IAM COMPACT

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

D4.3 - Broad scenario logic

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

26/05/2023

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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 for all modelling work taking place to address research questions in the first modelling cycle of IAM COMPACT. It, furthermore, points forward to further work on harmonisation and management of model inputs and outputs that will be undertaken during 2023 and early 2024. It also describes the role of a broad scenario logic and harmonisation of assumptions and input data in general and can thus be useful for other projects that will investigate a similarly diverse set of research questions or employ a similarly diverse set of models as IAM COMPACT.

3. Short summary of results (<250 words)

This report provides the first iteration of a broad scenario logic for the IAM COMPACT project. A broad scenario logic is a narrative and/or a set of assumptions and specifications that serve as a common basis for a number of different modelling exercises that in turn address a collection of different research questions. It serves as a default background, which is then complemented and potentially overridden by more specific and detailed scenario protocols for each modelling exercise. In IAM COMPACT the set of research questions is highly diverse, without a common thread across the whole project. This report, therefore, does not contain a background narrative but focuses on harmonising assumptions and input data that are likely to be relatively independent of specific research questions and can serve as common defaults across most modelling exercises. It also briefly outlines how input data will be shared and gives guidelines for model output formats. Because the definition of the concrete modelling approaches to be used to address the individual research questions follow the submission of this deliverable, this report is only a first iteration and maps out questions that need to be settled through more detailed discussions with modelling teams at the beginning of the first IAM COMPACT modelling cycle. A more complete update will be given in D4.4, at the transition from the first to the second modelling cycle (July 2024).

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	EPU N·T·U·A
Aalto – Aalto Korkeakoulusaatio SR	FI	A! Aalto University
AAU – Aalborg Universitet	DK	
BC3 – Asociacion BC3 Basque Centre for Climate Change – Klima Aldaketa Ikergai	ES	bc3 BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai
Bruegel – Bruegel AISBL	BE	bruegel
CARTIF – Fundacion CARTIF	ES	CARTIF
CICERO – Cicero Senter for Klimaforskning Stiftelse	NO	°CICERO
E3M – E3-Modelling AE	EL	E3Modelling Energy Economy Environment
KTH – Kungliga Tekniska Hoegskolan	SE	KTH
POLIMI – Politecnico di Milano	IT	POLITECNICO MILANO 1863
UPRC – University of Piraeus Research Center	EL	TEESlab Technoeconomics of Energy Systems
UVa – Universidad De Valladolid	ES	Universidad de Valladolid
WI – Wuppertal Institut fur Klima, Umwelt, Energie GGMBH	DE	Wuppertal Institut
IIMA – Indian Institute of Management	IN	IIM Ahmedabad
THU – Tsinghua University	CN	
USMF – University System of Maryland	US	
AAiT – Addis Ababa University	ET	
KEI – International Civic Organisation Kyiv Economics Institute	UA	KSE Kyiv School of Economics
RUSL – Raja Rata University of Sri Lanka	LK	
TUM – Technical University of Mombasa	KE	
UNIGE – Université de Genève	CH	UNIVERSITÉ DE GENÈVE
Imperial – Imperial College of Science, Technology and Medicine	UK	Imperial College London

Executive Summary

A broad scenario logic is a partial scenario description that can serve as a default background for a range of different research questions and corresponding modelling exercises and model scenarios used to address those research questions. Each model exercise will then supplement the broad scenario logic with a specific and more complete scenario protocol, and, if necessary, override parts of the broad scenario logic where appropriate for addressing the given research question. The broad scenario logic should contain assumptions and specifications for harmonised input data that are relatively independent of specific research questions and that can be used as common defaults across most modelling exercises.

Harmonised assumptions and input data are important as a common starting point and to ensure that variations in results between different models are due to intended variability between models that helps to map uncertainty and inform the research question, and not due to differences in assumptions that should be shared and are not relevant to the research question (which can include, e.g., differing population or GDP trajectories, or calibrating to different historical datasets for emissions or energy use). At the same time, it is often important not to harmonise parameters that should be allowed to vary to reflect model diversity or genuine uncertainty about appropriate parameter values. Specific research questions may also need to vary or deviate from harmonised parameter values in order to assess uncertainty or to represent variations that are key to addressing the research question.

The modelling in IAM COMPACT is driven by a wide array of research questions that emerge from stakeholder interactions and does not have a pre-determined narrative or thread running across all research questions. The broad scenario logic in this report, therefore, does not contain an overarching scenario narrative, but instead focuses on providing a set of default assumptions and harmonised input data that are likely to be appropriate for most modelling tasks and research questions. The report also gives preliminary specifications for how input data will be shared and how model outputs should be reported.

Some aspects that may be possible to harmonise across research questions or can be used for common reference scenarios may, nevertheless, require research question-specific considerations before suitable choices can be made. The list of research questions will be finalised as an immediate next step, including settling the modelling approach to each of these questions. Further discussions with modellers were still needed to settle a range of detailed questions such mapping differing sector boundaries, energy and emissions categories between models and input data, specific per-model requirements for detailed socioeconomic and technology parameters, etc. This report, therefore, defers decisions in a number of areas but provides an overview of what harmonisation questions need to be settled at the beginning of the first IAM COMPACT modelling cycle. The results of this continuing work will be reported in D4.4.

The current iteration of the broad scenario logic in this report provides specifications for harmonised input data for population and GDP, both historical values and reference values for future scenarios. It also specifies harmonised input data for historical energy production/consumption and emissions, but not future values, as this will normally be too dependent on the specific research questions. Some options are also discussed regarding how to harmonise past and future assumptions for energy prices, technology costs, and performance parameters, but final decisions are deferred awaiting further dialogue with the modelling teams. Other, more detailed socio- and techno-economic parameters are also deferred.

The contents of this report should be used as one starting point for designing the modelling approach and specific scenario protocol for each research question. It should be used in conjunction with other deliverables that are complementary to this one, including D2.2 on the summary of stakeholder input and background to the research questions, D4.1 on guidance on representing policies in the modelling work, and D3.2 and D3.6 on guidelines on data management and open science protocols.

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1 Introduction

1.1 What is a broad scenario logic?

The **broad scenario logic** is the question-agnostic and default input assumptions and output requirements that are the background to specific modelling exercises.[1] In general, the logic may define a default socioeconomic narrative and socioeconomic data, the historical energy and emission data, reporting requirements, key reporting and validation criteria, in addition to methods for baseline and mitigation scenarios. A **specific modelling exercise** would supplement the broad scenario logic with specific methods of implementing a user-driven research question, and more specific assumptions that are not shared by most other modelling exercises and not covered in the broad scenario logic. A specific model exercise may also supersede some of the broad scenario logic depending on the research question by, for example, overwriting the socioeconomic narrative and input data. The broad scenario logic represents a common starting point for all models and will help with harmonisation, interlinkage, and intercomparison throughout the IAM COMPACT project.

An important consideration in a broad scenario logic is the level of harmonisation that is specified, i.e., to what extent various parameters and assumptions used by different models should be made identical or consistent with each other and to what extent they should be allowed to vary. For model linkages, harmonisation of parameters that are shared by linked models can be crucial. For model comparisons, the level of harmonisation might be relaxed depending on what dimensions are to be compared. Depending on the research question, harmonisation may not be relevant. Third parties may additionally harmonise the results, such as the emission scenario climate assessment pipeline used in the IPCC (Kikstra et al., 2022) or in model-intercomparison to determine what causes differences between results from different models (Sognnaes et al., 2021).

The broad scenario logic primarily focuses on enumerating parts of the scenario logic that are expected to be agnostic to the research question. Harmonising historical population, GDP, energy, and emissions data across model calibration can facilitate the analysis of model results by ensuring the starting points are the same, avoid the need for third-party harmonisation to perform activities such as climate assessments (Kikstra et al., 2022), and aid communication by avoiding the perceived uncertainty cause by a spread in results at a point in history (such as a model calibration year). There may also be a standardised set of future population and GDP assumptions, for example, based on 'current trends', that are common across models, unless superseded by a specific model exercise. The future energy and emissions data are usually a model output, although in some cases these variables may be pre-specified, either entirely or for certain years – for example for policy research questions that assume that countries meet their Nationally Determined Contributions in 2030, or their Long-Term Targets in 2050 or beyond, or if the research question involves finding optimal solutions for meeting specific energy demands or emission pathways.

1.2 Connections to other tasks and projects

There are some existing examples of scenario logic that we draw upon here. In the PARIS REINFORCE project, a harmonisation activity (Giarola et al., 2021) was used as the base for a model intercomparison (Sognnaes et al., 2021). Even with harmonisation efforts, it was still difficult for modellers to harmonise across energy and emissions data as each model had specific needs, for example in terms of their sectoral representation, or the range of technologies represented. Likewise, because of different model treatment of how technologies are represented (e.g., their costs and performance parameters), harmonising technology can also be challenging. Because of

[1] By "modelling exercise", we mean a series of activities, including actual model runs, undertaken to answer a specific set of questions or simulate a specific scenario or set of scenarios. It may involve just one model or a range of models, possibly run by different teams of modelers (the latter is the case in most modelling exercises in IAM COMPACT). The activities will typically include designing scenarios, followed by a detailed specification of how the models are to be run and what assumptions to use, as well as for what output must be produced.

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these model specific issues, we surveyed modellers in IAM COMPACT to learn what the preferences are for different modelling teams and what constraints their models have in terms of input data sets and calibration (see section 2.2.1).

This task has links to several other Work Packages and Tasks in IAM COMPACT, and this deliverable should be used by modellers in conjunction with other deliverables from those tasks. This includes D2.2 ("Scoping policy-relevant research questions"), D3.4 ("An outline of planned interlinkages among models, analyses and scenarios"), D4.1 ("From policy needs to scenario frameworks"), D3.2 ("Open data management plan") and D3.6 ("Open science protocols"). See section 2.2.2 for further description of these links.

Since the user-driven activities in IAM COMPACT are constantly evolving, this deliverable will have two versions. This version, D4.3 (due in late May 2023 / project month 9), provides a preliminary broad scenario logic. It is then later revised and made more specific in D4.4 (due in July 2024 / project month 23) after the integration of another round of user feedback.

1.3 Reading guide

In chapter 2 we describe what needs this deliverable is supposed to meet in the IAM COMPACT project, and how those needs have been mapped.

Chapter 3 is the main substantive part of this deliverable and contains specifications and recommendations for research question-independent assumptions that modellers should make, and what data should be used for harmonisation. That chapter should be used for reference in the modelling work in the project and can for the most part be read independently from the rest of the document.

The chapter 3 introduction along with subsections 3.1 and 3.2 provide background. Subsection 3.3 provides a summary of all the main recommendations in the chapter, and a table of all specifications for harmonised data sets (Table 1). Readers who are only looking for concrete specifications of harmonised data and references for that data do not need to read the following subsections. Subsections 3.4 through 3.7 provide thematically organised background discussions and rationales for the recommendations in subsection 3.3 / Table 1, as well as stating them in greater detail.

In section 4 we briefly describe how the broad scenario logic relates to specific research questions. The present deliverable does not have much content in this section, as the approach and specific scenarios for each research question have not yet been determined. Instead, it forms a basis for more content to come in D4.4 (July 2024), which is an update of this deliverable.

Finally, in section 5 we describe how the harmonised data and other relevant modelling inputs will be made available, and how models should make their output available. Modellers should read subsection 5.3 carefully, which contains specifications for how to report model outputs.

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2 Mapping the need for a scenario logic

2.1 Core components of a scenario logic

A scenario logic covers both a qualitative scenario narrative and specific assumptions, harmonised input data and modelling protocols that should be used to implement the scenario narrative in models. As discussed in section 1.1, the "broad" scenario logic in IAM COMPACT covers those parts of these elements that are largely independent of specific research questions and can serve as common defaults or baseline assumptions across most modelling exercises.

As stated in section 1.1, the narratives in IAM COMPACT are tied to the various research questions that emerge from the stakeholder dialogue. The project does not have a single overarching scenario narrative or set of narratives that would apply to the project as a whole. This deliverable therefore does not contain a concrete scenario narrative. Instead, it focuses on what assumptions and input data can be harmonised across most research questions, and on specifying what those harmonised assumptions and data should be.

In this section we discuss in general what components a scenario logic can contain, and in particular what types of assumptions and data can typically be chosen for harmonisation. In section 2.2 we summarise what elements of a typical scenario logic are required for the broad scenario logic in IAM COMPACT and describe the process by which input was gathered from the project consortium to arrive at those conclusions. In subsection 2.2.2, we also describe how this deliverable should be used by other tasks in the project.

