PARIS
REINFORCE

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D2.1 Map of models, tools and stakeholder knowledge

WP2 – I^2AM PARIS

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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 deliverable will serve as a reference document among consortium partners (experts and non-experts), as well as other researchers and members of the scientific (modelling and otherwise) community, to know about the available modelling capabilities, at the national, regional and global level, within the PARIS REINFORCE consortium, as well as about the stakeholder engagement plan. It will also be used by policymakers and other stakeholder groups as a documentation of the modelling features of the PARIS REINFORCE models, serving as a means of facilitating their participation in the co-creation process envisaged in the project.

3. Short summary of results (<250 words)

Twenty-two models are included in this project providing different levels of results aggregation (national, regional and global). The diversity and heterogeneity of the models allow to cover a large set of mitigation options and policy instruments. Despite some potential overlap, the capabilities of these tools can be effectively interlinked to cover a wide range of relevant policy aspects.

The global models produce aggregated projections for the whole world and generate results aggregated at continental/regional level, with national models covering 76 disaggregated nations.

Results are driven by specific parameters, determined either endogenously (within a model's own calculations) or exogenously (as an input from external sources); their projections are used to define the socioeconomic context to compare scenarios with and without climate policies.

The primary focus of most models is on CO_2 emissions from fossil fuels, but overall the modelling ensemble covers all types of gases and pollutants.

The models produce outputs to inform mitigation and adaptation planning. As they were originally developed for mitigation, they are very vague when addressing adaptation issues, but still manage to respond to some questions (e.g. regarding afforestation, land-use change and/or negative technologies). Despite most models not having originally been designed to handle the SDG targets, several models can also provide great insights into the progress towards their achievement.

PARIS REINFORCE also employs an innovative approach in the modelling activities, where stakeholders are involved from the beginning of the process and co-create, together with the scientists, the different policy questions, seeking to intertwine science and policymaking.

4. Evidence of accomplishment

This report.

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Preface

PARIS REINFORCE will develop a novel, demand-driven, IAM-oriented assessment framework for effectively supporting the design and assessment of climate policies in the European Union as well as in other major emitters and selected less emitting countries, in respect to the Paris Agreement. By engaging policymakers and scientists/modellers, PARIS REINFORCE will create the open-access and transparent data exchange platform I^2AM PARIS, in order to support the effective implementation of Nationally Determined Contributions, the preparation of future action pledges, the development of 2050 decarbonisation strategies, and the reinforcement of the 2023 Global Stocktake. Finally, PARIS REINFORCE will introduce innovative integrative processes, in which IAMs are further coupled with well-established methodological frameworks, in order to improve the robustness of modelling outcomes against different types of uncertainties.

NTUA - National Technical University of Athens	GR
BC3 - Basque Centre for Climate Change	ES
Bruegel - Bruegel AISBL	BE
Cambridge - University of Cambridge	UK
CICERO - Cicero Senter Klimaforskning Stiftelse	NO
CMCC - Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici	IT
E4SMA - Energy, Engineering, Economic and Environment Systems Modelling Analysis	IT
EPFL - École polytechnique fédérale de Lausanne	CH
Fraunhofer ISI - Fraunhofer Institute for Systems and Innovation Research	DE
Grantham - Imperial College of Science Technology and Medicine - Grantham Institute	UK
HOLISTIC - Holistic P.C.	GR
IEECP - Institute for European Energy and Climate Policy Stichting	NL
SEURECO - Société Européenne d'Economie SARL	FR
CDS/UnB - Centre for Sustainable Development of the University of Brasilia	BR
CUP - China University of Petroleum-Beijing	CN
IEF-RAS - Institute of Economic Forecasting – Russian Academy of Sciences	RU
IGES - Institute for Global Environmental Strategies	JP
TERI - The Energy and Resources Institute	IN

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Executive Summary

This deliverable is an initial effort to document all model characteristics that are present within the PARIS REINFORCE consortium, including information regarding assumptions behind models, their geographical and socioeconomic coverage, along with detailed insights regarding methodologies, coverage of emissions, as well as mitigation and adaptation parameters. The document has a twofold purpose: i) to be used a reference document among consortium partners (experts and non-experts) to know about the available modelling capabilities within the consortium; and ii) to familiarise stakeholders on the availability of modelling features to facilitate their participation in the co-creation process.

