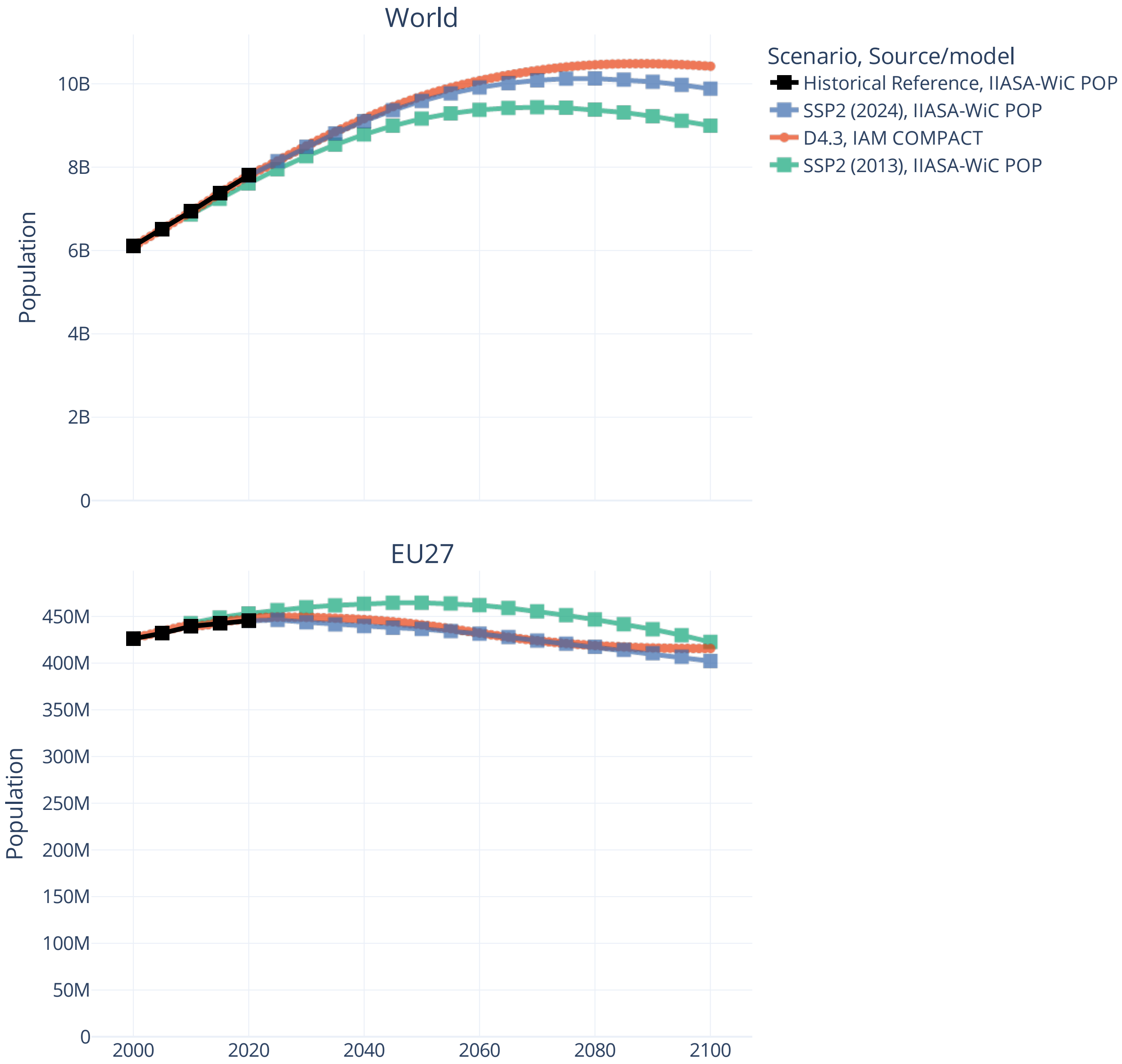

Figure 2: Comparison of global and EU27 population projections in old and new SSPs, and in the harmonised data from D4.3 and the 1st modelling cycle. The recommendation for the 2nd modelling cycle is to use population numbers from SSP2 combined with the SSP Historical Reference data.