2.1.1 Broad scenario logic vs research question-specific scenario protocols

The broad scenario logic covers assumptions and other elements that can be shared across most modelling exercises, independently of specific research questions. To investigate specific research questions and perform specific modelling exercises, the broad scenario logic must be supplemented with a specific scenario protocol that fully specifies all elements needed to run models and provide output that adequately addresses the research question.

The specific scenario protocol will typically prescribe specific scenarios to be modelled, which are tailored to the research question. The specific scenarios may be tied to their own narratives and will include assumptions and input parameters that are not covered by the broad scenario logic or not specified in sufficient detail.

Specific scenario protocols will typically require models to harmonise on a specific set of parameters, dictated by the research question. This set may be just a supplement to the harmonised parameters in the broad scenario logic, in which case the specific scenario protocol simply adopts all the specifications from the broad scenario logic. It may also require that some assumptions be different from those in the broad scenario logic, and thus override the broad scenario logic on some aspects. In exercises where assessing uncertainty is central, it may even give more room for model diversity by specifying a lesser degree of harmonisation for some parameters that are harmonised in the broad scenario logic. Perhaps more commonly, a research question may require exploring both sensitivity scenarios that deviate significantly from parts of the broad scenario logic, and a reference scenario that sticks more closely to it.

In all cases, the broad scenario logic serves as a background or a set of default recommendations, but it is not meant to be restrictive. The needs of specific research questions will override parts of the scenario logic, and in general take priority over it. The main case in which a broad scenario logic might nevertheless take priority is if there is a requirement to compare results across different research questions, such as a single project-wide research question that should be addressed along with multiple more detailed research questions. This is not the case in IAM COMPACT, and we therefore do not expect many cases in which the broad scenario logic should take priority over the needs of any individual research question.

2.1.2 Harmonisation of data and assumptions

The purpose of harmonised assumptions and data is to ensure that different models have a consistent starting point, to reduce the possible set of causes for differences between the results from each model.

A multi-model modelling study is often conducted to assess uncertainty or ranges of options by comparing the results of different models, and it is then imperative to minimise or eliminate variability stemming from other sources than the modelling techniques or the parameters that the study intends to explore. For example, if a study intends to assess the range of nearly cost-optimal technology pathways that can reach a certain climate goal, one would in most cases not want model results to differ because of differing assumptions about past emissions or current technology deployment. But conversely, one might want to keep variability that stems from different assumptions about technology performance, or different assumptions for future final energy demand, and use that variability for sensitivity analyses and for assessing the robustness of conclusions.

A multi-model study may also involve models that have different scopes and differ in terms of which variables are modelled endogenously versus exogenously. In this case, the output from some models may serve as input for other models. One example could be to model how certain changes in global economic conditions affect a specific sector in a specific region. A global economic model might then be used to model how the changing conditions affect demand for products from the sector and region in question, while a sector-specific model might take the demand from the global economic model as input and model how it affects energy demand, technology choices, profitability, etc. in the specific sector and region. If the models have certain inputs in common, such as interest rates, global oil prices or other parameters, those inputs need to be consistent to ensure that the output from the sector-specific model truly reflects the input to the global economic model.

To achieve complete and consistent harmonisation, all models must both use assumptions and input data that are consistent with the harmonised assumptions and data, and also produce *results* that are consistent with the harmonised data. This of course means using the harmonised assumptions for input data that can be set directly as exogenous inputs to the model. But other parameters of the model may also have to be adjusted, to ensure that they themselves are consistent with the harmonised data. In the case that some of the harmonised data is modelled endogenously by a model, other parameters of that model must in principle also need to be adjusted so that the modelled results are consistent with the harmonised data. The last point implies that each model may need to be calibrated to be consistent with parts of the harmonised data that are outputs from, rather than inputs to, the model. In cases where historical trends or the present state are used to place constraints on future evolution, the way in which such constraints are derived and imposed may also need to be harmonised if it is relevant to the given research question.

In principle, therefore, harmonising assumptions and data means ensuring that both inputs, internal parameters and calibrated outputs are consistent with the harmonised values. In practice, full consistency with the harmonised parameters is rarely possible unless the models involved are extremely similar to begin with. In particular, harmonising aspects like technology costs and technological performance can be made extremely difficult by differences in what technologies are represented by different models, boundaries between different technology types, and what parameters are used to characterise them in each model. Fully harmonising detailed socioeconomic parameters will often also be complicated by differences in what variables are represented by each model, and the complex ways in which different social and economic variables correlate to each other. Calibrating modelled outputs to match harmonised values can often be time-consuming and tricky and will therefore often require compromise.

The extent of harmonisation must ultimately be a research question-specific compromise between the need for consistency and the effort required to adjust correlated parameters and calibrate outputs. This applies to all harmonised parameters, whether they come from a broad scenario logic or a research question-specific scenario protocol. It can sometimes be possible to post-process the output results to mitigate inconsistencies in the input data or internal parameters, or to simply be aware of the issue and interpret the results accordingly. How to do this and the appropriate amount of effort to put into harmonisation ultimately depends both on the specific research question and on the models involved, and cannot be fully specified in a broad scenario logic.

2.1.3 What parameters to harmonise

What parameters should be harmonised in any given modelling exercise will depend on the research question. A broad scenario logic should ideally specify default values for all parameters that most likely can be harmonised across a range of different research questions, which may then be overridden by custom values as appropriate for each modelling exercise.

In this subsection, we list parameters that can be candidates for harmonisation in general, along with a brief description of when it is appropriate to do so. In section 2.2 and chapter 3, we then discuss which of these parameters can and should be harmonised in IAM COMPACT specifically. "Past" and "future" below refer to time before and after the start year of the modelling runs, which is not necessarily the same as the actual past and future relative to when the modelling runs are being performed.[2]

In most cases there is a range of level of details at which harmonisation may be carried out, such as whether to harmonise final energy demand at a detailed sectoral level or only by major sectors, whether to harmonise only total population or population by sex and age bracket, etc. This choice will depend both on the research question and on the level of detail at which the models involved represent the relevant parameters. In principle, comparability is maximised if harmonisation is done at the finest level of detail that is either available in the input data used for harmonisation or that is supported by the models in question, but this must be weighed against any practical challenges to detailed harmonisation, technical issues that may results from over-constraining models, and any considerations that arise from the research question.

Common parameters for harmonisation include:

- **Energy data:** Including primary energy production, final energy demand, power and heat generation, and other types of energy conversion, and installed power generation capacity by generation type.
  - **Past:** Should almost always be harmonised
  - **Future:** Will be part of the model output in many cases. Some future energy-related data may be specified and harmonised as part of a study of how other parts of the economy or the rest of the energy system evolves in a scenario with a fixed trajectory for final demand, installed capacity or other aspects of the energy system. This will typically depend on specific research questions and may not be part of the broad scenario logic.
- **Emissions data:** Data for greenhouse gas emissions, as well as particulates and other relevant pollutants.
  - **Past:** Should almost always be harmonised. Must be done in a way that is consistent with harmonised energy data and other activity data, if relevant.
  - **Future:** Usually not harmonised except in particular types of studies, same as under "Energy data" above.
- **Socioeconomic parameters:** Population, GDP or sectoral value-add, income and income distribution, trade volumes, etc.
  - **Past:** Should usually be harmonised.
  - **Future:** Depends on the study. Large-scale parameters such as population and GDP/value-added will often be harmonised if they are not modelled endogenously. The wide range of possible parameters and level of detail can make full harmonisation challenging if the range of parameters and level of detail varies greatly from model to model.
- **Energy prices:** Oil, natural gas and coal prices, wholesale electricity prices, etc. Sometimes included as part of technology parameters (see below) but can be independent variables.
  - **Past:** Usually harmonised to have a common starting point
  - **Future:** Can be modelled endogenously by some models and if estimating possible price

[2] This definition of "past" and "future" pertains only to the general discussion in this subsection. In the discussion of harmonizing variables in chapter 3, we construct a single time series in the cases where we think that both past and future data are needed, and refer to "historical" and "future" based on when the availability of historical data for each variable.

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pathways is warranted by the research question. Otherwise usually harmonised to avoid an extraneous source of variability.

- **Technology / technoeconomic parameters:** Technology costs (capital costs, O&M, fuel prices, ….), energy conversion efficiency and other performance parameters, operational lifetimes, etc.
  - **Past:** Usually desirable to harmonise to ensure a common starting point. Many parameters relating to technology costs and performance can be challenging to harmonise due to differences in what technologies are represented, how they are characterised internally in models, and boundaries between them.
  - **Future:** Desirable to harmonise in many cases, but depends on research question and models, hence not necessarily harmonised in the broad scenario logic. Some parameters may be modelled endogenously, such as technology costs from learning rates, and not harmonised. Same challenges to harmonisation as for past data.
- **Policy assumptions:** Taxes, incentive schemes, carbon pricing mechanisms, standards, tariffs, etc. Aspects of policy assumptions will often be implicit in other parameters, but can also be independent variables, in particular carbon pricing and other price mechanisms.
  - **Past:** Desirable to harmonise if relevant, but the harmonisation is often done implicitly through other parameters.
  - **Future:** Should almost always be harmonised if relevant, but what is harmonised in the broad scenario logic vs in research question-specific scenario protocols will vary
- **Other parameters:** Can include a wide variety of sector- or domain-specific parameters, climate system parameters or any number of other specialised quantities. Typically used in special-purpose models. Typically, not harmonised in the broad scenario logic of a project with global scope and covering potentially all parts of the economy. Usually challenging to harmonise due to diverse or lacking representation in different models, except in specialised studies involving only models that represent the relevant parameters in similar ways.

2.2 Mapping needs in IAM COMPACT

2.2.1 Model survey and summary of conclusions

A survey was sent out to all modellers in IAM COMPACT in March 2023 to gauge the opportunities and need for harmonising various parameters in the project. The survey asked each modelling group to provide information on what input data was used by each model, constraints on usable data sources, and a number of other questions relevant for performing harmonisation and constructing a broad scenario logic that would be useable by all models. The survey contained questions in the following areas, which in sum were aimed at collecting information on all input data used by each model:

1. **General information:** Model time step, reporting formats, general comments about the model
2. **Sector classifications:** What sectors or hierarchy of subsectors are represented in each model
3. **Emissions and forcings:** Which species of greenhouse gas and other emissions are represented, whether they are modelled endogenously, spatial and temporal resolutions, and default sources of historical data
4. **Energy:** Energy types represented, whether modelled endogenously, default data sets used and constraints on alternative datasets, details of primary energy accounting and representation of non-energy use
5. **Socioeconomics:** General information on how socioeconomic narrative affects other aspects of the model, ties to SSPs, list of socioeconomic input data required, with default historical data sets and/or future scenarios are used, constraints on use of alternative data sources
6. **Calibration:** General information on what input data are required for calibration, default data sets used and constraints on using alternative data
7. **Other required input data:** For each model, asked for a list of all required inputs that were not explicitly

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listed under the responses to any of the other topics

The relevant parts of the responses to the survey and the conclusions drawn from them are reflected in the discussion of harmonisation throughout Chapter 3. We therefore only briefly summarise the responses here.

Survey responses were submitted for 21 models, which constitutes almost all the models participating in IAM COMPACT with only a few exceptions. A wide range of different models are represented, from global integrated assessment models and macroeconomic models through sub-national, near-real-time electricity system models. The reported time steps in the models range from hourly (EnergyPLAN, Calliope, DREEM) through 10 years (WISEE-EDM Global Steel), meaning that time resolution of inputs and outputs will have to be adapted to each use case rather than standardizing on a single time step for all models.

The models report a wide variety of sector classifications, both in terms of sector categorisation logic and level of detail. Again, the sector categorisation and resolution to use must therefore most likely be decided on individually for each research question, based on what is most useful for the research question at hand and what sector categorisations are supported by the most suitable models.

Most models represent energy use in some way, though the way in which this is done varies greatly. Some represent all aspects of the energy system endogenously but at differing levels of details, such as most IAMs and macroeconomic models. Others represent only parts of the energy system endogenously and take other aspects as exogenous inputs, such as electricity system or energy system models, which take electricity demand or different types of final energy consumption as inputs and model how the system meets those demands. Still others take energy supply or just energy prices as an exogenous input along with other sector-specific inputs, and model the behaviour of a given sector based on those inputs. Many models use historical energy data to determine the current state of the energy system or for calibration purposes. Most models that use historical energy data as inputs report that they use IEA data in some form, although there are a few exceptions. Some also supplement IEA data with data from IRENA for renewables and BP for biofuels, as well as national data for the US and China (the US Energy Information Agency (EIA) and China's National Bureau of Statistics (NBS), respectively). The models are roughly evenly split with respect to whether or not non-energy use of fossil fuels is represented.