The information presented in Section 2 serves as a synthesis of models, as featured in D5.1 on regional-level analysis for Europe and national-level analysis for EU Member States and countries outside the EU region; in D6.1 on national-level analysis for major emitting economies and less developed/emitting countries outside Europe; and in D7.1 on the global-level analyses and subsequent model inter-comparisons. Data coverage and characteristics are presented in different scale and sector granularities, allowing one to zoom in and/or scale out if and when necessary, when dealing with model specificities and features.

Thereafter, Section 3 connects modelling capabilities to relevant yet hypothetical policy questions that may arise when meeting post-Paris pledges and targets, reinforcing the Paris agenda, concerning mitigation and adaptation efforts as well as Sustainable Development Goals (SDGs). We present an ensemble of examples of policy questions that have already been addressed by some of the models present in the modelling consortium and touch upon potential policy questions that may arise in the future.

Section 4 outlines the model validation procedures that will be followed in the project, to ensure that the outcomes from these models can be trusted, and seen as useful and valid, by both the scientific community and—equally if not more importantly—stakeholders such as policy- and decision-makers, who will plan low-carbon strategies on their basis.

In Section 5, we highlight the necessity of combining modelling efforts with a stakeholder co-creation process, a core part of the PARIS REINFORCE project, for creating collaborative roadmaps for future robust and legitimate energy transition pathways. We present insights from the Stakeholder Engagement Plan (D3.1) and how the different bodies of stakeholder knowledge will direct the modelling processes and therefore legitimise relevant science for policymaking processes.

Ultimately, in Section 6, we present insights on the objectives of the I^{2}AM PARIS platform, which can be used as a bridge to connect modelling efforts with a demand-driven stakeholder co-creation process. The platform is set out to bring together and harmonise all modelling inputs, activities, and outputs, making them available to users over the course of the project.

The document at hand is the revised version (v1.10R) of deliverable D2.1. The deliverable has been revised with the aim of rephrasing a couple of instances of poor wording choices, and of documenting validation procedures undertaken to build trust into the models and their results (Section 4). These procedures are also documented in the platform, as part of the documentation overview and comparative assessment (WP5, WP6, and WP7).

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1 Introduction

While most of the Integrated Assessment Models (IAMs) have in common that they provide estimates in aspects related to climate change, they may have very different scopes and modelling approaches. The following document provides a synthesis of the key features of the models used in PARIS REINFORCE drawing from the expertise of the partners in the consortium. It details, among others, socioeconomic drivers, methodologies, geographical and sectoral coverage, range of greenhouse gas (GHG) emissions, adaptation and mitigation parameters and example studies.

These modelling characteristics are explained from a non-technical perspective, in order for the document to be easy-to-digest for all relevant stakeholders and enable effectively incorporating their expert judgement into the project. This synthesis document has a twofold purpose: (i) to facilitate smooth integration of all models, by serving as a glossary and reference document and allowing all project partners to know more about all available options within the consortium; and (ii) to familiarise both experts and non-experts (primarily policymakers and all other stakeholder groups) with the scope and capabilities of each model and their assumptions. It serves as a basis for gathering information on potentialities of tools for enhancing collective learning among consortium members and constructing shared meanings on the added value of each approach, methodology and field of expertise.

The approach of models working at different scales and sectors with increased granularity has the potential to substantially improve the design and decision-making process of climate policies. The combined effort of the partners in the consortium prevents working in silos and allows benefitting from the strengths of each modelling tool to adopt the most beneficial mitigation and adaptation measures in each context. Additionally, the co-creation of the design with stakeholders supports informed decision-making and tool ownership by the involved actors.

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2 Model stocktake

A total of 22 models are included in this project providing different levels of results aggregation (national, regional and global). This section is intended to provide an accessible description of the capabilities and methodologies of the models. It is aimed at providing a clear picture of how each model captures and makes use of the inputs and of which outputs it is able to produce. The different parts in this section will allow the reader to identify the level of detail the modelling tools are able to work with regarding the geographic and sectoral coverage, the types of emissions, the socioeconomic parameters, the policy questions it can address, the SDGs it can track, and the possible mitigation and adaptation measures whose impacts can be assessed with each tool.