4.4 Energy consumption and electricity generation

Recommendations for harmonised energy consumption and electricity generation data are unchanged from D4.3, except for updating the recommended data to the latest available version. We still recommend using the World Energy Balances dataset from the International Energy Agency (IEA) for harmonised historical energy data, but

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updated to the latest version, the release of July 2024(International Energy Agency, 2023c).[7]

The full data of the World Energy balances still require a paid license and cannot be reshared in any way in any relevant form. It is therefore not made available on the IAM COMPACT SharePoint and must be downloaded from the IEA website by each modelling group using a login with a valid license.

A more limited free version of the IEA World Energy Balances is available, the "World Energy Balances Highlights"(International Energy Agency, 2023d). This data set disaggregates fewer products, flows and individual countries than the full dataset, but may be sufficient for calibration purposes and for models that do not have a very high geographical or sectoral resolution of the energy system.

It was considered whether the recommendation from D4.3 should be changed and instead recommend using energy statistics from the United Nations Statistics Division(United Nations Statistics), which can be accessed for free when using its API or if downloading individual time series from their web portal (obtaining the full database as a file, and data from before 1990, requires a paid license). However, that data set has a more limited resolution of industry sectors than the IEA data, is not currently used by as many modelling groups in the IAM COMPACT project and requires using an SDMX API which might be more challenging than exporting CSV or Excel data from IEA's interfaces. The decision was therefore made to continue with the IEA data. The IEA data also has the advantage of providing a consistent greenhouse gas emissions data set, as well as being consistent with fossil fuel CO_2 emissions in the EDGAR emissions database (see section 4.5).

4.5 Emissions

The recommended harmonised data for GHG emissions are unchanged from D4.3, except that updated data from each source should be used where available (details below). Please see D4.3 section 3.7 for detailed specifications and rationale for the choice of data sources.

Only historical data is recommended for harmonisation. As in D4.3, it is assumed that future emissions are modelled endogenously and are an output of each modelling study.

In summary, the recommended historical harmonisation data are as follows:

- **CO_2, CH_4, and N_2O from energy:** IEA "Greenhouse gas emissions from fuel combustion" dataset, or IEA "IPCC fuel combustion emissions (2006 guidelines)" for studies that require a split between IPPU and energy emissions that is compliant with 2006 IPCC guidelines, 2023b)
- **All gases from industrial process and product use (IPPU)**: EDGAR v8(Joint Research Centre, 2023)
    - **CO_2 emissions from cement production**, for studies that require an extra accurate treatment of cement/clinker production and emission factors: (Andrew, 2018, 2019)
- **CO_2 from land use change:** Global Carbon Budget 2023 (Friedlingstein et al., 2023)
- **Other greenhouse gases:** EDGAR v8

All data sets are available on the IAM COMPACT SharePoint, apart from the IEA data due to licensing restrictions.

NB! For CO_2 emissions from land use change, D4.3 did not recommend a single harmonised data set, due to the high uncertainties in LUC activity data and emissions estimates, and the large differences in how the land-use sector is treated (if at all) between different models. Instead, it was recommended that all models should check that the historical data used for calibration falls within the ranges spanned by the three bookkeeping models used for the LUC CO2 emissions in the Global Carbon Budget. This recommendation still stands, and discussions with

[7] At the time of the writing this deliverable, the latest available version was April 2024 for IEA members and associated countries, and July 2023 for the rest of the world. However, the next version, July 2024, is expected to be released shortly after submission of the final version of this deliverable, and before the start of modelling work in the second modelling cycle.

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modelling groups in the year since D4.3 was written has further confirmed that it would not be feasible within the scope of the IAM COMPACT project to further harmonise the calibration data that the various models use for the land-use sector.