The extent to which models calculate emissions and make use of historical emissions data varies, as does which gases, climate forcers or air pollutants they model. Most models that calculate emissions, calculate fossil CO_2 emissions, but that is practically the only common denominator. A range of data sources are used by models that take historical emission data as an input, with EDGAR, CDIAC, IEA and CEDS being the most prevalent. Models that calculate emissions from land-use change and agriculture also typically use FAO data.

The representation of socioeconomic variables is equally variable. Only 6 models model GDP endogenously, but 8 more take it as an endogenous input. The sources used for historical data and for calibration are mostly IMF and/or the World Bank for global data, supplemented by NBS for China and the U.S. Bureau of Economic Analysis. In-depth economic models also include a wide range of other parameters, such as government investment levels, household incomes, capital and labour productivity, employment by age and education level, etc. 15 different models report taking historical and in most cases projected population numbers as input. Historical data are for the most part taken from the UN, the World Bank and Eurostat, the U.S. Census and NBS for the EU, US and China, respectively. Almost all models that use future population and/or GDP projections, use SSPs or a hybrid of SSPs and EU projections (EUROPOP and/or the Ageing Report).

Apart from the variables mentioned above, different models take a wide variety of parameters related to technologies and natural resources as inputs. The wide variety of such parameters as well as the wide range of modelling frameworks that they are used in for different models make harmonisation challenging.

2.2.2 Inputs to and from other tasks and work packages in IAM COMPACT

This deliverable is intended to serve as part of the basis for all modelling tasks in IAM COMPACT. This includes

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the modelling tasks T4.3, T4.4 and T4.5 in WP4[3] as well as potentially all tasks in the modelling-focused work package WP5. The current version of this deliverable provides specifications for harmonised data and assumptions to be used as defaults for all modelling tasks, but potentially overridden wherever specific research questions require it. It also provides some preliminary specifications for output formats and sharing of data (in chapter 5). Research question-specific assumptions, scenarios, and modelling protocols as well as additional requirements for model outputs will be developed in each modelling task in the context of specific research questions.

The current version of this deliverable leaves several questions open that require more in-depth discussions with individual modelling teams and with other tasks, in part due to the final list of research questions and approach to them not having been settled yet, as well as the relative timing of deliverables from different tasks. These open questions are noted throughout the remainder of the document. The update to this deliverable, D4.4, will report on how these questions are resolved, as well as potentially providing additional scenario logic for the second modelling cycle.

D4.3 is only part of the input to modelling tasks. It should be used in conjunction with other deliverables to form a complete basis for developing the concrete modelling approaches:

- **D2.2 - Scoping policy-relevant research questions:** Not yet submitted in a final version at the time of writing, but will contain a preliminary list of research questions, based on stakeholder interactions. Also includes a summary of the content of stakeholder interactions for context. A parallel process to finalizing D2.2 itself also involves narrowing down the list of questions that will actually be addressed through modelling and selecting the modellers that will participate in designing the approach to each research question and carry out the modelling. An update is planned in D2.3.
- **D3.4 - An outline of planned interlinkages among models, analyses and scenarios:** Provides guidance on how to link models and narrower analyses to address complex policy questions that cannot be answered by a single model or class of models alone. Includes a description and feature comparison between each model in IAM COMPACT that may be useful for selecting models to perform composite analyses. Also attempts to map specific research questions to concrete sets of models, but this mapping reflects the status of research question development at the time the deliverable was submitted (April 2023) rather than the final research questions. An update is planned in D3.5.
- **D4.1 - From policy needs to scenario frameworks:** Provides guidance on how to create scenario frameworks to address different types of policy questions and how to represent policies in models. Also provides some considerations for how to select models for addressing specific policy questions, but mostly leaves the mapping to concrete models in IAM COMPACT to the update D4.2.
- **D3.2 - Open data management plan / D3.6 - Open science protocols:** These deliverables have not yet been completed at the time of writing but will give specifications for how input data and outputs should be managed and shared. In addition, this deliverable (D4.3) provides a very brief specification of output formats and sharing of output data, but the details of this are to be worked out with modellers after submission of D4.3, and subject to change based on D3.2 and D3.6.

In addition to these linkages, T4.2 will develop a pilot for comparing and managing the outputs from models together with T3.4 ("Upgrade and operation of the I^{2}AM PARIS data exchange platform"). As well as piloting a solution for how to store and publish outputs, the pilot will test comparability of results and assess whether variability in results between different models give a good representation of uncertainty.

[3] Full titles: T4.3 "Global and national/regional mitigation analysis", T4.4 "A deep dive into sectoral dynamics and specific cross-sectoral aspects", and T4.5 "A deep dive in Europe with spatially-explicit modelling for subnational analysis".

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3 Broad scenario logic and harmonisation

In this section, we discuss the concrete content of the broad scenario logic. The section focuses on specifying common assumptions and data sources that can be used as defaults across models and research questions. For research questions where these assumptions and data do not need to vary, they can be used in all scenarios. For research questions that require custom scenario assumptions to investigate the question, the assumptions specified here could instead serve as the basis for a reference scenario if appropriate.

Harmonising assumptions across different research questions has value both in terms of simplifying work for modellers working on more than one research question and for potentially being able comparing results from modelling exercises for different research questions. Nevertheless, to prioritise the needs of stakeholders, the requirements of specific research questions should take precedence over the broad scenario logic. If entirely different assumptions are required to adequately address a research question, those requirements should override the broad scenario logic.

We specify which assumptions and data sets should be used as defaults from section 3.4 onwards. The specifications and recommendations for harmonisation and the rationale for them are discussed at length from subsection 3.4 through 3.7, while section 3.3 provides a consolidated summary. In sections 3.1 and 3.2, we discuss considerations stemming from the probable research questions and the selection of models in IAM COMPACT, respectively. In subsections 3.4 through 3.7, each concrete recommendation is distinguished by being written in **bold text**.

In the following, all statements about whether parameters can or should be harmonised are conditional on those parameters actually being relevant. If certain parameters or other parameters that correlate strongly with them are not represented in models or relevant to the modelling study at hand, there is generally no need to harmonise them. To avoid repetition, we do not state this in every single case.

We only recommend harmonisation for variables that are not likely to be overridden by most research questions, and that are used by more than one or a very small number of models. This means that we specify harmonised data sets for historical values of most broadly used variables, but future/projected values for only a small number of variables. We also do not specify harmonised values for very sector-specific or highly disaggregated variables that are only used by one or very few models, and instead rely on these models to check that the data they already use are broadly consistent with the harmonised aggregated data.

In selecting data sets, the main selection criteria have been, in rough order of priority, that the data are 1) as up to date as possible, 2) relatively widely used and recognised in modelling and/or policy circles, and 3) are already used by many models in IAM COMPACT, thus reducing the overall effort required. We have also preferred sources that include both historical data and projections as part of the same dataset, to minimise potential problems with breaks in trends or assumptions that are inconsistent with the historical trend or starting point. Where entirely different sources are used for historical and future variable values, we attempt to avoid discontinuities or non-smooth behaviour by extending the historical data with growth rates from projections, rather than naively stitching together the raw time series.

In this deliverable, we only make recommendations on what datasets to use, but do not provide production-ready data files. After this deliverable is submitted, CICERO plans to undertake discussions with modellers to determine the most appropriate formats and channels for providing the recommended data, and to find solutions to potential issues that individual groups may have with specific recommendations. In some cases, we need to discuss further details with modellers before making any recommendations at all, and instead simply point out the need for such discussions.

3.1 Constraints from research questions

The *broad* scenario logic aims to specify assumptions and data that are largely independent of specific research questions. This contrasts with *specific* scenario logics, which will need additional specifications based on each research question. In doing so, it is nevertheless necessary to keep in mind what the likely research questions will be, to ensure that the recommendations in the broad scenario logic will be useful as a common base or reference scenario, and not require substantial modifications in the context of all or most of the research questions.

At the time of writing this deliverable (April 2023), the process of gathering input from stakeholders in WP2, deciding on the final selection of research questions for modellers to investigate and the designing the modelling approach for each research question is drawing to a close but not yet complete. This process and the outcomes from it are to be reported in D2.2, due at the end of May 2023. See further comments about the process in section 4.1. None of the candidate research questions at the time of writing appeared to necessitate backward-looking counterfactual scenarios. It is therefore possible that all types of historical data can be harmonised across research questions, to the extent the models themselves allow.

For future scenarios, the candidate research questions from D2.2 focus mainly on the cost-optimality and resilience of the energy transition, the impact of different technology choices, relocation and reallocation of different types of industrial production, as well as whole system factors such as interest rates or behavioural changes. Investigating these questions will probably not involve making varying assumptions about future population and will not necessarily need to vary much in terms of total GDP or sectoral value-add outside of industry and the energy sector. Population and overall GDP are therefore good candidates for harmonisation across future scenarios.

The research questions *will* require very different assumptions about energy technology deployment, resulting differences in energy consumption and emissions, as well as geographical distribution of industrial production in- and outside the EU and demand for various raw materials. Different assumptions about technology prices and availability may also be needed, and differing assumptions about consumer behaviour may additionally affect value-add in consumer-oriented sectors outside of industry. Assumptions about the future evolution of all these factors should therefore probably *not* be harmonised across scenarios. There may still be a need for default assumptions in cases where choice of technology costs and performance are not dictated by the research question or when there is a need for a neutral baseline scenario. We therefore discuss options and make some very tentative recommendations in section 3.5.

Although several assumptions for reference or background scenarios in principle could be harmonised in a "broad" scenario logic, the most appropriate choices may still depend on the totality of the research questions. In the following sections, we therefore in many cases point out needs and opportunities for harmonising future scenario assumptions but defer recommending specific assumptions or values for many of the relevant parameters until the list of research questions and corresponding modelling scenarios have been finalised and discussed with stakeholders (e.g., in workshops planned for May-June 2023).

In some cases, we also defer decisions because of a need to conduct more detailed discussions with modellers, see further comments at the end of section 3.2. In these cases, the following sections serve to map out what discussions need to happen, and the results will be reported in the update to this deliverable (D4.4).

Modelling teams in the IAM COMPACT project have already conducted a series of model runs to investigate the impact of replacing all imports of natural gas to the EU following the 2022 Russian invasion of Ukraine, informally referred to as the "energy crisis" analysis. A scenario protocol including many of the elements mentioned here was developed for that exercise. The harmonisation choices made for population and GDP figures in this chapter are to a large extent similar to the baseline assumptions made in that protocol, but with some significant differences. See section 4.2 for a brief description of the energy crisis scenarios and the commonalities and differences between the energy crisis scenario protocol and the current deliverable.

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3.2 Model considerations

IAM COMPACT encompasses a wide range of models with very different structures and scopes. They differ widely in what types of inputs are used, what data sources are used by default, and the amount of work required to use alternative data. In the following, we therefore aim to provide default specifications that strike a balance between harmonisation and flexibility. To ensure that the default inputs we specify can be used by as many models as possible, we will therefore lean towards matching those models that have the strictest constraints on inputs and assumptions, as long as those choices do not create unreasonable challenges for other models.

For a comprehensive overview of the models in IAM COMPACT, their key features and differences, see section 3 of D3.4 as well as the model documentation on the I²AM PARIS website.[4] In the following, we discuss only the aspects that are most salient for selecting the most appropriate assumptions and data sets to be used in the broad scenario logic.

