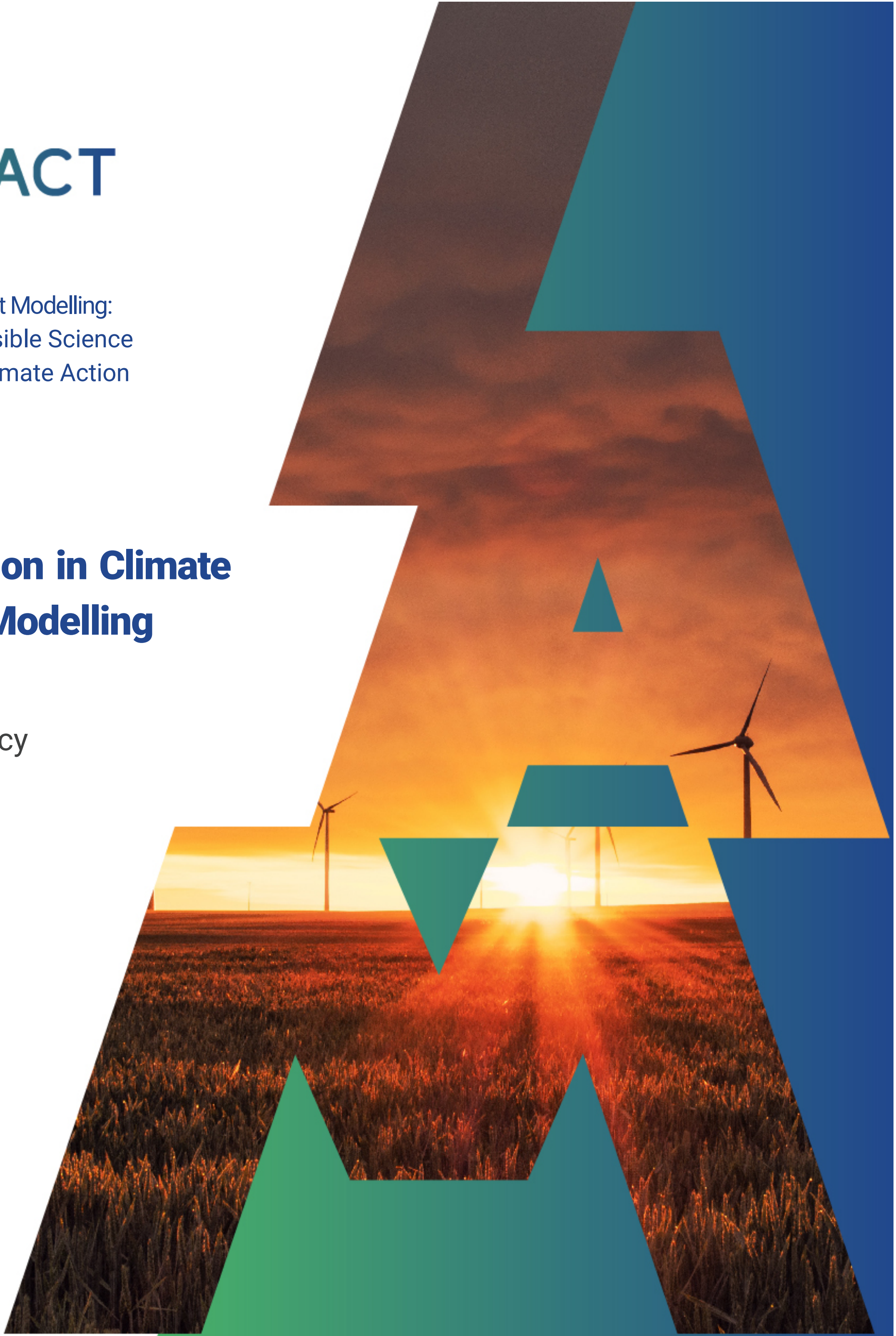
IAM COMPACT

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



Stakeholder Inclusion in Climate and Energy Policy Modelling

The IAM COMPACT Policy Response Mechanism

The aim of this publication is to provide stakeholders with an overview of the envisaged modelling process of the IAM COMPACT project and explain the stakeholder engagement strategy that will form a core part of this process. The strategy revolves around a policy response mechanism to facilitate constructive dialogue and knowledge sharing between stakeholders and scientists with the aim of generating policy-relevant insights.

The IAM COMPACT project has received funding from the European Union's HORIZON EUROPE Research and Innovation Programme under grant agreement No 101056306.

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1 Introduction

IAM COMPACT is an EU Horizon Europe project operating from September 2022 to August 2025. The project brings together an international and interdisciplinary consortium of modelling teams to support the design of a multi-dimensional set of policy measures to help set the world on a path to climate neutrality and meet our Paris Agreement goals. Project partners are based across Europe and the globe.

In its modelling activities, IAM COMPACT will employ a diverse ensemble of national and global integrated assessment models (IAMs) as well as other sectoral models. The project objectives include supporting the assessment of global climate progress and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030. Enhancing the robustness of scientific outputs is another key element of the project, particularly through incorporating social, political, behavioural, and innovation aspects and providing detailed information about the barriers and drivers of transitions. Insights from stakeholders—mainly including but not limited to policymakers, industry representatives, and civil society organisations—will be especially important in this part of the project.

There have been steps in acknowledging the value of stakeholder input in climate policymaking, such as in the Talanoa dialogue established through the UNFCCC. The importance of stakeholder engagement is also firmly established in climate and energy research, but there continues to be insufficient inclusion of non-scientists in modelling practice. Novel topics and broader scenarios have been better included in climate-economy modelling recently, but direct involvement of stakeholders throughout the modelling process is still lacking.

The policy response mechanism in IAM COMPACT aims to directly involve stakeholders in the modelling process. This approach will aim to co-create policy-relevant modelling by connecting stakeholders and modellers, matching policy questions to suitable models, to collaboratively refine scenario assumptions, and to enhance mutual learning throughout the modelling process. This policy brief outlines this mechanism and provides non-scientist readers with a broad understanding of the capabilities of models to address policy questions. Section 2 discusses the modelling process and how it can inform policy needs. Section 3 outlines the policy response mechanism, setting out the process step-by-step. Section 4 provides two instructive examples of the policy response mechanism.

2 How can models inform policymaking?

As coordinators of the Policy Response Mechanism (PRM), it is Bruegel's responsibility to manage the engagement between stakeholders and modellers. A shared understanding of the needs of stakeholders and the capabilities of modellers is essential to ensure these engagements are useful.

Evidence-based climate and energy policies are required to meet the goals of the Paris Agreement. These policies will drive change across most of our economies and societies. Therefore, climate and energy policy measures should be, as best as possible, designed to achieve socially optimal outcomes. A typical example is the need to balance rapid decarbonisation with distributional impacts. Modelling can provide evidence to support a policy measure or point out potential unseen impacts. Given that modelling plays this important role in the policymaking process, it is important that models are well-understood by stakeholders. Modelling can offer powerful insights, but results must be considered in the appropriate context.

2.1 Model Types

The IAM COMPACT modelling ensemble includes a range of model types that differ across a number of dimensions: their geographical coverage; the range of technologies and measures that they include; the detail in which each economic sector is represented; the timescales which they cover, and how finely (e.g. seasonally, yearly, multi-yearly) they represent time; as well as how they assume economies behave. Each model has its advantages and limitations.

2.1.1 Brief overview of the modelling types available to IAM COMPACT

Energy System models (otherwise referred to as energy system optimisation models, energy models, energy-economic models, etc) have detailed representations of energy sector processes. These essentially include fuel extraction, transformation into useful energy forms (e.g., electricity), delivery of this energy to end users, and finally consumption of this energy to provide consumer services (e.g., transportation and heating). They may not include any aspects of behavioural or economic system responses to changes in the energy system.

Partial equilibrium models also typically focus on a specific sector, such as energy or other greenhouse gas-emitting systems (e.g., the land use and agricultural sectors). They explicitly account for how changes in energy and other prices affect demand for energy and other services in each sector of interest, thereby achieving a supply-demand equilibrium in each sector.