4.5.1 Updated emissions data

The following data sets are the same as recommended in deliverable D4.3, but should be updated to the most recent version:

- **EDGAR (for IPPU emissions and gases other than CO_2, CH_4 and N_2O)**: Should be updated to version 8 as far as possible but see note under section 4.5.2. Version 7 was recommended in D4.3.
- **IEA greenhouse gas emissions data**: Should be updated to the version of July 2024.[8]
- **Global Carbon Budget (CO_2 emissions from land use change)**: Should be updated to the 2023 version, if possible, but see note under section 4.5.2. The recommendation in D4.3 was based on the 2022 version.

All the updated datasets except IEA data are available on the IAM COMPACT SharePoint.

4.5.2 Continued use of old data to avoid recalibrations

We recommend updating the harmonisation data sets as written above if possible, but recognize that this in some cases can be challenging, due to the large amount of work that can be required to change calibration data in some models.

For harmonisation to be useful, each model involved in a given study should agree on which data sources to update and in which cases they should continue to use the data recommended in D4.3. This will need to be agreed before modelling work starts in the 2nd modelling cycle. The work required to prepare new inputs and to recalibrate needs to be considered against the value of using data sets with one extra year of historical data and that more closely reflects recent revisions of past years.

For studies that model the dynamics during and immediately after the COVID19 pandemic and models that resolve those years, using the latest data sets can be particularly important, given that the data sets in D4.3 had very little data that reflected the developments after the end of the pandemic, so that even one year of extra data can be highly significant. If this is not the case, having one extra year of data may be less important, but the new data sets still contain revisions of past data that may be significant.

The following updates warrant particular attention:

- **EDGAR version 8:** The update from version 7 to 8 has made relatively large revisions to past years for IPPU CO2 emissions (sector codes starting with 2 and 3). For years prior to and including 2012, global IPPU emissions have been revised down by 9–10 percent in most years. For some smaller subsectors the change can be more than 60 percent. In most years after 2012, IPPU emissions have been revise down around 3 percent. For models that rely on historical IPPU emissions in their calibration, it is therefore imperative to update to the new data, unless it is agreed that the modelling study as a whole should continue to use EDGAR version 7. The changes in the energy sectors are much smaller, at only a fraction of a percent. Because of the smaller size of the IPPU sector, total CO2 emissions have been revised down by only on the order of 1-2 percent, but the relative changes can still be large for some smaller countries.
- **Global Carbon Budget, land use change CO_2 emissions:** Some of the bookkeeping models used for CO2 emissions from land use change in the 2023 version of the Global Carbon Budget underwent significant methodological changes relative to 2022. If the data used in studies is updated from the 2022 version to the 2023 version, all historical calibration will therefore have to be redone, it is not enough to

[8] As for IEA energy data, the 2024 version was not yet available at the time this deliverable was written, but is expected to be available close to the end of July.

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just add the last year. The updated numbers are of course believed to be more accurate, but given the continued uncertainty and wide range of estimates in the literature and the significant work that is often involved in calibrating the land use sector in many models, the modelers involved in each study should discuss carefully whether it is worthwhile to make the update in the 2nd modelling cycle.

4.5.3 Free alternatives to IEA emissions data

For groups that do not have a license for IEA emissions data for greenhouse gas emissions from energy consumption (combustion), there are some alternatives that are consistent with the IEA emissions data, although they are very limited in terms of resolution.

If relatively low sectoral resolution and no resolution of different fuel types is acceptable, the energy-related CO2 emissions from EDGAR can be used. The energy-related CO_2 emissions in EDGAR's dataset is made in collaboration with the IEA and consistent with IEA's energy data and can therefore be used in place of IEA emissions data without introducing any inconsistencies. However, care must be taken that the split between energy and IPPU emissions is handled consistently. See chapter 3.7.1 in D4.3 for a detailed discussion of this issue. Fortunately, EDGAR provides data using both the 1996 and the 2006 IPCC guidelines. The former can be used as a replacement for IEA's main dataset "Greenhouse gas emissions from fuel combustion', while the latter can be used in place of IEA's "IPCC fuel combustion emissions (2006 guidelines)".