This document compiles information on five models with records at the national and regional level for Europe, nine models covering major emitting regions outside of Europe, and eight global IAMs with documentation on the entire globe as an aggregated region. A short description of the models will be given in the following.

The national and/or regional modelling tools for **Europe** are:

- **ALADIN** is used to calculate the total cost of ownership for different drivetrains (e. g. gasoline, diesel, Battery Electric Vehicles, Plug-in Hybrid Electric Vehicles for passenger cars) based on large data sets of individual user-driving behaviour and to determine the utility-maximising driving option under various constraints. In the context of PARIS REINFORCE, ALADIN can be effectively used to simulate modal shifts or electrification and recharging infrastructure strategies.
- **FORECAST** is a tool designed to support scenario design and analysis of energy demand and GHG emissions of the industry, residential and tertiary sectors at country level.
- **JET** (or **JRC-EU-TIMES**) analyses the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy objectives. It models uptake and deployment of technologies as well as their interaction with the energy infrastructure with an energy systems perspective.
- **LEAP** is an energy-environment modelling tool based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price, etc.
- **NEMESIS** is a macro-economic model which deals with EU climate mitigation policies and focuses on different economic instruments and their economic impacts at EU, EU-national and sectoral level.

The national-level modelling tools for countries **outside of Europe** are:

- **CONTO** details the industrial, business and household energy demand of the **Russian** economy as well as the road transport.
- **GCAM-CHINA** is a region-specific variant of the global, multi-region GCAM integrated assessment model, which details the energy, agriculture and land use demand in the provinces in **China**, including flows of energy and goods between them.
- **GCAM-SOUSEI** is a region-specific variant of the global, multi-region GCAM integrated assessment model, which details the energy, agriculture and land use demand of **Japan**.
- **GCAM-USA** is a region- specific variant of the global, multi-sector GCAM integrated assessment model, which details the energy, agriculture and land use demand between all 51 **USA** states (50 U.S. states plus the District of Columbia.)
- **MARKAL–India** models the energy demands in households, buildings, transport and industry in **India** as

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a single region.

- **MAPLE** is a region-specific variant of the global, multi-region TIMES energy modelling framework, which details the energy demands in households, buildings, transport and industry in **China**.
- **NATEM** is a region-specific variant of the global, multi-region TIMES energy modelling framework, which details the energy demands in households, buildings, transport and industry in **Canada, Mexico** and the **USA**, including their trade flows.
- **SISGEMA** is a land-use model for **Brazil**.
- **TIMES-CAC** is a region-specific variant of the global, multi-region TIMES energy modelling framework, which details the energy demands in households, buildings, transport and industry in **Kazakhstan, Uzbekistan, Turkmenistan** and **Azerbaijan**, including their trade flows.

The modelling tools of the project aggregating results at the **global** level are:

- **DICE** is a global, optimal growth or welfare optimisation IAM that represents the economic, policy and scientific aspects of climate change, integrating the climate system in the framework of economic growth theory.
- **GCAM** is a global, partial equilibrium IAM that represents both human and Earth system dynamics and explores the behaviour and interactions between the energy system, agriculture and land use, the economy and climate, towards mapping the implications of uncertainty in key input assumptions and parameters into implied distributions of outputs, such as GHG emissions, energy use, energy prices, and trade patterns.
- **ICES** is a recursive-dynamic, multi-regional general equilibrium model developed to assess impacts of climate change on the economic system and to study mitigation and adaptation policies, while allowing for the analysis of market flows within a single economy and international flows with the rest of the world; extending this analysis to the economic evaluation of second and higher-order effects within specific scenarios of climate change, climate policies and public-policy reforms; and focusing on all other sustainable development goals (SDGs) of the 2030 Agenda for Sustainable Development.
- **GEMINI-E3** is a multi-country, multi-sector, recursive general equilibrium model that simulates all relevant markets as perfectly competitive, in order to calculate inter alia carbon taxes, marginal abatement costs and prices of tradable permits, abated emissions, welfare loss and components, macro-economic indicators, exchange rates and interest rates, and data at the industrial level.
- **TIAM** is the multi-region, global integrated assessment version of the TIMES energy system modelling platform with a technology-rich basis for estimating how energy system operations will evolve over a long-term time horizon; as a global, partial equilibrium model that combines an energy system representation of fifteen different regions with mitigation options, it can be used to explore a variety of questions on how to mitigate climate change through energy system and transformations.
- **MUSE** is a modelling environment for the assessment of how national or multi-regional energy systems might change over time, covering the entire energy system; it is both a partial equilibrium and an agent-based model, in that it provides a detailed account of the energy sector, while developing an accurate description of investment and operational decision making.
- **42** is a simulation model for estimating CO_2 emissions associated with energy consumption in the world, which is divided into 50 countries/regions, aimed at describing in detail the target characteristics of the