Computable general equilibrium (CGE) models are large-scale models describing the entire economy and the multitude of interactions between its constituent sectors. Prices adjust so as to achieve an equilibrium between supply and demand; however, contrary to partial equilibrium models that assume equilibrium by sector, this CGE equilibrium is achieved throughout the entire economy.

Other sectoral models simulate specific sectors of the economy, such as land use, transport, or inter-industry, often to a greater level of detail than in whole-system energy models.

It should be noted that the above categorisations are not all mutually exclusive. Energy system models generally form the heart of partial equilibrium models, once a demand-response functionality is added. Macroeconomic models (such as CGE) can also have detailed representations of the energy system.

In addition, some models (integrated assessment models) combine representations of energy, land and agricultural systems, in some cases with modules that calculate the temperature change resulting from the emissions from these systems.

Taking an ensemble approach, in which several models work in concert to address the same question, can account for the respective strengths and weaknesses of the various model types and reveal deeper and more robust insights than if models are employed in isolation. Models can work together by either being set to address the same questions separately or by being linked together to provide a more complete analysis in one policy area.

2.2 How do models work?

Models do not all operate in a similar way, but they do share some fundamental methodologies. Most importantly, all models depend upon socioeconomic, technological, and other assumptions to produce results. For instance, energy system models typically use exogenous data on socio-economic drivers such as population and economic growth, which drive demand for energy, as well as assumptions about the supply and cost of different sources of energy. They then model how energy technologies and fuel mixes might evolve over time, under scenarios targeting different emissions or climate outcomes. Most energy system models cover multiple sectors of the energy system.

The models are run based upon an initial calibration to current or recent historical data (on energy, emissions, technology costs and socio-economic variables such as population and GDP) whilst setting exogenous variables, for example around future socio-economic trends, technology learning rates, future fossil fuel extraction costs, future carbon prices and/or emissions targets. The models then calculate key variables, such as emissions pathways, the investment and annualised economic costs of mitigation towards emissions targets, or under particular carbon price projections. Different models may define a different relationship between variables, such as the demand response to an increase in energy prices, or the "stickiness" of substitution between high-carbon and low-carbon technologies. Others might allow for stochastic effects, such as setting a range of carbon price pathways or technology costs and allowing the models to find an "optimal" outcome under conditions of uncertainty (e.g., an outcome that represents the lowest expected cost over time).

One critical distinction between modelling types is that some models (generally CGE) assume that before any climate policies or targets are imposed, economies are operating at an equilibrium reflecting full employment of resources, such that any deviation from this results in an economic loss. There exist other models, however, commonly macro-econometric ones, which do not assume such equilibrium, such that they do not necessarily lead to economic losses once emissions targets or policies are imposed. The output of the models depends on the definition of these relationships. Therefore, different models will output different results, even with the same input assumptions.

2.3 What methods are applied in policy-oriented modelling?

2.3.1 Scenario analysis

Models can assess the possible evolution of sectoral, national, and global economies as well as energy systems across a range of scenarios. The scenarios can be differentiated by the underlying socioeconomic assumptions, such as population growth and energy demand, or specific policies, such as regulations, fuel efficiency standards, renewable portfolio standards, carbon prices, or cleantech subsidies (depending on what can be represented in the model). Consumer preferences or technological costs could also be systematically adjusted to understand the potential impacts on outputs such as technology, fuel mixes, and economic indicators.

The policy mix can be adjusted across scenarios and the impact of a new set of policies on the economy, the energy system, and climate indicators can be calculated. The underlying exogenous assumptions relating to socioeconomic and technological parameters can also be adjusted, while keeping the policy mix constant. Depending on the policy need, certain models would be better suited to evaluate different policy areas based upon the model type and its characteristics.

For example, the shock of increased energy prices as a consequence of the Russia-Ukraine war could be investigated. One area of model-based investigation could be to explore the impact on GDP growth or fuel switching under scenarios, in which high prices persist for different periods of time. Alternatively, an energy system model could explore how fuel-switching in response to reduced supply and increased cost of natural gas due to the Russia-Ukraine crisis might affect future national emissions or power system costs. Linking the outputs of the energy system model to a macroeconomic model could then look at household income effects or employment figures.

Models are perhaps most informative when they can provide insights into policy effects across a range of scenarios. A mix of policies can be modelled under a baseline scenario and then compared to results under when the policies are implemented under other scenarios. For example, under different trajectories of global oil prices, what are the policies needed to encourage investment in EVs.

2.3.2 Forecasting

Forecasting in modelling means to initialise the model at a point in time, typically in the recent past (usually using the latest available consistent data sets on energy, emissions, and other key model input data), and then to run the model forward to gain insight into how the energy system might evolve into the future. For example, forecasting has been used to assess how energy systems and emissions levels could evolve in response to a steadily increasing carbon price. It could also be used to understand the impacts on national and regional energy systems of the supply shock of reduced Russian gas to Europe, with impacts of interest including the costs of the low-carbon energy transition, the alternative sources of gas demand, and the set of replacement fuels and energy vectors. This could be extended across a range of scenarios that make different assumptions about the policy mix enacted in response to the supply shock.

2.3.3 Backcasting

Backcasting, in contrast to forecasting, tends to set a future goal, towards which models (once again beginning in an initial configuration representing recent history) goal-seek. This type of model run is therefore more constrained than a forecasting approach and it is distinct from forecasting in that it starts with a desired end goal in mind, such as a technology mix or a certain level of carbon emissions. For example, a backcasting exercise could begin with an energy system that meets the REPowerEU targets (the EU's response to the energy market disruptions caused by Russia's invasion of Ukraine) in 2030 and then work backwards to understand how much wind and solar generation capacity would need to be installed each year to arrive at that energy system, as well as the associated investment costs of doing so.

2.4 What policy questions are suitable for modelling?

As the IAM COMPACT project includes a diverse mix of model types across sectors and geographic scales, the ensemble is suitable for assessing a large set of mitigation and adaptation options and policy instruments. Models can rarely represent a policy perfectly, but some models are better suited than others. With this in mind, it is essential to properly frame policy questions such that models can provide useful insights. To do so, policy questions must consider the structure of the models and the necessary inputs to, and possible outputs of, models.

2.4.1 Model inputs

Model inputs refer to the assumptions (e.g., socioeconomic and technoeconomic projections, scenario-specific assumptions, etc.) that are necessary for a model to run. As the assumptions are closely linked to the policy questions, it is vital that the questions be posed in a such a way that the models can be constructively used to provide insights for policy makers. For example, asking what the effects of increasingly large climate protests are on emissions levels is not something most models in the IAM

COMPACT ensemble could address. Technically speaking, model inputs can refer to numerical parameter values, model structures, and model system boundaries.

Model inputs also relate to the policy questions under consideration in the modelling research. Depending on the assumptions used and the inputs given to the model, certain policies can be represented. A common example is the implementation of a carbon tax in the model, which can be represented by assuming that the price of energy from different sources increases by an amount relative to the carbon emissions of those sources. It is imperative to point out that, in most cases, policies cannot be perfectly represented in models. Often, modelling teams will develop a proxy for a given policy, or a simplified indicator of the "social benefits" of assumptions related to the policy and then evaluate the indicator instead.

To illustrate the point, to investigate the distributional impacts of a policy, macroeconomic models may split the consumers into income cohorts and then assess how the policy affects the different groups defining certain effects as "social benefits". This is an incomplete picture of the distributional dynamics and, while it is not a perfect representation of the policy, it may be sufficient to provide useful insights for policymaking. Another model may not be able to represent different income cohorts and may need to take more drastic simplifications in order to arrive at a representation of the policy.

2.4.2 Model outputs

Model outputs refer to the results of a model run. Implementing a policy mix or assessing different scenarios will result in many changes to economic and climate indicators. Models output changes, depending on their configuration. Policy questions should be framed in consideration of the information that can be output from models. As noted above, the "socio-cultural benefits" of implementing a given policy instrument cannot be easily assessed by a model that does not explicitly output the distributional impacts of policies. More specificity, such as asking what the impact on an economic or environmental indicator that is explicitly represented within the model, would be more appropriate.

Examples of model types and their inputs/outputs include:

General equilibrium models

- *Input examples:* taxation, interest rates, population growth, emissions targets.
- *Output examples:* GDP, employment, emissions levels, trade flows, energy demand.