If somewhat greater resolution of sectors and/or a minimal resolution of fuel types is required, but high precision is not, another alternative is to use energy data from the free "World Energy Balances Highlights" dataset from the IEA (see section 4.4) and manually apply tier-1 emission factors from the IPCC guidelines. Since the free energy balances group all solid fossil fuels together, and do not resolve different types of petroleum products, this will not be very precise, and suitable average emission factors will need to be chosen. If any groups need to make use of this alternative, CICERO can give guidance on how best to proceed.

4.5.4 Emission factors

D4.3 specified that emission factors from the 2006 IPCC Guidelines for national greenhouse gas inventories should be used when explicit emission factors were required but did not provide these factors directly. To spare modelers the need to obtain these models themselves and to remove any ambiguity about what source to use, an Excel file has now been made available on the IAM COMPACT SharePoint with all the emission factors from the 2006 guidelines and the refinements to the guidelines released in 2019.

The Excel file was downloaded from the IPCC Emission Factor Database (EFDB)(IPCC, 2022), by selecting "IPCC Guidelines" as the "Source of data" on the EFDB "Basic search" page, downloading the results as an Excel file, and selecting the rows with "Type of parameter" equal to either "2006 IPCC default" or "2019 refinement default".

The resulting file contains a high level of detail, with 9109 different factors. This includes not just emission factors, but also heating values, oxidation fractions and some other parameters that are useful for calculating emissions in various circumstances. Since we cannot predict with certainty what factors will be needed, we provide the full database without further filtering beyond selecting the factors from the 2006 IPCC guidelines and 2019 refinement.

In order to find the relevant emission factors, the following procedure can be used:

1. Select the desired gas using the filters on the column "Gas".
2. Select the most specific sector desired in the filters on the column "IPCC 2006 Source/Sink Category". If simply seeking a default factor for combustion of a certain fuel, simply select "1.A - Fuel Combustion Activities".
3. Select the desired fuel by filtering the column "Fuel 2006", and then try to find a factor with an appropriate description in the filters for the column "Description". Note that for some sectors, the "Fuel 2006" column is blank if the fuel or material is unambiguous (e.g., for some waste sectors). Also note that if you do not find the required factor in the "Description" column or the required fuel type, you may need to try selecting a less specific sector in the "IPCC 2006 Source/Sink Category" column. It can sometimes be unpredictable

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at what level(s) certain factors are specified, so some trial and error may be needed to find the right factors.

4. If needed, narrow down the factor values further by filtering on other columns, such as "Region / Regional Conditions" for region-specific factors, "Technologies / Practices" for different technologies, vehicle types, etc., or "C pool", "Abatement / Control Technologies", or "Other properties".

4.6 Technological factors and energy prices

4.6.1 Background

Technology costs, technological performance and energy prices are important factors for determining the electricity mix, energy mix and choice of end-use technologies in the model which in turn heavily affect emissions and potentially several other modelled aspects of the economy. In economy-energy models, it is assumed that agents make decisions about technology to minimize the total system cost. As highlighted in Fuhrman et al. (2024), it is important for the deep decarbonisation scenarios to more explicit represent the complete range of mitigation policy and technology in different sectors. The assumed or modelled future evolution of technology parameters and energy prices of course affects the corresponding evolution of the energy mix, technology mix and emissions. Given the impact on model results, it would be highly desirable to harmonise the data used for historical & current technology costs, technology performance and energy prices, and where relevant also assumptions about future evolution.

4.6.2 Technology costs

For future technology costs and energy prices, the most appropriate choices of specific values may depend on the exact research questions, even for a reference scenario. Furthermore, model requirements such as formats and technology category breakdowns need to be clarified further with modellers in IAM COMPACT before any decisions can be taken on whether and how to construct a harmonised "default" set of technology prices.