The models in IAM COMPACT can roughly be divided into six broad categories:

1. **General equilibrium integrated assessment models (GE IAMs):** *CHANCE, IMACLIM-China*. In principle, these model the entire economy, energy system and environment endogenously, but with little sectoral detail and low temporal resolution.
2. **Partial equilibrium integrated assessment models (PE IAMs):** *GCAM/GCAM-USA, MUSE, TIAM*. These models aim to cover the entire economy, energy system and environment, but not all sectors and systems are modelled endogenously, and not all couplings typically included in GE models will be included or will only be included in one direction.
3. **Other/non-equilibrium integrated assessment models (NE IAMs):** *CLEWs, DyNERIO, MEDEAS, WILIAM*. These are a diverse set of models that aim to represent most of the economy, energy system and environment, but either focus on specific aspects or otherwise do not employ equilibrium-based dynamics and are typically driven by exogenous inputs.
4. **Energy and electricity system models**: *Calliope, China-MAPLE, DREEM, ATOM, EnergyPLAN, EXPANSE, MENA-EDS, OSeMOSYS, PROMETHEUS*. These models focus specifically on modelling the energy system, or specifically the power sector and electricity markets. Temporal and spatial resolution vary, with some models including hourly simulation of electricity dispatch and markets. Relevant impacts from other sectors are typically taken as exogenous inputs.
5. **Sectoral system models**: *WISEE-EDM, DREEM, ATOM, WTMBT, AIM/Enduse-India*. These models focus on specific sectors or parts of the economy: Industry in the EU and/or the global steel sector for WISEE-EDM, global trade for WTMBT, and energy end-use sectors in India for AIM/Enduse-India. The scopes and modelling techniques are correspondingly diverse. WTMBT can be used as a general economic optimisation model based on multi-regional input/output analysis but will presumably be used with the output of other models as input in IAM COMPACT. WISEE is a model family with many modules, but only the ones for industry in the EU and global steel are planned for use in IAM COMPACT.
6. **Simple climate models**: *CICERO-SCM, FaIR, Hector, MAGICC*. These models only model the climate system, not the economy or energy systems. They take relevant factors such as emissions from energy use and land use change as exogenous outputs, and simulate the effect on global temperatures and other climate impacts.

[4] A graphic presentation of key features of each model can be found at https://www.i2am-paris.eu/dynamic_doc/. Somewhat more detailed textual descriptions are found at https://www.i2am-paris.eu/detailed_model_doc. The I²AM PARIS website covers models from multiple projects, not just IAM COMPACT. At the time of writing, documentation for a few of the models IAM COMPACT has still not been added to the website.

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The GE and PE IAMs generally model a greater share of variables endogenously and use fewer exogenous inputs to determine their evolution, while the other categories to a greater extent are driven by exogenous inputs and model how their sectors or systems of interest evolve in response. However, GE and PE IAMs tend to contain a larger number of variable parameters, which typically must be calibrated using historical data. All the model categories therefore require a substantial number of external data to determine their behaviour, in most cases including a combination of GDP, demographics, energy use and/or emissions, technology costs, commodity costs, etc. They differ in terms of which inputs are required and especially in terms of how those inputs are broken down by sectors and, to a lesser extent, by energy types and/or emission species.

The models also differ greatly in terms of how flexible they are with respect to what data sources can be used for input, and how much work is required to recalibrate models when switching data sources. In the following sections, we discuss different input types further. For each input type, we recommend data sets to be used as defaults in the scenario logic, based in part on what is likely to require the least amount of work in total for modellers to adopt for their respective models.

The models in IAM COMPACT encompass a wide range of different time resolutions, from hourly time steps in some energy system models, to 5- and even 10-year time steps in some of the macroeconomic models and IAMs. Models with different time resolutions will typically be used to answer different research questions, either alone or in combination, and the start and end year of model runs will vary accordingly. Time steps and start and end years will therefore need to be specified in scenario protocols for individual research questions, not in the broad scenario logic.

3.3 Consolidated recommendations for harmonisation

In Table 1, we summarise all recommended harmonisations of variables that are specified in this chapter. In the following subsections, we discuss background and rationale for the choices made for each variable or thematic area, and also repeat the corresponding recommendations themselves. Readers who are only looking for the recommendations themselves need only read this subsection. Please note that output specifications (formats, reporting conventions, etc.) are given in chapter 5 / section 5.3, not there. Most non-proprietary harmonised datasets will be published in the IAM COMPACT community on Zenodo (IAM COMPACT, n.d.). This will in particular include consolidated time series for the rather complex harmonisation of population and GDP figures outlined in Table 1. Modellers should not need to perform the integration of multiple socioeconomic data sources listed there themselves.

We reiterate that all recommendations are defaults that should be overridden whenever research question-specific considerations call for it. In exercises where some variables included in the recommendations are to be modelled endogenously, the models should obviously not be constrained to use the harmonised data for the modelled time period, except possibly as a consistency check if that is deemed to be appropriate.

When the recommended harmonised data are used, modellers should ensure that all aspects of modelling are consistent with the harmonised data as far as possible. This means that any models that use the harmonised variables as part of model calibration, should recalibrate using the harmonised data. Modellers should also consider whether other assumptions or variables may be correlated with the harmonised data, and if so whether they should be adjusted accordingly. If any models model the harmonised variables endogenously and cannot be explicitly calibrated to reproduce the harmonised data, they should at a minimum check to what extent the modelled results are consistent with the harmonised data. Research question leaders will need to decide on a case-by-case basis how to deal with significant deviations.

The starting year for modelling may depend on research questions, and we therefore do not specify a harmonised starting year in the broad scenario logic. Where we recommend harmonisation for both past and future variable values, we create spliced time series of suitable historical data and future scenario data, but leave it up to research question leaders and modellers to decide which years are appropriate to use for the given modelling exercise, and which years to treat as "past" and "future" in contexts where such a distinction is needed.

In all cases, harmonisation should be done at the level of detail of either the specified harmonised datasets, or of the level of detail for which the model in question normally requires for external input or calibration, whichever of the two is coarser. Harmonising at a coarser level than either of these two can be considered if the level of detail specified here would constrain some models more than is appropriate for the given research question or would lead to pathological dynamics in some models. Most datasets specified in this section have country-level and one-year resolution, and sectoral resolution corresponding to IEA's energy balances for energy and emissions.

Some sectoral and regional models will require more finely resolved or different datasets than the ones recommended here. See comments about how to address this in the subsection for each topical area. We make no recommendations for variables of for topics not listed in Table 1, but possible approaches to some variables within the given topical areas are discussed in the later subsections. In most cases this pertains to variables that should be harmonised but require further discussion with modellers or more clarity about the modelling approach to each research question before we can make specific recommendations. In addition to datasets, it may be necessary to make some degree of structural harmonisations, such as sector boundaries or energy type definitions. These types of harmonisation will need to be considered in the context of specific research questions but may in general be constrained by the flexibility of the participating models.

Finally, modellers will need to consider other elements that may require harmonisation, such as whether any constraints are used to ensure that the future evolution of endogenously modelled variables stays consistent with observed historical trends. If any participating models use such constraints, they should probably be harmonised, if possible (unless they are a part of desired model diversity), but how and whether to do so will depend on the research question and the models involved.

Table 1: Summary of all recommended harmonisations. See following subsections for rationale for each recommendation, and further discussion about each topical area.

Topic	Variable	Context	Recommended data
Socioeconomics	**Population**	EU27+Norway[5]	Population data from Eurostat: Historical statistics through 2018 (Eurostat, n.d.); EUROPOP2019 projections from 2019 through 2100 (Eurostat, 2022a, 2022b)[6]
		OECD+[7] except EU27/Norway	Population data from OECD Economic Outlook 109 Long-term baseline projections (available for 1990 through 2060), to ensure consistency with GDP projections (OECD, 2021). Extend with growth rates from UN WPP2022 after 2060 if necessary (see below).
		Rest of World	UN World Population Prospects 2022 (United Nations, 2022) figures for all years (available from 1960 through 2100, with historical data until 2022)

[5] EUROPOP2019 also includes population projections for the United Kingdom (EU28) as well as the EFTA member countries Iceland, Liechtenstein, Norway and Switzerland. However, in the 2021 Ageing Report, GDP and other data are only provided for EU27 and Norway. To ensure consistency between population and GDP numbers, only the EU27 and Norway are therefore included here.

[6] The EUROPOP2019 projection is used rather than the most recent EURO2023. This is done to ensure consistency with the harmonised GDP projections from the EU Ageing Report, which are based on EUROPOP2019.

[7] OECD member countries, Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia, South Africa.

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Topic	Variable	Context	Recommended data
	GDP	All regions, through 2028	GDP from IMF World Economic Outlook April 2023 (International Monetary Fund, 2023a, 2023b)[8], in constant 2017 international dollars unless otherwise indicated by the research question
		EU27+Norway, from 2029	Extend IMF forecast with linearly interpolated real GDP growth rates from the 2021 Ageing Report (European Commission, Directorate-General for Economic and Financial Affairs, 2021a, 2021b)
		OECD+ except EU27/Norway, from 2029	Extend IMF forecast with real GDP growth rates from the OECD Economic Outlook 109 long-term baseline
		Rest of World	Extend IMF forecast with GDP growth rates *per working age capita* from SSP2 (must be calculated using the projected population figures) multiplied by population growth rate from the harmonised population time series
Techno-economics	**Technology costs (for reference scenarios)**[9]	EU27 and comparable countries[10]	Should be decided case-by-case, but most suitable option is likely to be technology costs from the EU Reference Scenario 2020 (European Commission, n.d.; European Commission et al., 2021)

[8] The IMF World Economic Outlook does not include a time series for GDP PPP in constant prices. To obtain this, either the GDP PPP at constant 2017 prices *per capita* (which is included) must be multiplied by population numbers from the same dataset for each country, or GDP PPP at current prices must be calculated using the deflator provided in the same dataset (must be done per country).

[9] 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.

[10] "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
		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 2022 (International Energy Agency, 2022, 2023a). Alternatives include technology costs from TIAM database as used in PARIS REINFORCE (Napp et al., 2019), 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 EUR Reference Scenario 2020.
	Fossil fuel prices	Historical prices	Regional prices from IEA datasets (International Energy Agency, 2023c). 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 2022 report (International Energy Agency, 2022), or if global benchmarks are sufficient, some of these are available for free from the World Bank "pink sheet" (World Bank, 2023b).
		Price projections	Regional price forecasts from the World Energy Outlook 2022 extended dataset (International Energy Agency, 2023b), requires subscription. Participating modellers who do not have a license can extract some prices visually from charts in the World Energy Outlook 2022 report (International Energy Agency, 2022). For long-term EU-specific exercises that do not need short-term trends, price projections from the EU Reference Scenario 2020 may be used (European Commission et al., 2021).

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Topic	Variable	Context	Recommended data
Energy	**Energy production and consumption**	Historical data[11]	IEA World Energy Balances (International Energy Agency, 2023e)
Emissions	**Energy-related[12] CO_2, CH_4, N_2O**	Historical data	IEA Greenhouse Gas Emissions from Energy dataset (International Energy Agency, 2023d), if modellers have or can acquire access. Alternatively use EDGAR v7.0 (Branco et al., 2022), which is consistent with IEA but with less detailed breakdowns. 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.
	IPPU CO_2 from cement	Historical data	Production data and emission factors from Andrew (2018). Updated data available on Zenodo (R. Andrew, 2023).
	F-gases and non-energy CO_2, CH_4, N_2O	Historical data	EDGAR v7.0 (Branco et al., 2022)
	Other emissions	Historical data	CEDS (O'Rourke et al., 2017/2021)
	Land-use change emissions	Historical data	No firm recommendation on harmonised data, but should check that used or generated data falls within or close to range spanned by 3 bookkeeping models in the Global Carbon Budget 2022 (Global Carbon Project, 2022). 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 subsection 3.7.5 for approach when alignment with national inventories is required.

[11] No harmonised data is proposed for projected energy consumption. This is assumed in most cases to be research-question specific and/or modelled endogenously.

[12] NB! The recommended datasets use the 1996 IPCC Guidelines for GHG inventories to define the boundary between energy-sector and industrial-process and product-use (IPPU) emissions, not the newer 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.

Topic	Variable	Context	Recommended data
	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 et al., 2020, 2022, 2019/2022)

3.4 Gross Domestic Product (GDP) and population inputs

In this section we specify how population numbers and GDP (both historical and, where needed, projected) should be harmonised, and discuss the rationale for why. The final specification is quite complex, and the final numbers will be provided to modellers as consolidated CSV files, to be shared as specified in Chapter 5. We do not specify how to harmonise other socio-economic parameters, due to the high diversity in what parameters different models use, and uncertainty about whether the final research questions will lend themselves to using a harmonised set for many other socioeconomic parameters. See brief discussion in section 3.4.4.

3.4.1 Background and general considerations

Most of the models that incorporate socioeconomic variables include population and GDP at the country level in some form. For historical GDP data, almost all the global models use data from either the IMF, the World Bank or both. For historical population data, most models use UN data, in some cases combined with Eurostat for EU-specific data. Almost all the models that take future GDP as an exogenous input use one or more Shared Socioeconomic Pathways (SSPs) (Dellink et al., 2017), or combinations of SSPs and EU-specific projections, which is natural given that there are few other sources for mutually consistent long-term population and GDP scenarios suitable for use with IAMs (Sognnaes et al., 2021).