Energy system and partial equilibrium models

- *Input examples:* energy efficiency targets, energy technology costs, commodity prices.
- *Output examples:* fuel mix, electricity generation mix, sectoral emissions.

Sectoral/technological-policy options can be applied into a range of sectors. Many models in IAM COMPACT represent energy systems in detailed sectoral depth. Listed below are some examples of sectors that may be considered important for investigation:

- Upstream technologies (e.g., synthetic fuel production, such as coal to gas; hydrogen production).
- Electricity and heat generation (e.g., coal/gas with CCS, nuclear fission, solar PV, offshore wind).
- Electricity storage.
- Buildings (heating, such as heat pumps replacing gas boilers, hydrogen; lighting, efficiency; appliances, efficiency; cooling).
- Industry (process heat; machine drives; steam; CHP).
- Land use (payments to landowners for holding carbon stocks, e.g., trees)

Further details on the IAM COMPACT modelling ensemble can be found in the Annex.

2.5 What don't the models do?

Models are an approximation of the real world, and their outputs are dependent upon their underlying assumptions. As set out above, these assumptions include socioeconomic factors (e.g., population growth, GDP growth), energy technology parameters (e.g., cost and efficiency), and representation of policies, such as carbon prices, regulations, or technology portfolio standards.

Behavioural changes are typically not well represented in models, such as company or household decisions to invest in solar PVs due to network effects and social pressures, rather than purely for financial reasons. Some models (such as MUSE, in the IAM COMPACT project) can represent agents' choices to make such shifts in response, for example, to changing prices or other specific preferences, but large-scale behavioural changes such as shifts to vegan diets or energy conservation are more commonly modelled through implementing exogenous changes. Decision-making is often modelled through the actions of a 'representative agent' (in practice representing an entire sector, such as iron & steel manufacturing, or road transport), with differences between agents (such as specific companies or households) in the energy system generally unspecified. Furthermore, decisions are usually driven by economic incentives such as cost-minimisation. Behaviour determined by non-economic incentives is rarely modelled. IAM COMPACT will explicitly seek to develop the modelling of behavioural changes in its research agenda to contribute to this emerging topic.

Given that models should be carefully interpreted and that their interpretation requires a certain level of understanding and engagement with the modelling process, a core element of IAM COMPACT is to directly involve stakeholders in this process via the *policy response mechanism*. This approach can aim to arrive at more realistic scenario building and more pertinent policy questions. Modelling is most effective when it is in constructive dialogues regarding realistic inputs, as well as why models output the results that they do.

In the context of the IAM COMPACT modelling ensemble, questions that focus on socioeconomic factors as inputs and on economic, environmental, and energy indicators as outputs will be most fruitful. Social and behavioural inputs and outputs are typically less well represented in the ensemble (although this area will be developed in IAM COMPACT), while distributional indicators (with some exceptions, such as income cohort differences, as discussed above) are generally poorly represented (Figure 1). These levels of representation should inform the approach to developing the policy questions for the IAM COMPACT research agenda.

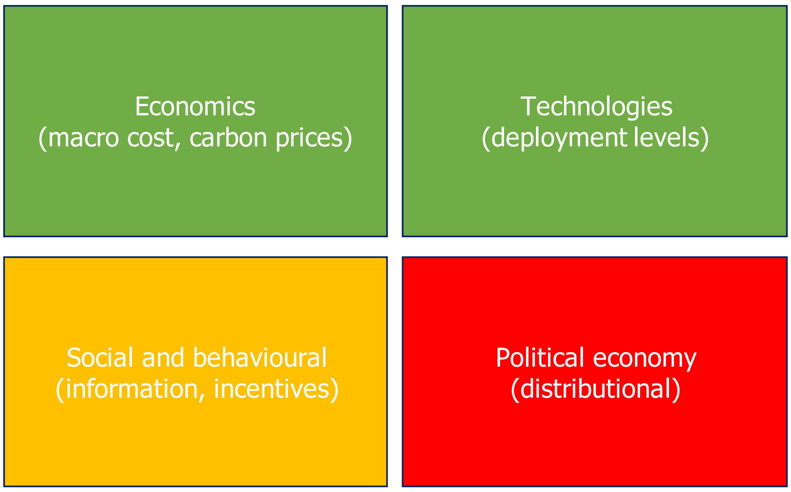

Figure 1. Suitable (green) to unsuitable (red) questions for the IAM COMPACT modelling ensemble

3 Policy Response Mechanism – Overview

Engagement and the exchange of knowledge between researchers and stakeholders is a fundamental part of IAM COMPACT. A stakeholder engagement strategy for successful knowledge co-creation and ensuring the policy relevance of IAM COMPACT research activities will seek to facilitate this exchange of knowledge. The policy response mechanism (PRM) is the core of the stakeholder engagement strategy for IAM COMPACT, aiming to create a structured, coherent format for engagement between modelling teams and stakeholders. Bruegel, the Brussels-based think-tank and a partner in IAM COMPACT, will operate the PRM and act as facilitator between modellers and stakeholders. The PRM organises the communication of model capabilities to stakeholders and the communication of the priorities and questions from stakeholders to modellers.

It is important that the PRM remains flexible throughout the IAM COMPACT project so that the consortium can adapt to changing policy agendas and stakeholders needs. There are likely to be lessons during the project that will lead to changes to the structure of the PRM. The fundamental aim of the PRM is to be inclusive in the spirit of the Talanoa dialogue and to ensure that stakeholders have a voice in the modelling process, such that the modelling process remains policy-relevant and co-owned by all involved.

3.1 Identifying Stakeholders

The first step in the PRM will be to establish *core working groups* (10-20 stakeholders) and *policy steering groups* (3-5 policymakers). These groups will form the foundation of the PRM.

Within the EU, each *policy steering group* will be focused on specific themes. Outside of the EU, each *policy steering group* will be country-specific. The themes within the EU and the regions outside the EU will be agreed upon within the consortium before stakeholders to fill the groups are identified. These themes will be based on the important policy issues at present, such as industry relocation, international energy trade flows, or energy efficiency, and the region-based group should be sufficient to cover the geographical areas of interest for the project partners, with an emphasis on non-European partners.

The *policy steering groups* will be primarily made up of policymakers responsible for preparing climate policies in their respective regions, for example, policymakers involved in upcoming NDCs or long-term emission reduction strategies. Policymakers will be identified from the internal project stakeholder pool, managed by Bruegel, based on their relevance for the modelling research and their level of experience in their field and with modelling, while ensuring a diversity of views and nationalities.

The *core working groups* will comprise stakeholders from policy, industry, academia, and civil society, and will also be thematically organised within the EU and country-specific outside the EU. The stakeholders for the *core working groups* will be selected by the consortium to represent a diverse set of relevant views from EU countries and project-relevant non-EU countries, as well as relevant industrial sectors and civil society groups.

3.2 Modelling iterations

There will be two co-creative cycles of stakeholder engagement and modelling in IAM COMPACT. In each co-creative cycle, there will be two iterations of stakeholder engagement and modelling.

Initial policy-relevant research questions will be co-created with stakeholders in the *policy steering groups* at the beginning of each iteration. Scenario building, in collaboration with the *core working groups,* will then create a structured research agenda. The first iteration of modelling will then take place, during which the project partners will undertake the modelling research based on the policy questions scoped with stakeholders. After this first iteration, further stakeholder engagement will discuss the results and refine the research questions. A second modelling iteration will then take place, before more engagement with stakeholders, during which the second round of results will be discussed. Policy briefs will be published after each co-creative cycle, incorporating stakeholder feedback and communicating the key policy insights from the modelling research.