For these reasons, we defer making final specifications for how to harmonise technology costs, but outline some tentative options:

1. **For EU-specific modelling exercises that require a "neutral" technology scenario, the most suitable option is likely to be the European Commission's EU Reference Scenario 2020 (European Commission et al., 2021)**[15] as specified in the D4.3.
2. **For global modelling exercises that require a neutral scenario (or regional ones where the regional models do not already use a region-specific dataset), some options are:**
    a. **Cost assumptions from IEA's power generation technology costs dataset (International Energy Agency, 2023a).** This dataset contains regional breakdowns through 2050 and excel file is available on the IAM COMPACT shared folder. Note that cost assumptions in for Europe for some technologies differ significantly from comparable technologies in the EU Reference Scenario as IEA dataset is more updated compared to EU reference scenario that was released in 2021, so consistency could be an issue if the EU Reference Scenario is used for Europe along with costs from the IEA WEO for other regions. For global assessment, it would be recommended to use one data source for the technology cost projections.
    b. **Technology cost assumptions for other technologies:** Technology cost assumptions from the TIAM database, which were recommended for harmonisation in PARIS REINFORCE(Giarola et al., 2021) (although not all models there could harmonise technology costs)
3. **Attempt to adapt the technology costs from the EU Reference Scenario to the regions in question, taking into account regional differences in capital costs, labour costs, etc.** This would

require a great deal of expertise and effort to do correctly and would most likely be appropriate only in exercises where the EU Reference Scenario must be used for the EU and it is imperative that the cost assumptions for other regions be consistent.

Regardless of which data are chosen, it is possible that not all models will be able to use the selected costs directly. If so, the models in question should try to modify their technology costs to fit the harmonised data to the best approximation possible. Models that use cost data to model energy technology deployment should check consistency with other parts of the harmonised data set where appropriate, for example the harmonised data for historical energy use (IEA energy balances).

In the weeks after this deliverable has been submitted, choice of technology costs must be discussed between modellers and research question leaders where relevant in the context of each research question. CICERO should be involved in any cases where modellers identify a need for a set of general reference costs not tied to the specific research question. Further details will be summarised in D4.4.

4.6.3 Other technological parameters

Apart from the cost of a technology, performance-related parameters can greatly affect the uptake and impact of a technology. This includes (but is by no means limited to) lifetime of all forms of infrastructure and equipment, construction times for infrastructure and large installations, capacity factors for power generation technologies, weighted average cost of capital, thermal efficiency for thermal generators and heat engines, etc.

A full harmonisation would probably not be possible due to differences in how different technologies are represented in different models, differing levels of detail, different categorisation of technology types, etc. What if any level of harmonisation is appropriate will also vary considerably by research question. In the case of research questions that investigate the impact of particular technological innovations or other prescribed technological pathways, it may be necessary to harmonise all technological assumptions as much as possible in order to make model results comparable. In other cases, different technological assumptions may be a desirable part of model diversity, and harmonisation should be kept to a minimum. In both cases, the appropriate choice of which parameters one should attempt to harmonise and how will depend on the specific research question.

1. **If harmonisation of non-cost parameters is attempted, it is important to ensure that the harmonised parameters as far as possible are consistent with technology cost assumptions. Both the EU Reference Scenario 2020 and the IEA World Energy Outlook dataset contain a selection of energy technology performance parameters in addition to just cost (see subsection 3.5.2). If either of these sources are used to harmonise technology costs, it would therefore be advisable to harmonise on non-cost parameters from the same sources as well.**

It is possible that a need for a cross-cutting technological scenario or a small set of common scenarios may arise as the research questions and the approach taken to address each of them are finalised. If so, this will emerge from RQ-specific discussions to take place in May and June 2023. Any such developments will be reported in D4.4.

4.6.4 Energy prices

By energy prices, we here refer to the price of crude oil, natural gas, coal and electricity. For historical values, there is a high degree of convergence in the data sources used by different models, but there is some variation.