Given the almost universal use of SSPs for the relevant models, it would be convenient to use a merging of the historical data sets mentioned above combined with an SSP with relatively "neutral" assumptions, e.g., SSP2 (current trends). At the time of writing, the SSPs are the only long-term GDP growth trajectories that include a comprehensive set of internally consistent socioeconomic parameters, and that also both have a global reach and include per-country breakdowns. As population, GDP and several other socioeconomic indicators are closely correlated, it is important that any assumed future values for these parameters be internally consistent as far as possible.

However, the SSPs are already quite dated, having been developed from the late 2000s and finalised in the mid-2010s. The observed trajectories for both population and GDP have already diverged significantly from the ranges spanned by the SSPs. The SSPs all have lower populations and higher GDP values in 2020 than what has been observed, even after correcting for the COVID19 pandemic (see figures 1 and 2). Furthermore, the medium to long-term projection for global population from the UN is considerably higher than all SSP pathways except the high pathway SSP3 (see Figure 1). The researchers who developed the original SSP population and GDP datasets are in the process of updating the population and GDP projections. This updated dataset should be completed in the second half of 2023 but will most likely not be available for use in time for the first modelling cycle in IAM COMPACT.

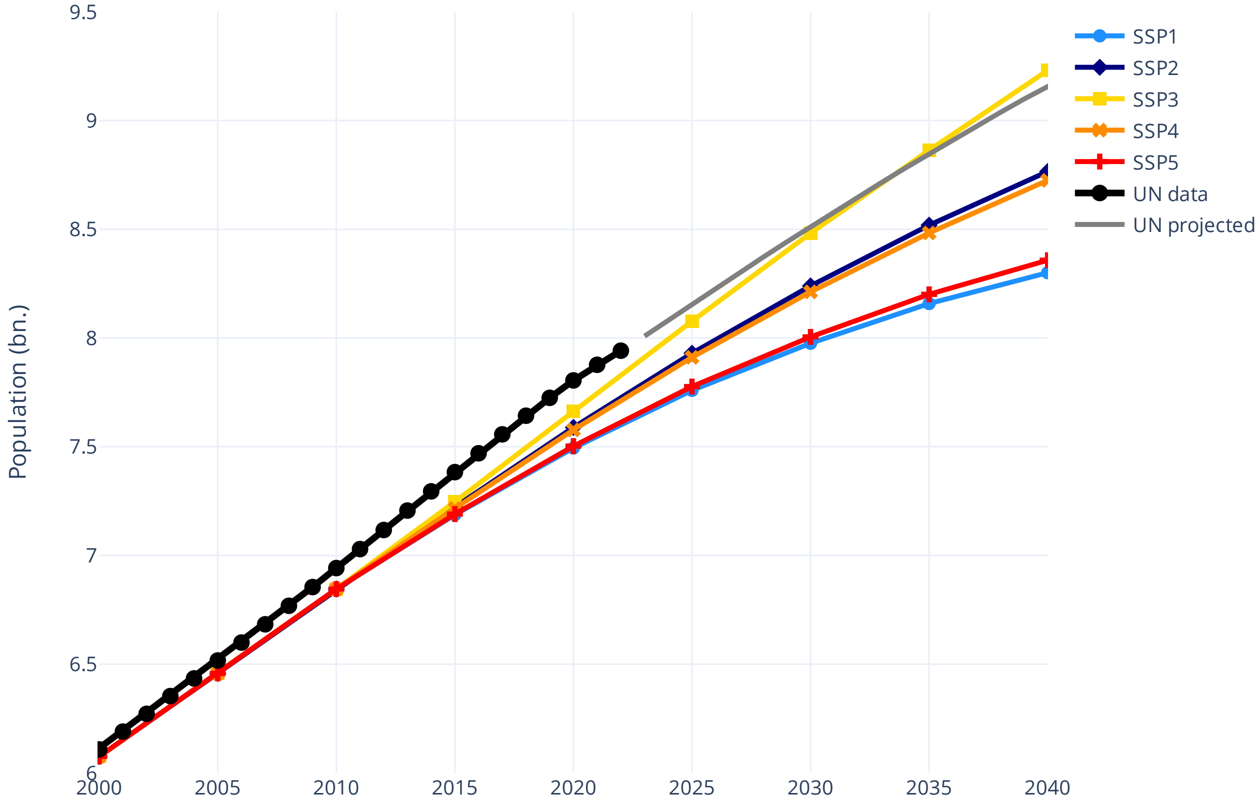

Figure 1: Population in the SSPs compared to observed populations from U.N. statistics and projection. The SSP pathways are the "illustrative cases" for population, most commonly used as inputs to integrated assessment modelling (Riahi et al., 2017; Rogelj et al., 2018). The UN data and projections are taken from the UN "World Population Prospects 2022" (United Nations, 2022), with historical data to 2022 and the "medium" projection after 2022. Observed population for 2010-2020 is higher than the range spanned by all SSPs, presumably due to a slower decline in global birth rates than assumed in the SSPs, while the projections are higher than all SSPs except for SSP3. This chart only shows values to 2040 in order to be able to distinguish the lines from 2000 to 2022 better, but the gap between UN projections and SSPs other than SSP3 remains and widens through 2100.

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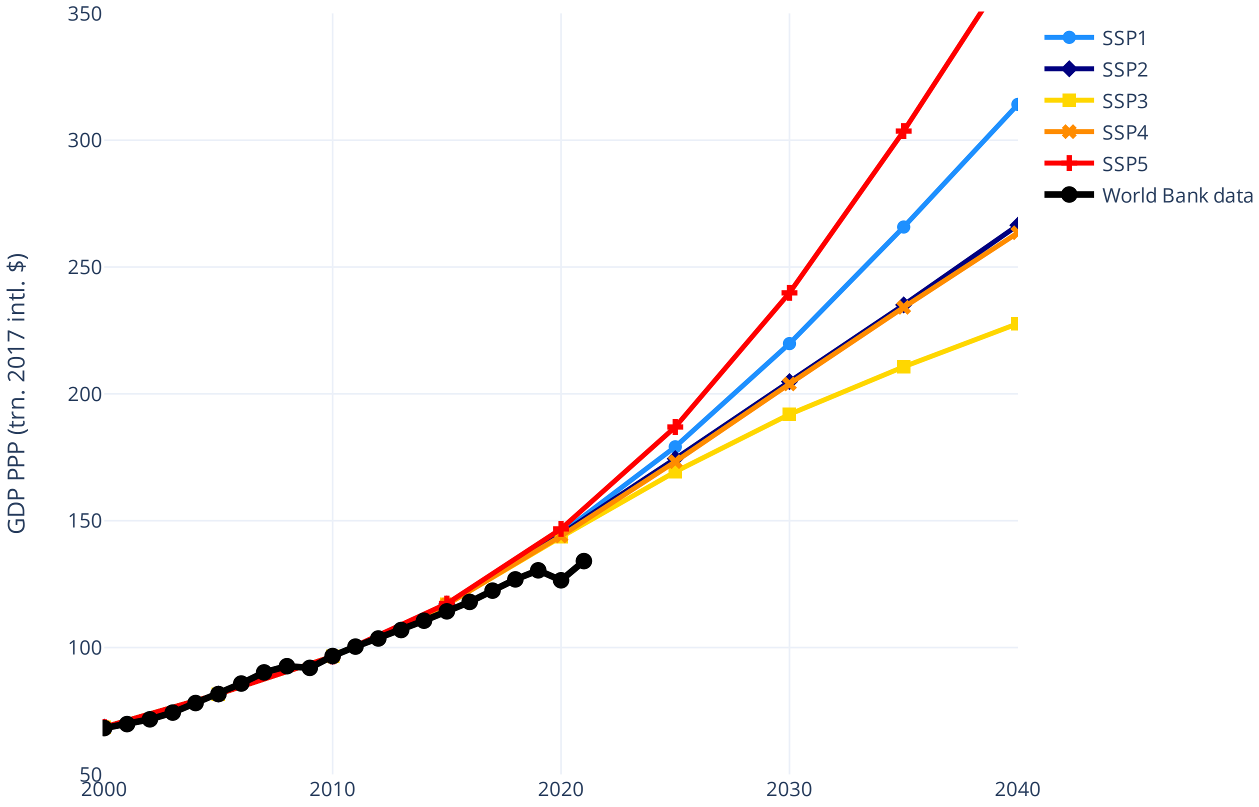

Figure 2: Global GDP (PPP) in the SSPs compared to statistics from the World Bank (World Bank, 2023a). All data are at constant 2017 prices and purchasing-power parity (PPP) measured in 2017 international dollars. The World Bank data is used here because it was part of the basis for the SSPs and because of its ease of use (IMF data require manual PPP conversion and deflation), but the data are consistent with IMF data and projections (International Monetary Fund, 2023b). The observed GDP is lower than the range spanned by all SSPs from 2020, even after correcting for the downward slump caused by the COVID19 pandemic. SSP GDP has been scaled to match World Bank data in 2005 to correct for differences in base years (the original SSP data use 2005 international dollars).

Because population and GDP levels in the SSPs have already diverged so significantly from reality, it would not be appropriate to use absolute levels either as a starting point for the present day or for future scenarios. Furthermore, since future population growth rates and age distributions are intimately connected to current population levels, it would likewise not be appropriate to use the growth rates from the SSPs, especially considering that more up to date population projections exist from the EU, OECD and U.N.

3.4.2 Specifications for harmonised data

The SSPs diverge significantly both from global and from regional and national projections, such as OECD- and EU-specific projections. For this reason, e.g., the PARIS REINFORCE project adopted a scenario protocol where SSP2 was used as a default for population and GDP, while EU- and OECD-specific data were used for the countries and years where they were available (Sognnaes et al., 2021). We here specify a similar approach, but with updated data where they are available, and with a few significant modifications to the approach (changes relative to PARIS REINFORCE are noted here, a complete specification is given in the following subsections):

1. Use U.N. population projections as the default for global population numbers instead of SSP2.

2. Use SSP2 growth rates in GDP *per working age capita* rather than absolute GDP to extend IMF and regional GDP projections.
3. Use updated GDP forecasts from the IMF World Economic Outlook (April 2023 edition) for GDP through 2028 for all countries.
4. Extend IMF projections after 2028 with GDP growth rates from the updated 2021 Ageing Report for the EU, and the OECD Economic Outlook 109 (2021) long-term baseline projections for OECD+ countries. Extend with SSP2 GDP per working age capita after the end of the regional projections if needed, as described above.
5. Use population projections from EUROPOP2019 for EU countries and from the OECD Economic Outlook 109 long-term baseline for OECD+ countries, to ensure consistency with the long-term regional GDP projections.[13]

GDP projections from the IMF World Economic Outlook are used for the short term (through 2028, currently the last year of available figures) even for the EU and the OECD+ instead of the slightly older and more long-term focused projections from the 2021 EU Ageing Report and the OECD Economic Outlook 109 long-term baseline, even though the latter are used for population projections for those regions. This choice is made to capture as far as possible the near-term fluctuations induced by both the recovery from the COVID19 pandemic, the European energy crisis and the Russian invasion of Ukraine.

Note that the specifications above and detailed in the following subsections are preliminary. To compensate for the lack of a single consistent dataset that both has global coverage and is up to date, the specifications merge a number of datasets from different sources, and also use recent but not the most current population projections for EU and OECD+ countries in order to ensure consistency with the selected long-term GDP projections for those regions. If any inadvertent inconsistencies or significant technical issues with these choices are discovered while implementing the specifications in models, changes may be necessary.

Despite its datedness, SSP2 is used (primarily the growth rates, to extend other datasets) due to their already widespread use and due to the lack of other globally consistent scenarios. SSP2 is chosen as a "neutral" middle-of-the-road background scenario. If specific research questions warrant a scenario that deviate from this middle-of-the-road, other SSPs may be considered. In particular, SSP3 may be an increasingly relevant scenario to explore, given that global population numbers already track closer to that scenario than to SSP2, and due to the marked growth in geopolitical tensions in the past decade.