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energy sector of each of these countries/regions for their effective integration into the global process of regulating emissions; as well as at calculating the impacts of possible structural changes and improvements in energy use efficiency.

- **E3ME** is a global macro-econometric (input-output) model that can be used to explore sectoral impacts, delve into socioeconomic dimensions, and look into the distributional and gender implications of nationally determined contributions (NDCs), mid-century strategies and Paris Agreement goals.

Table 1 summarises the main characteristics of the modelling tools in terms of time horizon, time step and type of approach for the projections. These may be macroeconometric models; have a specific sectoral focus (e.g. transport); or compute their outcomes through general or partial equilibrium. Partial equilibrium models describe processes and markets in specific sectors in detail and treat the rest of the economy with inputs from external sources, whereas computable general equilibrium (CGE) models cover the entire economy with a more detailed representation of specific economic sectors.

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Table 1: General characteristics of the models

	ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM
Full name	ALternative Automobiles Diffusion and INfrastructure	FORecasting Energy Consumption Analysis and Simulation Tool	JRC-EU-TIMES	Long-range Energy Alternatives Planning System	New Econometric Model of Evaluation by Sectoral Interdependency and Supply	CONTO	MARKet and ALlocation	Multi-pollutant Abatement Planning and Long-term benefit Evaluation	North American TIMES Energy Model
Type of model	Bottom-up sector perspective	Bottom-up sector perspective	Energy system	Energy-Environment System	Macroeconometric	Sectoral focus	Energy system	Energy system	Energy system
Time horizon	2050	2050	2060	2050	2050	2035	2050	2050	2050
Time steps (years)	1	1	Flexible (up to 12)	Flexible (usually 1)	1	1	5	5	10

	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Full name	SISGEMA	TIMES Central Asia and Caucasus region	Dynamic Integrated Climate-Economy model	Global Change Assessment Model	Intertemporal Computable Equilibrium System	General Equilibrium Model of International-National Interactions between Economy, Energy and the Environment	TIMES Integrated Assessment Model	ModUlar energy system Simulation Environment	42	Energy-Economy-Environment global Macro-Economic
Type of model	Sectoral Focus	Energy System	General Equilibrium	Partial Equilibrium	General Equilibrium	General Equilibrium	Partial Equilibrium	Energy System	Energy System	Macroeconometric
Time horizon		2050	2300	2100	2050	2050	2100	2100	2045	2050 (2100)
Time steps (years)		6	5	5	1	1	10	10	1	1

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2.1 Approaches and assumptions

The diversity and heterogeneity of the models allow to cover a large set of mitigation options and policy instruments as described along this document. Despite some potential overlap, the capabilities of these tools can be effectively interlinked to cover a wide range of relevant policy aspects.

- **ALADIN** is an agent-based dynamic simulation model that projects the stock and total energy consumption and CO_2 emissions of road vehicles (passenger cars, as well as light- to heavy-duty vehicles) in scenarios, in Europe. Changes in prices, user preferences, and model availability lead to a market evolution for fuels and vehicles in road transport. Thus, emissions can be calculated for different policy scenarios (Plötz et al., 2013).

- **FORECAST** is a bottom-up dynamic simulation tool that calculates long-term scenarios for future energy demand and CO_2 emissions of individual European countries until 2050 within a single model run. In the first step of the scenario process, an ambition level is determined qualitatively and quantitatively, which is than translated into important general and sectoral model parameters (*e.g.* CO_2 price, energy carrier prices, renovation rates, financial incentives for RES, etc.). After this first model setting, a scenario run is started. This is an explorative simulation approach considering the dynamics of technologies and socioeconomic drivers (Fraunhofer ISI et al., 2019).