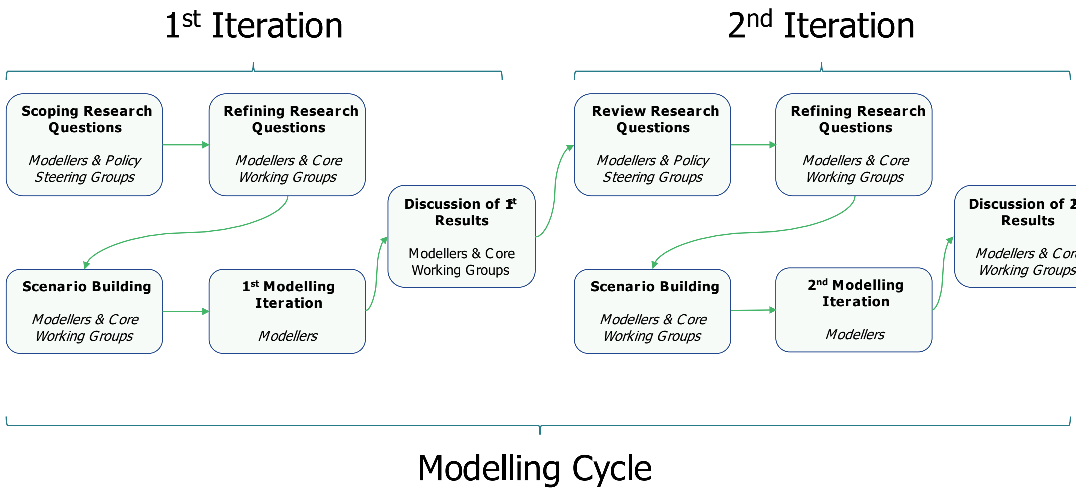

Figure 2. Stakeholder engagement steps within each modelling cycle

3.2.1 Scoping policy-relevant research questions

An initial set of discussions will be held between the consortium and the stakeholders in the *policy steering groups* to co-create policy-relevant questions that are within the scope of project. The engagement will take place through a consultation process involving small meetings and semi-structured interviews. Modelling teams in the project will have the opportunity to engage directly with stakeholders. An indicative framework that encapsulates the most pressing climate and energy policy questions will be developed for each theme and each region. The framework will be captured in a short report to provide an overview of the discussed research questions and potential areas for investigation.

This document will then be shared with other stakeholders and in collaboration with the *core working groups*, the scope of the research questions and their policy relevance will be further refined, ensuring that the research agenda is politically and socially realistic, while incorporating the knowledge and receiving the endorsement of a wider group of stakeholders. The scenario building process for the first modelling iteration then begins. There will be a second process of scoping policy-relevant questions ahead of the second co-creative cycle, incorporating the lessons from the first cycle. A report on the updated policy questions will also be published.

3.2.2 Scenario building and modelling

Scenario building, a key element of modelling, will be the next step in each PRM cycle. Like the scoping of research questions, this will be done at the beginning of both cycles. Modellers and stakeholders in the core working groups will co-create scenarios, considering both realistic input assumptions and desired outputs. Stakeholder involvement at this step should enhance the legitimacy of the modelling exercises later in the project.

In some cases, the scenario building process may take multiple iterations, depending on the complexity of the policy questions and the models employed. The nature of the scenarios, such as whether they capture the interests of several *policy steering groups* or just one, or if they intend to involve an ensemble of models, will depend on the research questions that arise from the initial scoping process. Broad scenarios that connect to several models will be preferred, as they can offer a wide perspective of insights for policymakers, but this approach is flexible and dependent on specific stakeholder and partner requirements.

Once the scenarios are defined, the first modelling iteration will begin. Upon completion of the modelling iteration, the modelling teams will report to the *core working groups* with the model results. After discussion of the first results, the second iteration of defining research questions and scenario building will take place, followed by another round of modelling and then discussion of the final results.

3.2.3 Discussing and communicating results

Through the operation of the PRM, the aim is to co-create a policy-relevant research agenda to guide the modelling and, therefore, result in model outputs that offer insights for real-world issues and can lead to concrete policy recommendations. From the point of view of the project partners, the goal for these post-modelling engagements will be to detail the insights from the model results but also any challenges that arose during modelling. To establish trust, the discussion after each phase of the modelling run aims to allow stakeholders to understand and query the model outputs. Bruegel will also produce a report on the proceedings of stakeholder interactions after each modelling iteration.

In each cycle, after the first modelling iteration, modellers will present to the *core working groups* the model outputs, along with the challenges faced and insights gleaned. At this point, stakeholders will again consider how to improve the legitimacy and relevance of the model results either through modifying policy questions, input assumptions, model parameters, or by other means. Given the technical complexity of this step, which requires a level of understanding of the modelling process, there may need to be several meetings held in smaller and more flexible groups to facilitate open and fruitful communication. The intended outcome of this step is a refined set of policy questions, which may include iterated versions of the initial questions or new entirely new questions, and associated scenarios. In addition, policy briefs (typically one per *policy steering group*), outlining how to translate the results of the first co-creative cycle into policy insights, will be published.

With the refined questions and scenarios in hand, modellers will carry out the second modelling iteration. Once completed, a report will be presented to the *core working groups* for comment. Input will be requested on both the report and on the efficacy of the PRM itself. The final step in each cycle will be to turn the technical modelling results into a set of policy recommendations within the final policy briefs. There will be an opportunity for a final round of feedback before the policy brief is published and disseminated to key stakeholders from the stakeholder pool, including but not limited to those in the *policy steering groups*.

3.3 Step by step example of PRM

1. A policy steering group is selected and made aware of the general model capabilities at our disposal.
2. Starting with an initial policy question co-created with a *policy steering group*, Bruegel moderates a discussion within the consortium on which teams would be best suited to fully or partially provide insight into the proposed question.
3. Models are then matched to the appropriate *core working group* (corresponding to the theme or region of the *policy steering* group) and enter a moderated discussion on how to make best use of the model capabilities to address various aspects of the policy research question.
4. Once the policy question has been refined, we then proceed to co-created scenario building (if necessary for the model and question) in collaboration with modellers and stakeholders.
5. The modelling teams then carry out their first modelling iteration.

6. After the first modelling iteration, engagement with the core working group will allow to further refine the research questions, modelling parameters, assumptions, etc.
7. The second modelling iteration then takes place, based on input from stakeholder regarding the results of the first modelling iteration and their policy priorities at the time.
8. The final model results will then be communicated to the stakeholders, with the opportunity for feedback and input to the policy recommendations stemming from the analysis.
9. The final step is the publication of a policy brief summarising the model results and their relevance for policy.

The above process will take place twice in the project (January 2023 – May 2024 and July 2024 – August 2025).

4 Policy Response Mechanism – Suitable and Unsuitable Policy Questions

Energy system modelling is a highly technical field in a strongly politicised environment. It can be a challenge for stakeholders and modellers to engage in a constructive dialogue that makes the best use of existing models to derive explicable and policy-relevant insights. It is important to stress that individual models are developed for answering a limited set of questions; to facilitate constructive engagement between stakeholders and modellers from the outset we find it useful to illustrate that there are many important and policy relevant questions that are not for addressing in IAM COMPACT—but should be better answered by other analytical tools.

4.1 Examples of policy questions and their suitability to the IAM COMPACT ensemble

Imagine that a *policy steering group* is established to focus on demand reduction. The group could suggest the following policy question:

How much will an EU-wide information campaign reduce gas usage?

There are several reasons why such a question is unsuitable for the modelling ensemble in IAM COMPACT. Primarily, the issue with this question and its focus on information campaigns is that behavioural change of this sort is not well represented with the models. The question does not consider how it could relate to model inputs or what assumptions could be adjusted in the arising modelling scenarios.

The question is also not specific regarding the sector that the campaign is targeted at or that might reduce its gas usage. While a focus on specific sectors could be determined via dialogue with the modelling teams, having a clear level of specificity in advance will lead to more constructive discussions from the outset.

Now consider a *policy steering group* on the theme of international energy commodity flows after the shock of the energy crisis. The following question could arise:

What are the economic consequences for emerging countries of altered international energy markets after the energy crisis shock?

This question is better suited to the IAM COMPACT model ensemble. It is focused on inputs that can be represented in the IAM COMPACT models (flows of energy commodities) and translated into modelling scenarios. The question is focused on economic consequences, (e.g., employment, GDP, welfare, etc.) that are also well represented in the model suite. Some refinement of the question would still have to take place, such as what emerging countries are investigated, which economic output variables are considered, or which specific energy commodities are focused on (e.g., LNG or oil). However, this question is much more useful from the outset for use in modelling and will lead to more fruitful engagement and, ultimately, more relevant policy insights.