3.4.2.1 Harmonised population data

In detail, we then recommend the following assumptions for population numbers:

- **By default (when region-specific projections are not available): Use population data from U.N. statistics for historical data through 2021 or the most recent year available. For future values, use projections from the U.N. "World Population Prospects: The 2022 Revision" (United Nations, 2022)**
- **When region-specific data and/or projections are available: Use the region-specific numbers for the relevant countries in the years they are available. If not available through 2100 or the end of the modelling exercise in question, extend from the last available year by using annual growth rates from the U.N. projections.**

[13] Note that these sources are slightly older than the currently most recent projections (EUROPOP2023 and OECD Stats 2022 population projections). This is done to ensure better consistency with the GDP projections. Unlike the SSP2 projections, we deem that these slightly older regional projections are not so out of date as to risk significantly skewed results.

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We recommend using the following region-specific data/projections to override the U.N. data and projections:

- **For the EU27 and Norway[14]: Use data from Eurostat, with historical data through 2021** (Eurostat, n.d.) **and the projection EUROPOP2019 from 2022** (Eurostat, 2022a, 2022b)**. This projection runs to 2100 and does not need to be extended with growth rates from the U.N. projections.**
- **For other OECD+ countries: Use projections for total population and working-age population from the OECD Economic Outlook 109 long-term baseline** (OECD, 2021) **through 2060. Extend with U.N. projection growth rates after 2060 (see further down for complexities that must be taken into account when making this extension).**

The projections specified here for the EU and OECD+ are one generation before the most recent ones (EUROPOP2023 and OECD Stats population projections from 2022, respectively). This is to ensure consistency with the recommended GDP projections, which are based on the same sources. The differences between the recommended EU and OECD+ population projections and the most recent versions are smaller than the discrepancy between global populations in SSP2 and the observed current population numbers. If updates to the Ageing Report or to the OECD Economic Outlook long-term baseline based on the more recent population projections are published in late 2023 or early 2024, these recommendations may be updated in time for the second IAM COMPACT modelling cycle.

When region-specific data are extended using the U.N. projection growth rates and the population data needs to be broken down by age groups, it can be challenging to consistently apply growth rates to each age group. Net growth in a given age group depends on the age distribution at the previous time step (through the number of people "exiting" to the age bracket above and "entering" from the age bracket below), and the net "flow" of people entering and leaving each age group through immigration/emigration, death and (for the first age bracket) birth. If the age distribution in the regional projections is different from the U.N. projections at the point when the regional projection ends, naively applying the net growth rates within each age group from the U.N. projections may produce inconsistent results.

If getting exact population growth rates and age distributions right is not critically important to the research question at hand, we would still recommend this naïve approach for the sake of simplicity. **However, in cases where precise and consistent demographics data are important, a stock-and-flow approach should be used to compute the evolution of each age bracket.** The net "flow" of people into and out of each age group through ageing, immigration, emigration, death and birth in the U.N. projections should be applied to each age bracket in the regional projections in order to extend them forwards to 2100.

3.4.2.2 Harmonised GDP

For GDP, we recommend the following:

- **Default (when region-specific projections are not available): Use data for GDP from the IMF World Economic Outlook (International Monetary Fund, 2023a, 2023b) for historical years and through 2028. For historical GDP, select PPP or market exchange rates, local currencies or US dollars as appropriate to the model and/or modelling exercise. To extend from the level from 2028 onwards, apply growth rates in GDP *per working-age capita* from SSP2, and multiply by *working-age population* from the projected population data set. For exercises that use future GDP numbers as input, PPP at constant prices should be used if at all possible,**

[14] Eurostat population data and projections are also available for other EFTA countries, but GDP projections in the 2021 Ageing Report (used for harmonised GDP data, see further below) are not. To ensure consistent population and GDP projections, only Norway is included here in addition to EU27 countries.

to avoid ambiguities arising from assumptions about inflation or exchange rate fluctuations (unless those assumptions themselves are part of a research question-specific scenario protocol).

- **When region-specific projections are available: Use GDP data from the IMF through 2028, as in the default above. From 2029, use region-specific GDP growth rates through the years they are available. If GDP figures are needed beyond the last year of available region-specific projections, extend them using GDP per working-age capita growth rates from SSP2, multiplied by the growth rate of the working-age population from the projected population data set. Also assess whether the last year in the regional projections is an outlier or otherwise special and should not naively be used as the base year for projecting forward. If so, consider how to adjust for this, either by using a longer term mean or trend as a basis or other custom adaptations. The most appropriate way to do this may depend on the research question.**

For region-specific data, we recommend the following:

- **For the EU: Use projected GDP growth rates from "The 2021 ageing report" from 2029 through 2070 (European Commission, Directorate-General for Economic and Financial Affairs, 2021a, 2021b), then extend with SSP2 growth rates as described above.**
- **For OECD countries: Use projected GDP growth rates from the OECD Economic Outlook 109 long-term baseline (OECD, 2021) from 2029 through 2060, then extend with SSP2 growth rates as described above.**

The GDP projections from the EU Ageing Report are recommended for EU countries due to their widespread use in policy making in the EU, so as to be consistent with the basis that many stakeholders already use.

Several models compute future GDP endogenously and cannot necessarily take GDP as an exogenous constraint. We assume that such models would be used in modelling exercises where calculating GDP endogenously is a desired model characteristic, and that any constraints on how this is done would be part of a research question-specific scenario protocol. We therefore do not make any specifications for harmonising future GDP for models that do not take future GDP or related variables as an exogenous input. For modelling scenarios where future GDP itself is not a constraint but rather should emerge from other assumptions, one of the models that represent GDP endogenously could be chosen and its output used by the models that require GDP as an exogenous input. How to utilise endogenous calculations of GDP and how to handle combinations of models that do and do not compute GDP endogenously will have to be decided by modellers and research-question leaders in the context of each research question.

3.4.3 Considerations for national models

The national models for China, the U.S. and India include national data for historical GDP and population at the national and/or sub-national levels, either in place of or in addition to global data from the U.N., IMF and/or World Bank. These models will need to continue using the national data where necessary but must check that both historical data and future projections are compatible with the harmonised historical and projected data specified above. For models that use GDP in local currencies, they should also consider whether this affects the comparability with the harmonised data. If any issues are found that could materially affect model results or comparability with other models, a custom solution will need to be found, which may depend on the specific research question. This should be done in dialogue with the research question leader and with CICERO to ensure consistency with the broad scenario logic as far as possible. Solutions might include modifying the input data in ways that come close to resolving the incompatibility with the harmonised data but could also involve using diverging input data and instead finding a suitable way to adjust or interpret the outputs.

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3.4.4 Other socioeconomic factors

Several models have detailed representations of specific aspects of the economy and society, such as household income distributions, value-add in specific sectors, age- and gender-related aspects, taxation, or trade. They therefore require a diverse set of socioeconomic inputs other than simple GDP or total population numbers by country. In the same way as for the national models, these models must check whether the data they currently use is compatible with the harmonised GDP and population data sets (both the numbers themselves and the assumptions behind them). If not, custom solutions will need to be found in a similar way as for the national models.

In addition to population and GDP, several models also require interest rates and/or discount rates as exogenous inputs. No models report any constraints on what values or data sources to use for these parameters, and only the national models for China report a default scenario (SSP2). For some research questions, in particular any that are affected by investment choices, the discount rate and/or interest rates may be an important part of the parameter space that models will need to explore. For others, it may be appropriate to fix them to single values, but the most appropriate choice of values may still depend on the research question. We therefore defer recommending any particular choices for discount or interest rates in this deliverable but may include further specifications in the update (D4.4).

3.5 Technological factors and energy prices

3.5.1 Background

Technology costs, technological performance and energy prices are an important input for determining the energy mix and choice of end-use technologies in many models, which in turn heavily affect emissions and potentially several other modelled aspects of the economy. 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, but the data used for current and historical costs/prices may also affect the starting point for some models. Specifically for the MENA-EDS and PROMETHEUS models, energy prices (from IEA, Enerdata and Eurostat) are also used to calibrate the model.

Given the impact on model results, it would be highly desirable to harmonise the data used for historical technology costs, technology performance and energy prices, and where relevant also assumptions about future evolution. In the PARIS REINFORCE project, it was recommended to use energy price projections from the IEA's World Energy Outlook and technology costs from the internal database in the TIAM model (Napp et al., 2019) combined with EU-level recommendations for the National Energy and Climate Plans (NECPs) (Mantzos et al., 2017), but not all models were able to use these inputs. Harmonising other technological parameters than just costs is likely to be even more challenging due to differences in how they are represented in models. This challenge comes in addition to the inherent difficulty of predicting a realistic evolution of technological performance, especially outside the context of research question-specific scenarios.

3.5.2 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] This scenario is widely adopted by the European Commission for various types of assessments, and would be the expected default scenario to use for questions concerning EU policy making.

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 World Energy Outlook 2022 for power generation technologies (International Energy Agency, 2023a).** This dataset contains regional breakdowns through 2050 and is among the most widely recognised technology cost scenario figures for the power sector. Note that cost assumptions in for Europe for some technologies differ significantly from comparable technologies in the EU Reference Scenario, 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.
    b. **Technology cost assumptions from the TIAM database**, which were recommended for harmonisation in PARIS REINFORCE (Napp et al., 2019) (although not all models there could harmonise technology costs)
    c. **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.

3.5.3 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, 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

[15] A zip file with technology assumptions as well as Excel spreadsheets with modelling results can be downloaded from a related web page (European Commission, n.d.). Direct link to the zip file: https://energy.ec.europa.eu/document/download/5959845e-435c-4780-9281-b64a709b273b_en?filename=ref2020_technology_assumptions.zip.

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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.

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.

3.5.4 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 2022 whenever they are appropriate for the research question at hand (International Energy Agency, 2023b, 2022). For long-term or EU-specific exercises where near-term trends are not important, fossil fuel price projections from the EU Reference Scenario 2020 (European Commission 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 (International Energy Agency, 2022). 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, 2023b). 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

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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.

3.6 Energy consumption and electricity generation

3.6.1 Background

Practically all the models in IAM COMPACT that use historical energy consumption and/or energy production data as an input use IEA's World Energy Balances (IEA-WEB) (International Energy Agency, 2023e) or the World Energy Outlook (which takes historical data from the same source). The only exceptions among the global models are WTMBT and DYNERIO, which use energy data from EXIOBASE, but EXIOBASE in turn takes its energy data from IEA-WEB (Stadler et al., 2018).

Among the national models, China-MAPLE and IMACLIM-China use energy data from China's National Bureau of Statistics (NBS) instead of IEA. While IEA base their energy balances for China entirely on data provided by NBS, they heavily process the data and use different primary energy accounting methods, so that NBS and IEA energy data are not exactly equivalent. For the United States, GCAM-USA uses the State Energy Data System (SEDS) from the US Energy Information Administration (EIA) for state-level energy data.

More specialised models supplement IEA's data and use alternative data sources where the IEA-WEB does not have an appropriate or sufficiently detailed breakdown by region and sector. The MENA-EDS energy model supplements IEA-WEB with proprietary energy data from the research company Enerdata, while MEDEAS and WILIAM supplement IEA's data with data from IRENA, the US National Renewable Energy Laboratory (NREL) and BP for renewables and biofuels. The sectoral WISEE-EDM Industry EU and Global Steel models primarily employ EU-specific energy balances from Eurostat, and sector-specific data from a variety of sources.

3.6.2 Recommended harmonisation

Given this background, we recommend that **in all modelling exercises that do not have research question-specific reasons to use custom historical energy data, all models should use IEA-WEB** (International Energy Agency, 2023e) **for historical energy production and consumption data as far as possible. Regional and sector-specific models that require specific data sets should check that their data are consistent with IEA-WEB as far as can be determined.** If this is not the case, custom solutions will need to be found, which may vary depending on the research question. The need for such solutions will be discussed with modellers after submission, and the outcome will be reported in the update of this deliverable (D4.4).

We do not specify any harmonised scenario assumptions for future energy use in this deliverable. The IAMs typically model deployment of energy technologies and in most cases also energy demand endogenously, although some can optionally take it as an exogenous input or can impose constraints on various aspects of the energy system. The energy system and sectoral models, on the other hand, typically require an energy mix or energy demand or both as exogenous inputs. Nevertheless, both future energy demand and the energy supply mix will typically depend sensitively on the research question to be modelled. Even the question of what energy mix and energy demand make most sense in a potential reference scenario needs to take research questions into account. Specifications related to future energy use will be developed in collaboration with modellers and in parallel with developing the research questions and will be reported in D4.4.