- **JET** is a scenario-based tool for the European Union (EU), which produces dynamic, least-cost pathways subject to a number of environmental and technical constraints. The model allows the exploration of several mitigation policies, including targets (*e.g.* annual GHG emissions binding targets and cumulative carbon budgets), and sectoral/technology-specific policies (*e.g.* standards, subsides and taxes). Results provide country-specific implications for (*i*) the economy (including energy prices, investments in the energy system, marginal CO_2 abatement costs, etc.), for (*ii*) the energy mix (fuels and technologies) and energy dependence, and for (*iii*) the environment (in particular GHG emissions) (JRC, 2019).

- **LEAP** is a scenario-based modelling tool; its climate module calculates changes in the atmospheric concentration of GHG emissions between a reference scenario (which depicts the current condition of energy demand, supply, demographics, income, etc.) and mitigation scenarios based on current and future limitations to reach a cost-minimising level of commodity production and consumption aligned with the ongoing global treaties and agreements (such as the goals set by the Paris Agreement or by increasing ambition) (SEI, 2019).

- **NEMESIS** uses a recursive-dynamic principle and is solved annually for every European country. Thus, the model can implement climate change mitigation policies on the basis of either annual GHG emissions constraints or a pre-determined level of a climate policy instrument. In the first case, the model adjusts the level of the policy instrument, mainly a carbon tax, to reach the emissions target and, in the second case, the level of the policy instrument is predefined and the model calculates the related GHG emissions. In the case of annual GHG emissions binding targets, several modelling simulations can be done considering different pathways (under carbon budget constraints) and ranked according to the selected criterion (SEURECO, 2018).

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- The **CONTO** model is an economic forecast model for Russia, which seeks to maximise the profits of producers and the welfare of consumers and achieve an "equilibrium" between the supply and demand for all goods and services in the Russian economy in a given time period represented. It represents economic growth by tracking investments and improvements in productivity over time. It tracks energy use from different fuels in the different economic sectors, as well as the household sector. It can represent mitigation of climate change through the changing relative prices of low-carbon versus high-carbon fuels in each sector in response to carbon taxes or subsidies for low-carbon fuels and technologies.

- The MARKAL/TIMES models (**MAPLE**, **MARKAL-India**, **NATEM**, and **TIMES-CAC**) consist of an energy system optimisation module based on the TIMES modelling framework. The energy system includes the capital and operational costs of the energy supply and demand technologies. They provide a technology-rich basis for estimating how energy system operations will evolve over the long term. They follow a bottom-up approach to describe the energy sectors in detail through a variety of specific technologies characterised with their technical and economic parameters. The models compute an equilibrium only on energy markets (partial equilibrium) and determine an optimal configuration of the energy systems to satisfy service demands at a minimum cost over a long-term horizon, while respecting GHG emission limits. They operate on a "perfect foresight cost-optimisation" principle (all consequences of technology deployments, fuel extraction and energy price changes over the entire time horizon are considered in the cost-optimisation calculation), whereby the total energy system cost over the time horizon over the model simulation period is minimised. The cost minimisation occurs in the context of not breaching any imposed limits or constraints, such as on the annual deployment rate of specified energy technologies, or the total emissions limit imposed. In this way, the models can calculate the least-cost way to undertake mitigation so as to meet specified emissions constraints (Loulou and Labriet, 2008).

- Although **DICE** can also be considered as part of the CGE family, it is distinguished as an optimal growth, welfare optimisation (or neoclassical) model, which does not feature the same level of sectoral or geographic detail (it exclusively covers the entire global economy). It determines the climate policy and investment levels that maximise welfare (future against present consumption) over time by identifying the emission abatement levels for each time step; its social welfare function represents a defined set of preferences and accordingly ranks different consumption paths, with welfare increasing in per capita consumption for each generation but with diminishing marginal utility of consumption (the wealthier the world is, the less valuable an additional unit of consumption is) (Nordhaus, 1993).