ANNEX

GCAM

Model:	GCAM	Partner(s):	Basque Centre for Climate Change
Type:	*Partial Equilibrium*	Coverage:	*Global*

Description

The Global Change Analysis Model (GCAM) is a multisector integrated assessment model aimed at analysing human and Earth system dynamics, by exploring the interdependencies between the economy, energy, water, climate, and AFOLU systems within a single computational platform. The model is designed to analyse alternative "what-if" type scenarios and assess potential impacts of different assumptions about future conditions. The model reads in exogenous scenario "assumptions" about key drivers (e.g., population, economic growth, technology/land costs...) and then assesses the implications of these assumptions on key scientific or decision-relevant outcomes (e.g., prices, energy use, land use, water use, emissions, and concentrations). See GCAM documentation for more details: https://github.com/JGCRI/gcam-doc/blob/gh-pages/overview.md.

Sample policy questions

- Which are the implications for the energy/land/water systems of limiting CO_2 emissions / concentrations / limiting global warming to XºC?
- What are the multisector effects of the deployment of different energy technologies (e.g., electric cars)?
- What are the system-wide implications of alternative agricultural trade futures?
- How does different socioeconomic development affect future energy demand?
- Which are the FEW implications of negative emission technologies?

Key journal papers

- GCAM v5.1: representing the linkages between energy, water, land, climate, and economic systems

Key policy papers

- Can updated climate pledges limit warming well below 2°C?
- Implications of sustainable development considerations for comparability across nationally determined contributions

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TIAM

Model:	TIAM	Partner(s):	Imperial College London
Type:	*Partial Equilibrium*	Coverage:	*Global*

Description

The TIMES Integrate Assessment Model, TIAM, is the multi-region, which combines an energy system representation of fifteen different regions with options to mitigate non-CO_2 greenhouse gases as well as non-energy CO_2 mitigation options. It uses emissions from these sources to calculate temperature changes using a simple climate module. As such, it can be used to explore a variety of questions on how to mitigate climate change through energy system and transformations, as well as reductions in non-energy CO_2 emissions and non-CO_2 emissions.

Sample policy questions

- What is the role of role of direct air capture in meeting global 1.5ºC and 2ºC?
- What is the role of advanced technologies in achieving deep decarbonisation of the energy system?
- What are the energy system cost and energy technology and fuel mix implications of imposing emissions or climate constraints earlier or later in the century, in different regions at different times and to different levels of stringency?

Key journal papers

- Enhancing the realism of decarbonisation scenarios with practicable regional constraints on CO2 storage capacity
- An inter-model assessment of the role of direct air capture in deep mitigation pathways
- The role of advanced demand-sector technologies and energy demand reduction in achieving ambitious carbon budgets

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MUSE

Model:	MUSE	Partner(s):	Imperial College London
Type:	*Partial Equilibrium*	Coverage:	*Global*

Description

The ModUlar energy system Simulation Environment (MUSE) is an agent-based framework, that explicitly simulates the decision-making process of firms and consumers in the energy system. MUSE is technology-rich, thereby it characterises the cost and performance of each technology option, tracks technology stock, and provides details on investment, operating costs, energy consumption, and emissions with a detailed bottom-up perspective.

MUSE-Global is an implementation of a global model in the MUSE framework, characterising 28-regions of the world, and running over a time horizon of 2010 to 2100. It can be used to explore a variety of questions on how to mitigate climate change given the presence of heterogeneous behaviours affecting the pace of the system change.

Sample policy questions

- What is the role of electrification, fuel switching, and CCS for steel decarbonisation?
- How influential are company size and governance on CCS uptake?
- How can investor preferences constrain decarbonisation and delay decarbonisation choices?
- What is the influence of electricity storage on the uptake of renewables?

Key journal papers

- Long-term development of the industrial sector – Case study about electrification, fuel switching, and CCS in the USA
- An agent-based modelling approach to simulate the investment decision of industrial enterprises
- Agent-based scenarios comparison for assessing fuel-switching investment in long-term energy transitions of the India's industry sector
- The role of energy storage in the uptake of renewable energy: A model comparison approach

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PROMETHEUS

Model:	PROMETHEUS	Partner(s):	E3Modelling
Type:	*Partial Equilibrium Energy System*	Coverage:	*Global*

Description

Prometheus is a global energy system model that simulates both the demand and supply of energy. It covers the main interactions between energy agents (e.g., energy consumers, power producers) through a price-driven energy market equilibrium. Main objectives: 1) Assess climate change mitigation pathways and low-emission development strategies for the medium and long-term 2) Analyse the energy system, economic and emission implications of a wide spectrum of energy and climate policy measures, differentiated by region and sector) 3) Explore the economics of fossil fuel production and quantify the impacts of climate policies on the evolution of global energy prices.

Sample policy questions

- What is the role of mitigation options and associated costs towards achieving the 1.5C goal?
- Which are the most important sectors and options to increase climate policy ambition in the next decade?
- What is the role of accelerated energy efficiency improvements and demand-side transitions towards meeting Paris goals?
- Is the goal of limited global warming to 1.5C technologically possible and what are the associated impacts and costs?
- What are the emissions, energy system, and economic impacts of post-COVID green recovery packages? Can they pave the way towards meeting Paris goals?

Key journal papers

- Model-based analysis of Intended Nationally Determined Contributions and 2 °C pathways for major economies
- Integrated assessment model diagnostics: key indicators and model evolution

Key policy papers

- COMMIT Project: Summary for Policymakers
- EU Reference Scenario 2016: Energy, transport and GHG emissions, Trends to 2050

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WTMBT

Model:	WTMBT	Partner(s):	Politecnico di Milano
Type:	*Sectoral system model*	Coverage:	*Global*

Description

The World Trade Model with Bilateral Trades (WTMBT) is a meso-economic linear optimization model based on the comparative advantage principle. Considering m world regions with n industries each, the WTMBT enables to endogenously determine the production yields and trades patterns required to satisfy an exogenously specified final demand yield in each region, minimizing the use of labour and capital by complying with regional factors endowments (e.g., availability of natural resources, land, workforce)

Sample policy questions

- How can consumption-based carbon emissions policies tackle carbon leakage?

Key journal papers

- A world trade model based on comparative advantage with m regions, n goods, and k factors
- Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part I: Conceptual Framework
- Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part II: Implementation

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EXPANSE

Model:	EXPANSE	Partner(s):	Université de Genève
Type:	*Energy and electricity system*	Coverage:	*EU-27 + AL, BA, CH, IS, ME, MK, NO, RS, UK*

Description

EXPANSE is a modelling framework that is composed of two separate European models: 1) spatially explicit EXPANSE for NUTS-2 and NUTS-3 analysis of electricity system capacity investment and operation as well as associated regional impacts (e.g., employment, land use). 2) D-EXPANSE is a retrospective electricity system transition model.

Sample policy questions

- What are the sub-national regional impacts and equity implications of implementing a low-carbon electricity system in Europe?
- Which European regions are in the best position to benefit, and which ones are most vulnerable to adverse impacts of implementing a low-carbon electricity system (e.g., employment, land use, air pollution)?

Key journal papers

- Accuracy indicators for evaluating retrospective performance of energy system models

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WISEE-EDM/Industry-EU

Model:	WISEE-EDM/Industry-EU	Partner(s):	Wuppertal Institut für Klima, Umwelt, Energie
Type:	*Sectoral system model*	Coverage:	*EU-27 + UK*

Description

The EDM-Industry EU model system is used to analyse possible futures of an industrial production system and to derive technically consistent paths to it, starting from today's production system. For particularly energy-intensive and GHG-intensive sectors (steel, basic chemicals, refineries), aggregated values such as the CO_2 emissions of the European steel industry are derived from the properties and activity values of the individual plants included in the model and can be reported at the sub-national level. Other sectors of the basic industries are modelled on the basis of activities and technologies at the country level. The non-energy-intensive industries are modelled econometrically.

Sample policy questions

- What do future climate-neutral European production networks look like technologically and geographically?
- How do plausible transformation pathways that meet CO_2 emission reduction targets look like and what are the costs associated with these pathways?
- When does a phase-in of break-through technologies need to start in order to reach a target state while maintaining usual reinvestment cycles?
- What energy sources are needed in the industry sector, in what quantities, when and where?