3.7 Greenhouse gas emissions

Greenhouse gas emissions are calculated endogenously by most models based on modelled activity, and usually not required as external inputs by models that do not model the climate system itself. Except for the case of modelling scenarios with constrained emission pathways, it is therefore usually not appropriate to harmonise future emissions across models. Conversely, it *is* desirable to harmonise emission factors in the vast majority of cases, to ensure that identical energy consumption or other types of identical activity in different models do not lead to different emission outputs. Furthermore, it will frequently be appropriate to harmonise *historical* emissions, not just emission factors, in cases when historical emissions are used as input data or for calibration purposes. Several models in IAM COMPACT do use historical emissions as part of their input data, including 7 models that use emissions data for calibration purposes.

3.7.1 Energy-related CO_2, CH_4 and N_2O emissions

According to the model survey, most models in IAM COMPACT use IEA energy balances for historical energy data but use a much more varied set of data sources for emissions. CEDS, CDIAC, EDGAR and FAO (the latter mainly for land use-related emissions) are the most prevalent sources, apart from (or in some cases in combination with) IEA emissions data for energy-related CO2 emissions. CEDS in turn takes its CO_2 emission factors from a variety of sources, including CDIAC, GAINS and SLEW, while EDGAR emission data closely track IEA emissions in the case of energy-related CO_2 emissions.

Because of the diversity of sources used, any harmonised dataset for either historical emissions or for emission factors must necessarily deviate from the preferred data sets for at least some models. Because of the link with energy data and because of their detailed sector and energy type breakdowns, **we recommend using emissions from IEA's "Greenhouse Gas Emissions from Energy" database (International Energy Agency, 2023d) for historical energy-related CO_2, CH_4 and N_2O emissions. For calculating emissions from activity data, we recommend using implicit emission factors inferred by dividing the IEA emissions data by the IEA energy balances, after aggregating to a level of detail that is appropriate for the model and/or research question at hand.**

Note that the IEA emissions follow the 1996 rather than the 2006 IPCC GHG inventory guidelines for delineating energy-related emissions, which are included in IEA's main datasets, vs industrial process and product use (IPPU) emissions, which are not. The main effect of this is that some emissions are classified as energy emissions and included in IEA's data even though the newer IPCC guidelines assign part of those emissions to IPPU. This is the case particularly for emissions from blast furnaces and other settings where coke or other fossil fuels are used both for energy and for reduction or other chemical processes. This must be taken into account by models that require emissions to be classified according to the IPCC 2006 guidelines. This can be done by using the information in IEA's "World IPCC Fuel Combustion emissions" (part of the "Greenhouse Gas Emissions from Energy" database), which reports how much of the CO_2 emissions in select sectors and processes should be allocated to IPPU emissions to match the 2006 guidelines.

IEA uses tier-1 emission factors from the 2006 IPCC guidelines (unlike the case for sector boundaries). **Any models that require explicit emission factors should therefore adopt the emission factors from the 2006 guidelines for energy-related emissions.**

The IEA emissions data are unfortunately proprietary and require a paid subscription. Since practically all models report using IEA energy balances for energy data, we assume that most modellers also have access to the IEA emissions data. However, **for groups that do not have and cannot acquire access, we recommend instead using energy-related emissions from the latest version of EDGAR, currently 7.0** (Branco et al., 2022)**, which are openly available. EDGAR energy-related emissions data use IEA energy data and the same emission factors and are in most cases practically identical to IEA if the IEA data are aggregated to EDGAR's sector boundaries.** In addition to being open and already used by several models, EDGAR data have the advantage of being more regularly updated than many other non-IEA datasets, and include detail on emissions of F-gases as well as CO_2, CH_4 and N_2O.

The disadvantage is that EDGAR has a far less detailed breakdown by sectors and fuel types. EDGAR uses sector classifications from the 1996 IPCC guidelines, which means that like with IEA, the split between energy and IPPU emissions is made using the same, older guidelines. Unlike IEA, EDGAR does not provide data that can be used to adjust the emissions to the 2006 guidelines.

3.7.2 IPPU CO_2 emissions from cement production

IPPU emissions from the production of cement come from calcination of limestone/calcium carbonate ($CaCO_3$) into calcium oxide/lime (CaO) during the production of clinker, the main binding agent in cement. The amount of CO2 emissions from this process per tonne cement can vary considerably, depending among other things on the amount of clinker used per tonne cement, and the different data sets that contain cement IPPU emissions have often diverged considerably both from each other and from national GHG inventories in countries that produce them regularly. In recent decades, new cement has tended to have lower clinker content than for traditional Portland cement, especially in emerging economies. With the growing dominance of China and increasingly India in global cement production and use, this issue has become increasingly important. This topic is explained and explored extensively in (R. M. Andrew, 2018).

The same article provides a data set with emission factors that take varying clinker content in China and India into account, and is also aligned with national GHG inventories for countries that submit them to the UNFCCC. The data set is shared on Zenodo (R. Andrew, 2023)**, and we propose using it for harmonised IPPU emissions from cement production.**

The data in Andrew (2018) **is quite close to the IPPU CO_2 emissions from cement in the latest version of EDGAR (sector 2.B). Models that have calibrated on EDGAR emissions and that would find it challenging to change data sets for this one sector can probably continue to use EDGAR without materially affecting outcomes.**

3.7.3 Other CO_2, CH_4 and N_2O emissions

For CO_2, CH_4 and N_2O emissions that are not energy-related or come from carbonates in cement production or from land-use change, we recommend harmonising to EDGAR emissions, both for their comprehensiveness and to avoid introducing more different datasets than necessary. These emissions should include all sectors in EDGAR's data other than 1.A (energy sector combustion emissions) and 2.B (cement production).

EDGAR does not include emissions from land use change. These are treated in section 3.7.5.

3.7.4 Other greenhouse gases

Apart from CO_2, CH_4 and N_2O, **EDGAR v7.0 also includes data for F-gases, and we recommend harmonising on their emissions data for the gases they cover. If it is necessary to aggregate the F-gases into CO2-equivalents, the appropriate Global Warming Potential (GWP) should be used (IPCC AR6 unless otherwise specified). As specified in Section 5.3, we recommend using tonnes of gas or tonnes of pollutant wherever possible rather than converting to CO2 equivalents**, so that custom GWP values of other metrics can be applied later if necessary.

For gases not covered by IEA's or EDGAR's data, such as black carbon, SO2, etc., we recommend using the Community Emissions Data System (CEDS) (Hoesly et al., 2017; O'Rourke et al., 2017/2021)**.** This data set is open-source and contains data on several greenhouse gases beyond the ones covered by the IEA and EDGAR. It does however not contain quite as many years of recent data as IEA and EDGAR (last year is currently 2019 rather than 2021) and uses emission factors that differ significantly from IEA. For these reasons we have not recommended it as a default dataset for the gases covered by IEA and EDGAR.

3.7.5 Land use change

3.7.5.1 Uncertainty and methodological challenges

Calculating and harmonising emissions from land use change (LUC) is complicated by both data and methodological issues. To what extent land use change (or land use in general) should be modelled and included and in what way will depend on the research question.

Many different methods are used to assess LUC emissions in the literature. Even for different studies using the same type of method, the wide range of possible assumptions, choice of raw data and inherent uncertainties in that data still tend to produce a wide range of results.

Another challenge for reconciling LUC emission data sets is a fundamental difference between how the boundary is drawn between anthropogenic and natural land sources and sinks of CO_2 in national GHG inventories vs. bookkeeping models or dynamic global vegetation models (DGVMs) commonly used in the scientific literature.

In national inventories, land areas are classified as either managed or unmanaged, based on whether or not the area has been utilised for human purposes or disturbed by direct human activity in the sufficiently recent past. Essentially all changes in vegetation and soil carbon on managed lands are included as emissions or sinks in the inventory. This can include changes that are not a direct effect of human activity in that area, such as climate change or other environmental changes, or natural cycles. Bookkeeping models and DGVMs, on the other hand, typically explicitly or implicitly define land-use change emissions and sinks as the changes in carbon stocks caused directly by human interventions and their aftereffects over time, but do not include the effects of climate change or other external influences that don't come from human activity localised to the same area. This will typically cause net emissions in national inventories to be much lower (or more negative) than bookkeeping models in regions where, e.g., warming or CO_2 fertilisation is causing forest biomass to increase, and higher in areas where climate change or other external impacts are having the opposite effect. This discrepancy and the background for it is explained at length in Grassi *et al.* (2018). The issue must be taken into account by any models that align with national GHG inventories.

3.7.5.2 Recommended approach to LUC CO_2 emissions

Due to the large divergence between different datasets and high overall uncertainty, it is difficult to recommend any particular dataset or method for harmonising LUC emissions. For several of the potential research questions, LUC emissions are not relevant and should probably not be included in the modelling. Where LUC emissions are relevant, preserving model diversity may be essential to reflect the uncertainty.

For these reasons, we do not recommend an overarching harmonised dataset for LUC emissions. Instead, we tentatively recommend that each group follow their default approach to land use and LUC emissions, including the calibration data that they prefer or find most appropriate, unless the research question indicates using a particular approach or data set.

However, **models that use historical LUC emissions for calibration or as input data should check that those emissions fall close to or within the range spanned by the three bookkeeping models that form the basis for the LUC emission estimate in the Global Carbon Budget 2022 (Friedlingstein et al., 2022; Global Carbon Project, 2022).16 If they are not, the model group in question and the research question leader should discuss whether the discrepancy has a large enough effect on the interpretation of the results to require action. If a harmonised dataset is needed, we then**

[16] Excel spreadsheets with the LUC emissions from the bookkeeping models can be downloaded from Global Carbon Project (2022), https://doi.org/10.18160/gcp-2022. Use the file labeled "2022 National LandUseChange Carbon Emnissions 2022" for national-level emissions, and the main file "2022 Global Budget 2022" for global emissions. Take the average of the three bookkeeping models "BLUE", "H&N" and "OSCAR". Note that the numbers are in GtC, not $GtCO_2$.

recommend using the central estimate of the Global Carbon Budget 2022, i.e., the average of the three bookkeeping models used there.

This recommendation presumes that the model defines LUC emissions in a way that is consistent with bookkeeping models and does not adopt the definition based on managed vs. unmanaged land that is used in national GHG inventories. See below for more on aligning with national inventories.

3.7.5.3 Adjusted approach for LUC CO_2 emissions aligned with national GHG inventories

If a model or a particular modelling exercise requires that LUC emissions be done defined based on total carbon stocks in managed lands, as in national GHG inventories, the approach described above can still be applied, with one modification.

Instead of checking consistency with the bookkeeping models in the Global Carbon Budget 2022 directly, modellers can apply the method and data described in Grassi et al. (2023b) **to adjust the emissions from the bookkeeping models to be closer to the national inventory approach**. The method there uses results from DGVMs to estimate "natural" fluxes on managed land in each country, i.e., fluxes not due to human activity on the managed land itself. It then adds those fluxes to the fluxes from the bookkeeping models, to arrive at a total flux that is conceptually (and in most cases numerically) closer to fluxes on managed land in national GHG inventories. The data can be downloaded in an Excel file from Zenodo (Grassi et al., 2023a).[17]

If the model or modelling exercise requires emission that are identical to national inventories for the countries and years where they are available, the harmonised and gap-filled LULUCF data for national inventories from Grassi et al. (2023b) can be used instead. This data is available from a different Excel file on the same Zenodo page.[18]

3.7.6 Climate emulation and infilling missing emissions

Not all models calculate all types of emissions as output. In modelling exercises where the outputs from models are fed to simple climate models to assess the climate impact, it may be necessary to select a set of default emissions to use for infilling missing emission types. What data to use may depend on details of research questions, and we therefore do not categorically specify what values to use for infilling in this deliverable. **When the research question does not imply any particular constraints, but a "neutral" set of infilled emissions is needed that is consistent with the emissions of modelled gases, we recommend using the Silicone Python package to generate such a set.[19]** This package has, e.g., been used to infill emission datasets used by IAMs for the Working Group III contribution to the IPCC's 6th assessment report (Kikstra et al., 2022).[20]

Infilling of missing emissions will most often be necessary in cases where climate impacts of modelled emissions are to be assessed using simple climate models. These models will typically need to be run with a historical emission dataset that is consistent with the harmonised energy and/or emissions data used by the models for any

[17] The fluxes from bookkeeping models and DGVMs are in the file "Global models land CO2 data 2000-2020.xlsx". To adjust the bookkeeping models to approximate national inventories, for each country, take the average over each model (including "org.soil") of "LULUCF net" from the worksheet "BMs", then add the flux for "NON INTACT FOREST" for the same country from the worksheet "DGVMs".