- The GCAM family of models (including the **GCAM** model with global coverage and its regional variants: **GCAM-China**, **GCAM-USA**, and **GCAM-SOUSEI**) explore the behaviour and interactions between the energy system, agriculture and land use, economy and climate. They process a set of assumptions to create a full scenario of prices, energy, commodity and other flows across regions into the future. The set of input assumptions include socioeconomic parameters, energy technology characteristics, agricultural technology characteristics, energy resources and policies. The energy, agriculture and land use, economy and climate systems are interconnected and interact with each other. The representative agents in the modules use information on prices and make decisions

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about the allocation of resources. They represent, for example, regional electricity sectors, regional refining sectors, regional energy demand sectors, and land users who have to allocate land among competing crops within any given land region. Markets are the means by which these representative agents interact with one another and they exist for physical flows such as electricity or agricultural commodities, but they also can exist for other types of goods and services, for example tradable carbon permits. The solution process is the process of iterating on market prices until market equilibrium is reached. The models use a "dynamic recursive optimisation" principle, meaning that they don't consider future time periods when undertaking a cost-optimisation calculation for fuel extraction and technology deployments in any given time period. After they solve each period, the models then use the resulting state of the world, including the consequences of decisions made in that period as a starting point for the next time period and perform the same exercise (JGCRI, 2019).

- The **TIAM** model, similarly to the models in the GCAM family, is a partial equilibrium model, in that it provides a detailed analysis of the interactions between environmental impacts and particular economic sectors, by achieving market equilibrium separately in each and every sector of focus. In essence, it features agents of the economy and of a detailed representation of the energy system, who indicate intended supply and/or demand for goods and services, and who are simulated so as to interact with one another so that supplies and demands are balanced in all markets and for every time step. In other words, market equilibrium is assumed to take place in each one of these markets (partial equilibrium) in the short-term (Loulou and Labriet, 2008).

- **ICES** and **GEMINI-E3** are CGE models and therefore have a detailed, multiple-sector representation of the economy and, rather than seeking optimal policies, they consider the impacts of specific policies on economic, social and environmental parameters. Their operation is similar to that of GCAM and TIAM, but differs in that market equilibrium is assumed to take place in the entire economy. Their rich representation of the economy comes at a cost in that the growth of the economy is harder to model and its structure more complex; as such, they require calibration to data on national and international socio-accounting information, as well as input in the form of a series of elasticities of substitution. In contrast to all other models described here, they also calculate economic indices endogenously (Bernard and Vielle, 2008; FEEM, 2019).

- **MUSE** and **42** are energy system models, providing a detailed account of the energy sector, i.e. energy technologies and their associated costs, in order to determine the least-cost ways of attaining GHG emission reductions or the costs of alternative climate policies. They both are bottom-up models that assume short-term microeconomic equilibrium on the energy system, which is achieved by iterating market clearance across all of the sector modules, interchanging price and quantity of each energy commodity in each region. **MUSE**, in addition, includes a land use sector and is also an agent-based model and determines a mitigation pathway by providing an as realistic as possible description of the investment and operational decision making in each geographic region within a sector.

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- **E3ME** is a macroeconometric model. Quite like CGE models, it is detailed in terms of energy technologies and geographic scope, but differs in that it does not assume that consumers and producers behave optimally or that markets clear and reach equilibrium in the short term. Instead, it uses historical data and econometrically estimated parameters and relations to dynamically and more realistically simulate the behaviour of the economy, by assuming that markets achieve equilibrium in the longer run (Camdrige Econometrics, 2019).

By assessing the complementarity of the models' approaches and their potential interactions, it seems relevant to establish linkages between them aimed at (*i*) providing a harmonised background to all the tools, (*ii*) ensuring coherency in the implementation of the tools and (*iii*) taking advantage of the specific expertise of each tool.

2.2 Geographic coverage

The global models produce aggregated projections for the whole world and generate results aggregated at continental/regional level as shown in Table 2.

Additionally, national models covering EU, European, major emitting and less emitting countries are able to cover 76 disaggregated nations as shown in Figure 1.