Key journal papers

- Simulating geographically distributed production networks of a climate neutral European petrochemical industry
- Risks and opportunities associated with decarbonising Rotterdam's industrial cluster
- Re-Industrialisation and Low-Carbon Economy—Can They Go Together? Results from Stakeholder-Based Scenarios for Energy-Intensive Industries in the German State of North Rhine Westphalia

Key policy papers

- Towards a Climate-Neutral Germany by 2045 – Agora Energiewende

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WISEE-EDM/Global-Steel

Model:	WISEE-EDM/Global-Steel	Partner(s):	Wuppertal Institut für Klima, Umwelt, Energie
Type:	*Sectoral system model*	Coverage:	*Global (split into 20 countries / regions, including EU27)*

Description

The EDM Global-Steel model is used to analyse possible futures of the global steel sector (divided into 20 countries / regions including EU-27), including technological transformation pathways in each country/region, potential future trade of direct reduced iron (DRI) between countries / regions as well as (impacts of) demand levels and material efficiency. Main outputs of the model are final energy demand and GHG emissions per country/region as well as investment costs.

Sample policy questions

- What do consistent global steel sector transformation pathways look like, taking into account new opportunities such as global DRI trading that arise from breakthrough technologies?
- How can the GHG emissions of the global steel sector remain within an emission budget that is compatible with the Paris agreement while meeting increasing global demand for steel?
- Which amounts of hydrogen are needed for EU steel industry under different scenarios of global value chain development?
- What are the global and EU investments associated with the global steel transformation?

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CHANCE

Model:	CHANCE	Partner(s):	Basque Centre for Climate Change
Type:	*Computable General Equilibrium*	Coverage:	*EU*

Description

CHANCE is a macro-micro model based on a computable general equilibrium (CGE) model that includes a large amount of household microdata. It is a disaggregated multiregional and multisector model that included information for around 200,000 households covering all EU regions, ensuring a large representation of the behaviour of the European households. Therefore, CHANCE is a model designed to analyse the socioeconomic and distributional impacts of public policies that directly affect households and consumers, both economic, energy, environmental or fiscal. The CGE of CHANCE is built on a latest version of the GTAP database (GTAP 10), while the main source of microdata is the latest harmonized European HBS, which is merged with SILC through statistical matching.

Sample policy questions

- What are the socioeconomic impacts of the energy transition and policies that could facilitate the energy transition?
- How best to protect or compensate vulnerable consumers to ensure a just transition?
- Which are the distributional implication of policies that could facilitate the energy transition?
- How are the costs of the energy transition distributed among households through the income and expenditure channels?
- What are the trade-offs between efficiency and equity of climate policies, and how to resolve them?

Key journal papers

N/A (new model).

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DyNERIO

Model:	DyNERIO	Partner(s):	Politecnico di Milano
Type:	*Non-equilibrium / Other*	Coverage:	*EU**

Description

DynERIO is an integrated energy-economy modelling framework. Based on input-output databases capturing the whole economic spectrum and multiple regions, it allows to model policies in terms of: (i) increase in consumption of goods; (ii) change of industries' productive structure (i.e., steel plants switch from coal/gas to electricity use). New production levels of energy commodities, needed to fulfil the shocked economic system, are tracked by the input-output table and converted into capacity to be operative at a given year. From the information of the capacity stock evolution over time it is possible to derive the associated net extraction of raw materials.

Sample policy questions

- What is the material footprint associated to a change of electricity mix or to an electrification of industrial processes in a given region (the focus may be on EU or any other region in the world, according to the underlying input-output database)?

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GCAM-USA

Model:	GCAM-USA	Partner(s):	University of Maryland
Type:	*Partial Equilibrium*	Coverage:	*National*

Description

GCAM is an open-source, global, long-term, multi-sector human Earth system model; it contains representations of energy, economy, agriculture and land-use, and water systems for 32 geopolitical regions in the globe. GCAM-USA divides the United States into 50 states and the District of Columbia. GCAM-USA is embedded within the global GCAM model, so conditions within the United States are internally consistent with international conditions. The state-level regions contain more detailed representations of national-level economic features, including socioeconomics, energy transformation, carbon storage, renewable resources, electricity markets, and consumer end-use energy demands.

Sample policy questions

- How much emissions reductions could be delivered by subnational climate actions; and how these actions may enhance climate ambition and contribute to meeting the U.S. climate targets?

Key journal papers

- The energy system transformation needed to achieve the US long-term strategy
- The surprisingly inexpensive cost of state-driven emission control strategies

Key policy papers

- Blueprint 2030: An All-In Climate Strategy for Faster, More Durable Emissions Reductions – America Is All In
- AN "ALL-IN" PATHWAY TO 2030: TRANSPORTATION SECTOR EMISSIONS REDUCTION POTENTIAL

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IMACLIM-China

Model:	IMACLIM-China	Partner(s):	Tsinghua University
Type:	*Computable General Equilibrium*	Coverage:	*National*

Description

IMACLIM-China is a single region recursive dynamic computable general equilibrium model in China. The model is constructed based on IMACLIM-S framework developed by Centre International de Recherche sur l 'Environnement et le Developpement (CIRED). IMACLIM-China aims to study the medium- and long-term effects of energy and climate policies on China's macro economy through the equilibrium framework of physical quantity, price quantity and value quantity. The main feature of IMACLIM-CHN model is to ensure the technical authenticity of the model's simulation of energy systems and major innovations in energy systems by coupling the technical details of energy supply and energy consumption in the bottom-up model.

Sample policy questions

- What are the economic costs of climate policies such as carbon neutrality?
- What are the impacts of climate policies on important socio-economic factors such as sector output, GDP, imports and exports, and household consumption?

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China-MORE

Model:	China-MORE	Partner(s):	Tsinghua University
Type:	*Energy and electricity system*	Coverage:	*National*

Description

China-MORE is a bottom-up long-term multi-sector multi-GHG emission reduction evaluation model based on the VEDA-TIMES model platform for energy system optimization. The China-MORE model adopts the principle of system analysis and takes the energy system optimization module as the core. It combines the modules of energy service demand, multi-greenhouse gas emission, air pollutants emission, power technology diffusion, emission space allocation and uncertainty analysis.

The core modules of the model are energy system optimization module and greenhouse gas emission module. Firstly, the energy service demand module provides the service demand of industry, construction, transportation, agriculture, waste treatment and other sectors according to the social and economic development factors. The model energy system optimization module can obtain the fuel combination and technology composition with minimum cost according to the given demand level. At the same time, pollutant emission module and GHG (CO_2 excluded) emission module output emission data of different scenarios. On this basis, the model can estimate the medium - and long-term optimal emission path accordingly.

Sample policy questions

- Through different scenario combination design, the problems of China's energy consumption, GHG emission and emission reduction cost are studied.
- China-MORE model provides an important research tool for China's medium and long-term low emission development strategy, and also helps to analyse the gap between China's current emission reduction efforts and the goal of carbon neutrality.
- Explore ways to achieve carbon neutrality at lower system cost by using multi-GHG joint emission reduction strategies.

Key journal papers

- The economic impact of a deep decarbonisation pathway for China: a hybrid model analysis through bottom-up and top-down linking

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BLUES

Model:	BLUES	Partner(s):	Imperial College London
Type:	*Partial Equilibrium*	Coverage:	*National*

Description

The BLUES model is the most recent version of a family of models built on the MESSAGE model platform. It was developed for the Brazilian energy system and has been sequentially updated and applied to assess issues relevant to the national reality. The model has recently been reconfigured for better detailing of both regional breakdown and endogenous energy efficiency and GHG mitigation options in the end-use sectors. A representation of the land-use system (forests, savannas, low- and high-capacity pastures, integrated systems, cropland, double cropping, planted forests, protected areas) was introduced, along with a suite of advanced biofuel technologies missing from previous versions. In addition, the cost assumptions on electric vehicles and photovoltaic (PV) solar power have been updated to reflect recent developments.

As a perfect-foresight cost-minimization model, BLUES produces the least-cost pathway to meet emission budgets subject to constraints to reflect socioenvironmental conditions, policies, and other limiting factors. The expansion of key technologies was constrained in the model to reflect technoeconomic restrictions to the deployment of new facilities, such as industrial capacity to manufacture equipment, skilled labour to build and operate the plants, and availability of capital to fund them. Innovative biofuel production routes with and without CCS were constrained following this rationale.