Practically all models that use energy prices (including oil, coal, natural gas and electricity prices) use prices from IEA data. The only exceptions are ATOM and DREEM, which use prices from the World Bank, China-MAPLE and IMACLIM-China, which use prices from NBS (the China Statistical Yearbooks), GCAM-USA, which uses prices from the EIA SEDS, and MENA-EDS and PROMETHEUS, which supplement IEA prices with data from Enerdata and Eurostat.

For models that already do or can use IEA data and have or can acquire a license for detailed energy price data and projections from the IEA, **we will therefore tentatively recommend using historical energy prices from IEA data sets** (International Energy Agency, 2023c)**. For research questions that require harmonising future energy prices but without dictating specific price trajectories, we also recommend using long-term energy price projections from the IEA World Energy Outlook 2023 whenever they are appropriate for the research question at hand (IEA, 2023). For long-term or EU-specific exercises where near-term trends are not important, fossil fuel price projections from the EU Reference Scenario 2020(De Vita et al., 2021) may also be an appropriate choice.**

A challenge for using IEA data is that detailed energy price data at country level and detailed projections from the World Energy Outlook require a paid subscription. For modellers that do not have or wish to purchase a subscription but still require energy prices as input, coarse price levels can be extracted graphically from charts in the World Energy Outlook report, which is available for free(IEA, 2023). If obtaining price data that way is not precise enough or if the regional breakdowns provided in the WEO report are not appropriate, the affected models could continue to use their current preferred data sources but would then need to check that they are broadly consistent with the data and projections in the World Energy Outlook.

Alternatively, for historical prices and fossil fuels only, the World Bank provides certain price benchmarks for free as part of their commodity price data the so-called "Pink Sheet" (World Bank, 2023). This data set contains three benchmarks for crude oil (Brent, Dubai and WTI) and an average, three benchmarks for natural gas (US/Henry Hub, Europe/Netherlands TTF, and Japan LNG import prices) plus an averaged global index, and two for internationally traded coal (Australia and South Africa F.O.B. export prices). The numbers are available both on a monthly and annual basis.

If these or other alternatives to IEA energy price data are used, the affected modellers and research question leaders need to determine to what extent the lack of exact harmonisation of energy prices is a problem, and if so whether it is possible to post-process the outputs in some way to mitigate the issue, or whether the energy price parameters used by the model can be calibrated in some way to give results that are likely to be consistent with the IEA energy prices.

Several models do not take energy prices as an endogenous input or do not represent it at all. In these cases, each modelling group must consider whether energy prices indirectly affect the results of their model in some way that is relevant in the context of the given research question. If the answer is yes, they should assess whether the assumptions made in the model are consistent with the harmonised energy prices, and if not make reasonable effort to adjust the relevant assumptions in their model. What level of effort is reasonable will necessarily depend on the research question and how the interpretation of the results are affected by diverging energy price assumptions, and must ultimately be decided collaboratively by the research question leader and the modellers.

4.7 Policies and targets

As highlighted in Sognnaes et al. (2021), explicitly representing the policies in the model provides a better representation of the current energy system transition dynamics compared to an economy-wide carbon price, which exaggerates the use of carbon capture and storage. To provide the current policies information to the modelling teams for harmonisation, a current policies database was created for each country and/or region in the 1st PRM cycle (see D4.5 for details). The combined policy database included 280 national policies such as such as the European cap and trade system for CO2 emissions, the share of renewables, or carbon tax, efficiency standard, capacity deployment target. We have updated the policies database for the studies to be conducted as part of the second cycle of the policy response mechanism.

The updated policy database now includes recent policies/targets for reducing emissions in different sectors(de Ven et al., 2024). We have also updated policy/target values if countries have strengthened their policies/targets. The updated policy database includes total 333 national and regional policies/ targets. Several new targets and policies are in place to support the deployment of hydrogen-based vehicles and the expansion of hydrogen

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production capacity. Based on the sector and regional granularity, the modelling teams will represent these policies in their models to develop a benchmark/baseline scenarios for comparison.