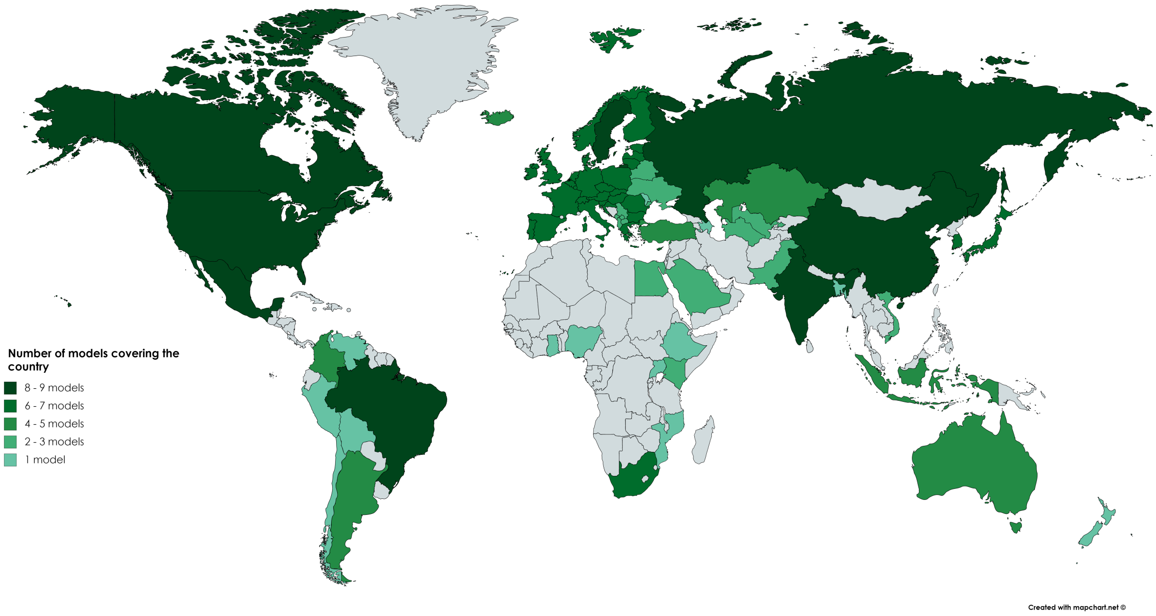

Figure 1: Country coverage map for the models with national granularity

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Table 2: Regional coverage of the models

	ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Global				✓									✓	✓	✓	✓	✓	✓	✓
EU-28			✓	✓	✓							✓	✓	✓	✓		✓	✓	✓
Europe				✓									✓	✓		✓		✓	✓
North-America				✓					✓				✓	✓	✓	✓	✓	✓	✓
Central/South America				✓									✓	✓	✓	✓	✓	✓	✓
Africa				✓									✓	✓	✓	✓	✓	✓	✓
Asia				✓									✓	✓	✓	✓	✓	✓	✓

✓ Represented

Not represented

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2.3 Socioeconomic dimensions

The results of the models included in this analysis are driven by the socioeconomic parameters detailed in Table 3. These are determined either endogenously (i.e. within a model's own calculations) or exogenously as an input from an external source. Most of the models share a common set of drivers, namely GDP and population. Their projections are used to define the socioeconomic context to compare scenarios with and without climate policies. In all models, economic growth (either as absolute GDP growth, or as GDP per capita growth, depending on the model) assumptions can be adjusted to reflect the Shared Socioeconomic Pathways (SSPs) or alternative scenario input choices.

Additionally, each model has a particular set of input requirements driving the sectoral changes (see Table 4). In most cases, as the underlying driver increases, the energy demand also increases, but tends to do so at a slower rate, to reflect the fact that there is a decreasing demand for additional energy services as incomes rise. This is defined as the *income elasticity of energy demand*. When dropping down to zero, it is an indication of saturation levels for energy service demand being reached. The analysed models also incorporate the concept of *energy price elasticity of energy demand* which captures the dynamics of rising energy prices leading to a fall in the demand for energy services.

The combined impact of these two concepts can capture, to some extent, behaviour changes in terms of uptake of more efficient modes of travel, or the responsible use of appliances in buildings. However, more profound behaviour changes, such as large-scale shifts from private motorised transport to public transport or active transport (i.e. walking and cycling) are not captured in these models. As such, any scenarios which assume policies to implement and support such shifts are most likely to be implemented through exogenous input assumptions.