Sample policy questions

- How do policies and technological change impact land use and energy systems and vice-versa?

Key journal papers

- Brazil's emission trajectories in a well-below 2 °C world: the role of disruptive technologies versus land-based mitigation in an already low-emission energy system
- The threat of political bargaining to climate mitigation in Brazil
- Are there synergies in the decarbonization of aviation and shipping? An integrated perspective for the case of Brazil

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AIM/End-use-India

Model:	AIM/Enduse-India	Partner(s):	Indian Institute of Management, Ahmedabad
Type:	*Sectoral system model*	Coverage:	*National*

Description

The AIM/End-use Indian model integrates the water and energy module at the resource and technological level into the existing energy and environment systems to capture the impacts of existing and future policies for water, energy, and land systems on the major water- and energy-intensive sectors. The model uses recursive dynamics and runs in annual time steps. It optimizes costs (technology, energy, and water) and resources (water, energy) by selecting a set of best available technologies based on given physical resources and technological and environmental parameters. A detailed characterization of the inputs reflects an optimistic engineering view of technological progress. Economic parameters, such as taxes, subsidies, resource (energy, water, and land) technologies, policies, and social costs are also classified. The final service demand is exogenous and is driven not only by the gross domestic product (GDP) but also by end-use consumption and policies across various sub-sectors. The model is also being soft-linked to climatic–hydrological models.

Sample policy questions

- What are the implications of NDC and climate compatible development pathways for India?
- What are the impacts of water, energy and emission constraints on water and energy systems?
- What are the mitigation options for India to meet the Paris Agreement?

Key journal papers

- SDG implications of water-energy system transitions in India, for NDC, 2 °C, and well below 2 °C scenarios
- Energy system transformation to meet NDC, 2 °C, and well below 2 °C targets for India

Key policy papers

- Assessing NDC and climate compatible development pathways for India – Climate Compatible Growth

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MENA-EDS

Model:	MENA-EDS	Partner(s):	E3Modelling
Type:	*Partial Equilibrium*	Coverage:	*National*

Description

The MENA-EDS model is a national-scale fully-fledged energy system model that covers in detail energy demand and supply and their complex interlinkages driven by energy prices. The model provides energy system projections until 2050, including energy consumption by sector, fuel mix, energy investment, and CO_2 emissions, under different policy or technology assumptions. It addresses energy system analysis, energy price projections, electricity system planning and emission reduction policies by sector for Middle East and North Africa (MENA) countries. MENA-EDS covers the main energy end-use sectors, including industries, transport and buildings, while the entire value chain of energy supply is represented through primary fuel extraction, energy transformation (power generation, refineries), and supply to final consumers (e.g., grids).

Sample policy questions

- Which are the benefits from a cooperation of MENA countries and EU in the field of energy and climate policies?
- Which are the linkages between energy demand, supply options and strategies in different NDC strategies, potential Paris-compatible pathways and climate policy ambition?
- Which is the most cost-efficient implementation of Moroccan NDC?
- Under which circumstances can a cooperation between MENA region and European Union in the energy sector become a win-win situation? How economically feasible is it to import power from North Africa?

Key journal papers

- Model-based analysis of the future strategies for the MENA energy system
- Chapter 9 - Analysis of Future Common Strategies Between the South and East Mediterranean Area and the EU in the Energy Sector

Key policy papers

- Assessing the energy system impacts of Morocco's NDC and low-emission pathways – Climate Compatible Growth

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MEDEAS

Model:	MEDEAS	Partner(s):	Universidad de Valladolid, CARTIF
Type:	*Non-equilibrium/Other*	Coverage:	*Global**

Description

MEDEAS is a set of policy-simulation dynamic-recursive models sharing the same conceptual modelling approach which have been designed applying system dynamics. Models at three different geographical aggregated scales have been developed: global (MEDEAS-W), European Union (MEDEAS-EU) and country-level for Austria and Bulgaria (MEDEAS-AUT and MEDEAS-BGR, respectively). MEDEAS models are structured in nine main modules: economy, energy demand, energy availability, energy infrastructures and EROI, minerals, land-use, water, climate/emissions, and social and environmental impact indicators. The biophysical limits associated with the exploitation of natural resources (energy and materials), the dynamic EROI and the feedbacks between the modules play an essential role in the model.

Sample policy questions

- What are the macroeconomic impacts of the energy transition at the global and the European levels?
- What are the limits of transport decarbonization under current growth paradigm?
- What are the materials-related implications of the energy transition, in terms of energy return on investment?

Key journal papers

- MEDEAS: a new modelling framework integrating global biophysical and socioeconomic constraints
- The limits of transport decarbonization under the current growth paradigm
- An Ecological Macroeconomics model: The energy transition in the EU
- Macroeconomic modelling under energy constraints: Global low carbon transition scenarios

Key policy papers

- Locomotion: towards a sustainable, Green post-covid-19 recovery

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WILIAM

Model:	WILIAM	Partner(s):	Universidad de Valladolid, CARTIF
Type:	*Non-equilibrium / Other*	Coverage:	*Global**

Description

The WILIAM ("Within limits") Integrated Assessment Model (IAM), developed in the scope of LOCOMOTION project, is a model running at three geographical levels – global, European and national for the 27 EU member states and United Kingdom (UK); integrating full models of water, land-use and society (including the endogenization of population); develop the economy module towards a comprehensive representation of production, consumption, government, international trade, finance and climate change impacts and include the full supply of materials. All the models run from 2015 to 2050-2100. WILIAM model is built on the existing MEDEAS model that was developed in the context of the EU-funded MEDEAS project. For the study of the highly complex interactions between humans and their environment, the project draws on different techniques and methods, such as System Dynamics (SD) modelling with Vensim software, Input-Output Analysis (IOA), Energy Return On Investment (EROI) calculations, Life Cycle Analysis (LCA), land and carbon footprinting, microsimulation, and many others.

Sample policy questions

- What are the land, material, energy, and water requirements for the energy transition?
- What are the social/economic policies that could facilitate the energy transition? What are the socioeconomic impacts of the energy transition?
- What sectors are the most relevant to the energy transition?
- How can the financial system facilitate the energy transition?
- What energy infrastructures/technologies should be prioritised?

Key journal papers

Model still in development.

Key policy papers

Model still in development.

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CLEWs

Model:	CLEWs	Partner(s):	KTH Royal Institute of Technology, Stockholm
Type:	*Non-equilibrium / Other*	Coverage:	*Global**

Description

The Climate, Land, Energy, Water systems (CLEWs) methodology is a model-based methodology to assess costs and benefits of policy and investment decisions made in one sector (e.g., land use) on the other sectors (e.g., water supply) and thereby support policy coherence. CLEWs models can be developed with different approaches and different modelling tools, such as OSeMOSYS, MESSAGE, LEAP, WEAP and GAEZ. Often, a CLEWs model consists of a techno-economic representation of the climate, land, energy, and water systems within the long-term optimisation tool OSeMOSYS. Here, the parts of these systems are represented as processes with certain transfer functions and exchanging between them different commodities. For example, one particular agricultural land use is represented as a 'box' that takes a certain quantity of water, energy and land area as inputs and delivers part of the water (through ground water recharge or surface run off) and a crop with a certain yield. The optimisation seeks to minimise the Net Present Value of all costs incurred across the water, energy and land sectors in the whole-time domain analysed (typically, of several decades), while meeting an increasing demand for commodities (e.g., food products) and resource availability constraints.

Sample policy questions

- What are the potential impacts of policy or investment decisions in the energy system on the land and water systems, or vice versa?
- What opportunities arise for the energy, land and water systems from integrated and coherent planning across the systems?
- How can planning across the climate, energy, land and water domains be coherent and at the same time comply with budget and resource constraints?
- How can national policies coherently and simultaneously address SDGs 6, 7, 13 and 15?