In addition to the policy database, we also compiled a database to gather data in a readable format on the nationally determined emission reduction targets and long-term targets announced by each country in the first policy response mechanism cycle(Mittal & de Ven, 2024). Eights countries have updated or submitted their first long-term strategies in the last 10 months to UNFCCC. These revised or new targets are included in the updated emission target database. Some countries announced their NDC target in terms of % reduction from its baseline emission and others in terms of % reduction from the reference year. A total of 75 countries have committed to reaching net zero before or by the year 2050 (see the figure 3). Additionally, 9 other countries have announced their long-term targets in terms of percentage reduction from their baseline value or percentage reduction from the reference year.

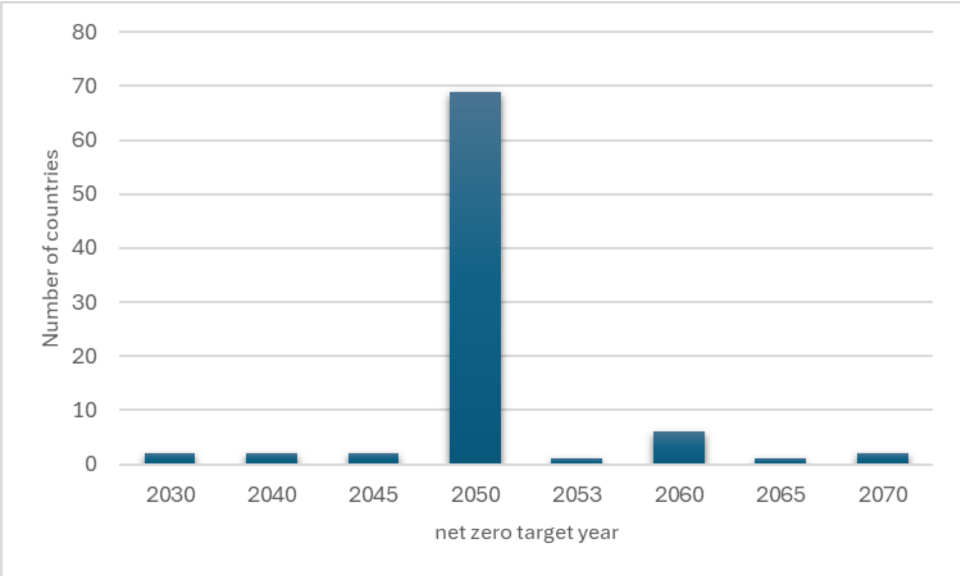

Figure 3 Number of countries announced net zero emission target(it includes both GHG or CO2 net zero emission targets, please see the database for further details)

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5 Modelling output formats and reporting requirements

This chapter provides updates and clarifications to D4.3 for how model results should be reported. Section 5.1 provides additional guidance for the IAMC format used to report model results, and stresses important points to keep in mind based on common mistakes in the 1st modelling cycle. Section 5.2 specifies how to use the validation and vetting procedures that have been developed after D4.3, respectively for checking variable/region names, and for checking the results themselves against the vetting checks in IPCC AR6 and selected parts of the harmonisation data. Finally, Section 5.3 specifies how use of harmonisation data and any deviations from it should be reported, both for each modelling study as a whole and for each individual model.

5.1 Output format for modelling results

As specified in D4.3, model output should be reported in Excel files following IAMC format conventions. To avoid common mistakes, we here specify in somewhat more detail what the format requires:

- The Excel file should contain all data on a single worksheet, named "data".
    - Data for different scenarios, different models or other groupings should not be on separate worksheets, as this will cause an error or not be recognized by many common tools for reading the IAMC format. Instead use appropriate values in the "Scenario" or "Model" column for this purpose, or split the data into more than one file if necessary.
    - The file can contain metadata, instructions or any other free-form content on separate worksheets, as long as they are not called "data" or "Data", and all actual model result data is on the "data" worksheet.
- The "data" worksheet must have headers on row 1, start in column A, and contain no gaps or rows that must be skipped to read the data
- The "data" worksheet must have model, scenario, region, variable and unit names as in shown in Table 2. Each column to the right of those should have a year in the header and contain all data for that year in the same column.
    - The years shown in Table 2 are examples, each modelling study should decide which years are required to be reported.
- Each year column must contain only numerical data, no blank text strings, "N/A", "…" or other text strings sometimes used to indicate missing numbers. The format is not designed to differentiate different types of missing data.
- If sub-annual time resolution is required (e.g., months, seasons, etc.), an extra column titled "Subannual" can be added, which denotes which part of each year a given row represents. The columns to the right should still represent one year each. For example, for a model with monthly resolution, the "Subannual" column would contain either month names or integer numbers 1–12 (to be agreed internally in each study), and the year columns on each row would then contain values for a given month in each year (i.e., one row for January in each year, one row for February in each year, etc.).
- The "Region" column should include the internal names that the model uses for regions larger than a single country, **and** include a global region called "World" if possible. If the model reports numbers for individual countries, the country names specified in the iamcompact-nomenclature repository (Korsbakken, 2024). The country names to use are the ones after each dash, directly below the "countries" in the yaml file under /iamcompact-nomenclature/data/definitions/region/countries.yaml. Each entry also contains the 2- and 3-letter ISO codes for each country, which can be used for searching.

Table 2: Mandatory columns in the "data" worksheet of an IAMC-formatted Excel file. The year columns are examples. Which range of years should be reported and what resolution to use should be agreed in each modelling study.

Model	Scenario	Region	Variable	Unit	2015	2020	…

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5.2 Validation of output format/variable names and vetting of results

The content of this section overlaps with content of the Milestone 7 report. For background and more detail on validation and vetting procedures, please see that report. This section only provides practical information, some of which was not included in Milestone 7.

Before submitting model results, modelers should use a validation tool to check variable and region names used in the results file against the repository "iamcompact-nomenclature" of common variable and region names used in IAM COMPACT (Korsbakken, 2024). A prototype of this tool can be found at https://validation.i2am-paris.eu/, but is under continual development and will be moved to a different location for final-stage testing and release. The iamcompact-nomenclature repository itself also contains a Python package that can be used for offline validation on the user's laptop.

After having validated the result output file(s), the results should be run through the iamcompact-vetting vetting tool, which both checks the results against the criteria that were used to vet scenarios submitted to the scenario database used by Working Group III in the IPCC's 6th Assessment Report, and gives feedback on whether the data in the result files are consistent with the recommended harmonisation data for population, GDP and historical emissions at a coarse sectoral level.

Modelers should check the subfolder "Validation and vetting" under the D4.4 folder on the IAM COMPACT SharePoint for updated instructions and links to the most current tools, as well as guidance on variable naming conventions.

5.3 Requirements for reporting choice of harmonisation data

Each study should report what common harmonisation data was chosen for the study for each of the categories listed in Table 1, and each modelling should additionally report what data was actually used by their model. This includes data used for calibration and for any type of input to the model. This should be done to ensure that later comparisons or other analyses can easily know about differences in inputs between the different studies and models and keep track of any variations or deviations from the data listed in this deliverable.

Each study should make a copy of an Excel template found in the subfolder "Study harmonisation reports" under "Harmonisation data" in the D4.4 folder on the IAM COMPACT project SharePoint.[9] The completed file should be stored in the same folder. The file contains one model-specific worksheet that should be copied and completed for each model in the study, and one common worksheet that should be completed once for the study as a whole.

Any questions about how to use or complete the template should be directed to the Responsible Author of this deliverable.

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[9] Link to the folder (can only be used by project users with access to the IAM COMPACT SharePoint): https://epuntuagr.sharepoint.com/:f:/r/sites/iamcompact/Shared%20Documents/General/2-Deliverables%20and%20Milestones/WP4%20(Modelling%20%E2%80%93%20Quantitative%20evidence%20in%20support%20of%20post-2030%20Paris-compliant%20climate%20action)/D4.4%20Broad%20scenario%20logic%20-%20Update/Harmonisation%20data/Study%20harmonisation%20reports?csf=1&web=1&e=zx1gKb

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