[18] Use the data in the Excel file "National inventories LULUCF data 2000-2020 (Dec 2022).xlsx", from the worksheet "Table 5" ("Net LULUCF CO2 flux in the NGHGI DB, gap-filled through linear interpolation")

[19] Silicone version 1.0 is described in a journal article (Lamboll et al., 2020). The code for the latest version (1.3.0 at the time of writing) is available on GitHub (Lamboll et al., 2019/2022). Documentation is available on readthedocs.io (Lamboll et al., 2022). Silicone is still undergoing active development. Each research question leader should therefore decide on a version to be used by all modelling teams for that research question, based on what version is available at that time and required features. Custom versions may need to be developed depending on the needs of each modelling exercise, but the research question leader should ensure that all modelling teams use a single consistent version for any given research question.

[20] Kikstra, J.S., Nicholls, Z.R.J., Smith, C.J. *et al.* The IPCC Sixth Assessment Report WGIII climate assessment of mitigation pathways: from emissions to global temperatures, Geosci. Model Dev., 15, 9075–9109, https://doi.org/10.5194/gmd-15-9075-2022 (2022).

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given research question, as well as consistent data on land use and other climate forcings, before switching to using emissions outputs coming from the IAMs, sectoral or energy-system models at the start year of the modelling run. The end year of climate simulations may depend on the research question, but in most cases a run to at least 2100 will be needed to assess outcomes against the goals of the Paris Agreement or to compare with scenarios from the IPCC assessment reports.

IAM COMPACT can deploy four different simple climate models, which are all compatible with the OpenSCM framework: CICERO-SCM, FaIR, Hector and MAGICC. If nothing about their characteristics or the research question suggests otherwise, all four should ideally be used for estimating climate impacts, in order to better assess uncertainty.

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4 Research questions

4.1 Themes and emerging research questions

The stakeholder engagement in IAM COMPACT and the research questions that will result from it are organised into three themes:

1. Industry and Innovation
2. Optimal Transition
3. System Effects

as well as the general theme "Energy and climate policies" across five regions outside the EU:

1. Ukraine
2. Mainland China
3. India and Sri Lanka
4. Kenya and Ethiopia
5. USA (with particular emphasis on the Inflation Reduction Act)

As part of the policy response mechanism in IAM COMPACT (PRM), work package 2 have conducted interviews with several EU-based stakeholders on the themes above (previously organised under slightly different titles), the results of which are described in D2.2. See D2.2 for the full and unabridged list of research questions that emerged from the interviews.

In parallel to finalizing D2.2, task T2.3 has also undertaken a narrowing of research questions to ones that will be addressed through modelling in the first modelling cycle, including recruiting modellers to lead and to participate in the modelling for each research question. At the time of writing, this process was being completed but not yet finalised. After completion, further meetings will then take place both among modellers for each research question and with stakeholders to further refine the focus of each question, validate the modelling approach from a stakeholder perspective and co-create research question-specific scenario protocols. This work should also contribute to closing most of the unresolved questions described in chapter 3.

The list of research questions to be modelled has not been finalised at the time of writing, and no work yet undertaken to create research question-specific scenarios. We do not report anything on tentative research questions here. More will be reported in the update to this deliverable, D4.4.

4.2 Energy crisis scenarios

Prior to work on the research questions in D2.2 and the writing of this deliverable, the IAM COMPACT project had already conducted modelling work in late 2022 and early 2023 specifically to address the ongoing energy crisis in Europe (hence informally referred to as the "energy crisis" analysis and scenarios). The work aimed to quantify the implications of different options for completely phasing out imports of Russian natural gas to the EU. The modelling was carried out using four integrated assessment models (GCAM, TIAM, MUSE and PROMETHEUS) and two sectoral models (MARIO[21] and EXPANSE). A policy brief describing the results was submitted to the European Commission's 2040 target planning process on 28 April 2023 (Nikas et al., 2023).

The energy crisis analysis explored the implications of phasing out Russian gas through four extremal scenarios

[21] MARIO was used for the energy crisis modelling work, but is currently not included in the first regular modelling cycle of the IAM COMPACT project.

for replacing the lost gas imports,[22] as well as two different baseline scenarios, reflecting continued imports as before the 2022 Russian invasion of Ukraine with only current policies and with NDC climate targets, respectively.

The scenarios used in the energy crisis analysis were (using scenario numbering and codes from the analysis itself):

- **Baselines:**
  - **1a CP_Default:** Continued imports as before the 2022 Russian invasion of Ukraine, only current policies
  - **1b NDC_Default:** Continued imports as before the 2022 Russian invasion of Ukraine, with NDC Net Zero climate targets
- **Extremal scenarios** (all include NDC net zero climate targets and no Russian gas imports from 2023):
  - **2 NDC_NoRus:** Each model models its own optimal pathway for replacing lost imports
  - **3 NDC_NoRus_Imp:** Replace Russian gas with imports from other sources and regions, including pipeline gas and LNG from global LNG markets
  - **4 NDC_NoRus_Dom:** Replace Russian gas with only increased domestic energy production (including electrification and any type of NDC-compatible increased electricity production), with imports from other regions as in scenario 2.
  - **5 NDC_NoRus_Eff:** Replace Russian gas with enhanced energy efficiency

The energy crisis analysis created a scenario protocol for how to model each of the scenarios, including background assumptions for GDP, population numbers, etc. The organisation of the scenario-specific parts of this scenario protocol can serve as inspiration for research question-specific scenario protocols to be developed for the research questions in the first regular modelling cycle (D2.2). The specifications for the broad scenario protocol in this deliverable (in chapter 3) to some extent follow the baseline specifications in the energy crisis scenario protocol, but differ in some ways (see chapter 3 for further description and rationale for the choices made in the current deliverable):

- For medium-term GDP through 2028, IMF World Economic Outlook is used, updated relative to the version used in the energy crisis scenarios (April 2023 version instead of April 2022).
- For longer-term GDP projections, this deliverable uses 2021 version of the EU Ageing Report for the EU due to its widespread use in EU policy making, rather than Cassetti et al. (2023) as used in the energy crisis scenarios. Like the energy crisis scenarios, this deliverable uses the OECD Economic Outlook 109 long-term baseline (2021) for GDP growth in included regions (OECD+)[23] through 2060. Also like the energy crisis scenarios, all sources are extended using GDP growth rates from SSP2 as needed, but this deliverable adjusts the growth rates based on how projected working-age populations differ from the population trajectory of SSP2, since this deliverable does not recommend using the SSP2 population projection.
- For population, this deliverable uses Eurostat projections (EUROPOP2019) [24] for EU countries and OECD Stat (2022) projections for OECD+. For the rest of the world, the latest U.N. projections are used instead of SSP2, since global population numbers are already considerably higher than the SSP2 trajectory.

These choices are mostly consistent with those made in the energy crisis analysis, while taking later data updates into account, and adjusting for the more general and potentially longer-term scope of the broad scenario logic.

[22] The scenarios were (using scenario numbering from the analysis): 2) No constraints other than an end to Russian gas imports starting in 2023, each model chooses its optimal way of replacing lost imports; 3) Replace Russian gas with gas imports from other sources, including both pipelines and from global LNG markets; 4)

[23] The "OECD+" regions covered by both OECD Stat's population and GDP projections include, apart from OECD and EU member countries: Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia and South Africa.

[24] EUROPOP2019 is used rather than the older EUROPOP2018 or the newer EUROPOP2023 in order to be consistent with the GDP projections from the 2021 Ageing Report, which are based on EUROPOP2019. The differences between the two population projections are not large enough that we consider adjustments to be necessary.

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5 Data/code availability and input/output formats

The final formats of the data to be provided to modellers have not yet been finalised (see section 3.2). The statements made here about data sharing and availability are therefore preliminary but set out principles and intentions for how the necessary harmonised input data will be provided.

5.1 Open Science principles

The harmonised data sets described in section 3 will as far as possible be provided in a manner consistent with open science principles. For further details on these principles and the protocols to be used in IAM COMPACT, see deliverable D3.6 (to be published in late June 2023). As D3.6 was not finalised at the time this deliverable was submitted, any statements made here are subject to change if necessitated by the final content of D3.6.

5.2 Input data availability

In general, data sets will be published on Zenodo (IAM COMPACT, n.d.) whenever possible. Custom code used to produce the data sets and any coded needed to process them further will be hosted on GitHub for version control, and release versions will be mirrored to Zenodo. The open data sets already recommended in chapter 3 will be prepared and published on Zenodo during the summer of 2023, while data sets decided on through ongoing dialogue will be published as soon as possible after they have been decided and processed. Direct links to each data set on Zenodo will be included in D4.4 in addition to being sent directly to modellers.

Some data sets may be proprietary and subject to restrictive license conditions and can therefore not be published on Zenodo or any other open platform. This notably applies to energy data from the International Energy Agency (IEA)[25]. We only recommend the use of proprietary and restrictively licensed data when most or all models already use them. In these cases, we expect that the modellers already have the necessary data and therefore only specify the data source without providing or publishing the data itself.

For data that are readily available for free online but have a semi-permissive license that allows free use but not republication, we will provide links and instructions for how to download the necessary data to modellers. We will also include this information in D4.4 but will not post the data on Zenodo.

5.3 Model outputs

Models should provide output in the format of the IAMC template (Integrated Assessment Consortium, 2020), with as many variables and at as high a level of detail as is practically possible. This must include any endogenously modelled or calibrated variables that overlap with the harmonised data specified in chapter 3, so that consistency with the harmonised data can be assessed. Sectors should be reported both using the sector categories that are used natively by the model at the highest practical level of detail, and additionally in IPCC sector classification. The latter is especially important for any models that report emissions and/or energy use or other activity data relevant for calculating emissions.

Models that use sub-annual time steps or sub-national regions can use the extensions to the IAMC format defined in the openENTRANCE project (Krey et al., 2019).

Greenhouse gas emissions should always be reported as tonnes of the gas in question when at all possible, rather than or in addition to CO_2 equivalents, both to avoid ambiguity and to make it possible to compute other emission

[25] IEA have stated that their data may be opened up in the future if member countries approve the necessary funding, but this has not yet happened at the time of writing. The issue was reported to have been discussed by IEA's board in March 2022 (https://www.energymonitor.ai/finance/reporting-and-disclosure/iea-chief-start-making-iea-data-freely-available/), but no more information appears to have been published about the matter since then.

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metrics than CO_2 equivalents with standard GWP values. If some emissions *must* be reported as CO_2 equivalents due to aggregation issues, GWP100 values from the IPCC's 6th Assessment Report should be used unless specific research questions require a different metric.

In keeping with the conventions used in IPCC assessment reports, when primary energy production is part of model output, it should be reported using the direct-equivalent method. I.e., for electricity and heat produced from sources other than combustible fuels[26], the corresponding primary energy should be reported as the electrical and heat energy produced. Models that use other conventions for primary energy accounting internally must convert primary energy to the direct-equivalent method before reporting it in the IAMC template.

Also, in keeping with IPCC conventions, the primary energy content of combustible fuels should be reported using the net calorific value (NCV) (also known as lower heating value, LHV), i.e., not counting the latent heat of water vapor or other condensable gases released in the combustion. Furthermore, models that represent consumption of traditional biomass should report this and separate it from modern forms of bioenergy by using the variable designation "Primary Energy|Biomass|Traditional". Likewise, models that represent non-energy use of fuels should clearly mark final consumption for non-energy purposes in an appropriate manner. For example, a variable designation like "Final Energy|Natural Gas|Non-energy" may be used to denote non-energy consumption of natural gas. Sector or other designations could here be added between "Final Energy" and "Natural Gas" to identify which sector or process it is being used for if such breakdowns are represented in the model.

Research question leaders may want to make additional specifications for what minimal set of variables, derived or aggregated variables and level of detail must be provided to adequately address each research question.

All model outputs will go through a vetting and quality control process, which is not yet finalised. This process will be developed in the context of task T3.6 ("Scenario validation and diagnostics") in the months following submission of the current deliverable, in collaboration with task T3.4 ("Upgrade and operation of the I²AM PARIS data exchange platform") to develop checks for uploads to the I²AM PARIS platform.

[26] This includes both non-thermal energy sources like hydropower, solar photovoltaics and wind power, as well as non-combustion thermal sources like nuclear energy, geothermal energy, solar heating and concentrating solar power.

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