Key journal papers

- Integrated analysis of climate change, land-use, energy and water strategies
- The Global Least-cost user-friendly CLEWs Open-Source Exploratory model
- The climate, land, energy, and water systems (CLEWs) framework: a retrospective of activities and advances to 2019
- Land, energy and water resource management and its impact on GHG emissions, electricity supply and food production- Insights from a Ugandan case study
- Chapter 9: Capacity development and knowledge transfer on the climate, land, water and energy nexus

Key policy papers

- Assessing how production and use of resources affect climate change
- Nexus Assessment for the Drin River Basin
- Nexus Assessment for the Drina River Basin

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OSeMOSYS

Model:	OSeMOSYS	Partner(s):	KTH Royal Institute of Technology, Stockholm
Type:	*Energy and electricity system model*	Coverage:	*Global**

Description

The Open Source energy MOdelling SYStem is a fully (data to solver) open source long-term bottom-up (technology rich) optimisation framework for energy systems modelling. It calculates for every year of a time domain the energy mix (in terms of capacity, capacity expansion and operation) that minimised the total Net Present Costs of the whole system while meeting exogenously defined demands for energy commodities or services and while complying with constraints dictated by resource availability, technical characteristics of technologies, policies. It is a partial equilibrium modelling tool. It can be used both with perfect or myopic foresight. It allows high temporal (up to hourly) and spatial resolution. It has been coupled with several other modelling tools. Its modelling paradigm is very close to MESSAGE's and quite similar to TIMES's. It is also the optimisation engine of LEAP (NEMO is a Julia translation of OSeMOSYS). Given its fully open-source nature, the availability of several interfaces with different degrees of technicality, the availability in three modelling languages (Pyhon, GNU MathProg and GAMS) and the fast learning curve, it is largely used in capacity development and education activities.

Sample policy questions

- What is the least cost capacity expansion and energy system operation path to reach certain long-term goals? (e.g. certain share of renewables, certain reductions of GHG emissions, etc.)
- What technological options are most cost-competitive for energy supply within an entire energy system and in the long term, in a defined context, with defined constraints?

Key journal papers

- OSeMOSYS: The Open-Source Energy Modeling System: An introduction to its ethos, structure and development
- From the development of an open-source energy modelling tool to its application and the creation of communities of practice: The example of OSeMOSYS
- The open-source electricity Model Base for Europe - An engagement framework for open and transparent European energy modelling
- Developing a community of practice around an open-source energy modelling tool

Key policy papers

- Energy projections for African countries – JRC Publications

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Calliope

Model:	Calliope	Partner(s):	Politecnico di Milano
Type:	*Energy and electricity system model*	Coverage:	*National**

Description

Calliope is a well-known framework to build energy system models, designed by Stefan Pfenninger and Bryn Pickering, and it is used to analyse systems with arbitrarily high spatial and temporal resolution, with a scale-agnostic mathematical formulation permitting analyses ranging from single urban districts to countries and continents. Calliope's key features include the ability to handle high spatial and temporal resolution and to easily run on high-performance computing systems.

Sample policy questions

- Revealing near-optimal solutions which are close to mathematical optimal but easier to put in practice for policymakers. Case of Italian energy system.
- How to reduce impact on grid stability by finding the best dispatch match in multi-carrier energy systems (electric and thermal)?

Key journal papers

- Calliope: a multi-scale energy systems modelling framework
- A multi-layer energy modelling methodology to assess the impact of heat-electricity integration strategies: The case of the residential cooking sector in Italy
- Advancing the representation of reservoir hydropower in energy systems modelling: The case of Zambesi River Basin

Key policy papers

- Policy Decision Support for Renewables Deployment through Spatially Explicit Practically Optimal Alternatives

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EnergyPLAN

Model:	EnergyPLAN	Partner(s):	Aalborg University
Type:	*Energy and electricity system model*	Coverage:	*Global* (can be modelled at any scale, but typically national energy modelling)*

Description

EnergyPLAN is an energy system analysis tool created for designing and studying future sustainable energy systems with an emphasis on systems with a high penetration of renewable energy sources. EnergyPLAN simulates the operation of national and regional systems on an hourly basis, including the electricity, heating, cooling, industry, and transport sectors. The tool is a deterministic input/output model and allows for modelling of all thermal, renewable, storage, conversion, and transport technologies. General model inputs are energy demands, renewable energy sources, energy technology capacities, costs (investment, operation, and fuel), and user-defined operation strategies.

Sample policy questions

- How can Denmark transition to a fully decarbonised energy system by 2045?
- How would electricity prices within the current electricity market structure respond to a 100% renewable energy system?
- What are the benefits of 4th generation district heating in a 100% renewable energy system?
- How should fluctuating renewable electricity be integrated in a 100% renewable energy system to limit biomass consumption?

Key journal papers

- EnergyPLAN – Advanced analysis of smart energy systems
- Review and validation of EnergyPLAN

Key policy papers

- Smart energy Denmark. A consistent and detailed strategy for a fully decarbonized society

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DREEM (TEEM Suite)

Model:	DREEM (TEEM Suite)	Partner(s):	University of Piraeus Research Centre
Type:	*Energy and electricity system model*	Coverage:	*National**

Description

The Dynamic high-Resolution dEmand-sidE Management (DREEM) model is a fully integrated simulation model resolving key features that are not found together in existing Demand-Side Management (DSM) models.

The model serves as an entry point in DSM modelling in the building sector, by expanding the computational capabilities of existing Building Energy System (BES) models to simulate transition scenarios in the building sector from the demand side, e.g., calculating energy demand profiles, assessing the benefits and limitations of energy efficiency and demand-flexibility primarily for consumers and then for other power actors involved, etc.

DREEM is a hybrid bottom-up model that combines the key features of both statistical and engineering models. The novelty of the DREEM model lies mainly in its modularity, as its structure is decomposed into individual modules characterised by the main principles of component- and modular-based system modelling approach, namely "the interdependence" of decisions within modules.

For more info about the model's architecture see the respective documents in the key journal papers column.

Sample policy questions

- What is the saving potential & cost-effectiveness of different energy-efficiency measures in the European residential sector? (National-scale analysis)
- An energy transition dilemma in the residential sector in Greece: Investing in natural gas or in electrification? (National-scale analysis) - pages 208-216
- Should national planning in Greece invest in new natural gas infrastructure in the Peloponnese region? (Regional-scale analysis) - pages 216-222
- Can promoting new natural gas infrastructures lead to a just transition in the Coal and Carbon Intensive municipality of Megalopolis, also considering the decommissioning of the lignite power plants in the area? (Local-scale analysis) - pages 222-229

Key journal papers

- A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector
- Monetising behavioural change as a policy measure to support energy management in the residential sector: A case study in Greece
- Existing tools, user needs and required model adjustments for energy demand modelling of a carbon-neutral Europe
- Report on model application in the case studies: challenges and lessons learnt: Deliverable 7.2. Sustainable Energy Transitions Laboratory (SENTINEL) project
- Model adjustments and modifications to match emerging energy citizenship trends and patterns: Deliverable 5.1. Energy Citizens for Inclusive Decarbonization (ENCLUDE)

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ATOM (TEEM Suite)

Model:	ATOM (TEEM Suite)	Partner(s):	University of Piraeus Research Centre
Type:	*Agent-based technology adoption model*	Coverage:	*National / Regional / Local*

Description

The Agent-based Technology adOption Model (ATOM) simulates technology adoption under policy schemes of interest, quantifying uncertainties related to agents' preferences and decision-making criteria.

The novelty of the model lies in obtaining realistic uncertainty bounds and splitting the output uncertainty in its major contributing sources.

A calibration module defines the parameters influencing the agents' behaviour, and suitable ranges of values according to historical data and observations are defined. A sensitivity analysis module quantifies uncertainties related to potential adopters' attributes and decision-making criteria. Finally, a scenario analysis module, based on historical observations, simulates the plausible behaviour of agents, within the investigated geographic and socioeconomic context, under technological support policy schemes of interest (i.e., forward-looking simulations).

Sample policy questions

- How can different socio-political developments and policy interventions affect the adoption of decentralised technologies (PV and storage systems) by citizens towards the achievement of the 2030 targets in Greece? - pages 197-201

Key journal papers

- An agent-based model to simulate technology adoption quantifying behavioural uncertainty of consumers
- A transdisciplinary modeling framework for the participatory design of dynamic adaptive policy pathways

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