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Table 3: Main socioeconomic drivers of the models by input type

	ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA
Population	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Not represented
Macroeconomics (GDP)*	Exogenous parameter	Exogenous parameter	Exogenous parameter (1)	Exogenous parameter	Endogenous parameter	Endogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Not represented
Employment**	Not represented	Endogenous parameter (3)	Not represented	Exogenous parameter	Endogenous parameter (4)	Exogenous parameter	Not represented	Not represented	Not represented	Not represented
Investment***	Not represented	Not represented	Endogenous parameter	Endogenous parameter	Endogenous parameter	Endogenous parameter	Not represented	Exogenous parameter (5)	Exogenous parameter (5)	Not represented
Public finances****	Not represented	Not represented	Not represented	Endogenous parameter	Endogenous parameter	Endogenous parameter	Not represented	Not represented	Not represented	Not represented
Economic activities*****	Exogenous parameter (8)	Endogenous parameter (9)	Endogenous parameter (10)	Exogenous parameter (11)	Endogenous parameter	Endogenous parameter	Not represented	Not represented	Exogenous parameter (12)	Not represented
Incomes******	Not represented	Not represented	Exogenous parameter	Exogenous parameter	Endogenous parameter	Endogenous parameter	Not represented	Not represented	Exogenous parameter	Not represented

	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Population	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter
Macroeconomics (GDP)*	Exogenous parameter (1)	Endogenous parameter (2)	Exogenous parameter	Endogenous parameter	Endogenous parameter	Exogenous parameter	Exogenous parameter	Exogenous parameter	Endogenous parameter
Employment**	Not represented	Exogenous parameter	Exogenous parameter	Exogenous parameter	Endogenous parameter	Not represented	Not represented	Not represented	Endogenous parameter
Investment***	Endogenous parameter	Not represented	Not represented	Endogenous parameter	Endogenous parameter (6)	Endogenous parameter (7)	Not represented	Not represented	Endogenous parameter
Public finances****	Not represented	Not represented	Not represented	Endogenous parameter	Endogenous parameter	Not represented	Not represented	Not represented	Not represented
Economic activities*****	Endogenous parameter (10) (11)	Not represented	Endogenous parameter (13)	Endogenous parameter	Endogenous parameter	Endogenous parameter (10) (11)	Endogenous parameter (14)	Exogenous parameter (15)	Endogenous parameter
Incomes******	Exogenous parameter	Endogenous parameter	Exogenous parameter	Endogenous parameter	Endogenous parameter	Exogenous parameter	Not represented	Not represented	Endogenous parameter

Endogenous parameter | Exogenous parameter | Not represented

(1) *Exports, imports* and *trade balance* are endogenously calculated; (2) Only *GDP*; (3) Exogenous input is also possible; (4) *By age* and *by sex* must be exogenously input ;(5) Only for aggregated private and public investments in the energy sector; (6) Only *private investment*; (7) Only *macroeconomics*; (8) Vehicle availability is given exogenously; (9) *Added value* and *employment* also allow for exogenous input; (10) *Production* and *value added* need to be exogenously input; (11) *Employment* not available (12) Only available for *production, imports, exports*, and *investments*; (13) Only available for *production, imports, exports*, and *energy expenditure*; (14) Only available for *investments* and *energy expenditure*; (15) Only for *value added*

* Includes: *GDP, private consumption, public consumption, gross fixed capital formation, exports, imports, trade balance*

** Includes: *total, by educational attainment level, by age, by sex, by economic activity*

*** Includes: *macroeconomic, private investments, public investments*

**** Includes: *expenditures, receipts, social benefits, balances*

***** Includes: *production, value added, imports, exports, employment, energy expenditure, investments, raw material consumption, other materials consumption*

****** Includes: *total gross disposable income, capital incomes, labour incomes, social transfers, by quantiles, energy poverty*

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2.4 Sectoral granularity

Table 4: Sectoral coverage of the models

SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Energy supply	Commodities / Sources	Coal			✓ (1)	✓	✓ (3)	✓	✓	✓	✓		✓		✓	✓	✓ (3)	✓	✓	✓	✓
		Lignite			✓	✓	✓ (3)	✓	✓	✓	✓		✓				✓ (3)		✓		✓
		Oil			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Natural Gas			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Nuclear			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Biomass			✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓	✓
		Hydro			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Solar			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Wind			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
		Geothermal			✓	✓	✓		✓	✓	✓		✓		✓			✓	✓	✓	✓
		Tidal / Wave			✓				✓	✓	✓							✓	✓	✓	✓
		Other / (partially) aggregated*			✓ (2)			✓			✓		✓			✓				✓ (4)	✓
	Transformation sectors	Electricity			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	
		Hydrogen			✓	✓		✓	✓	✓	✓		✓		✓			✓	✓		
		Oil-refining			✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	
		Gas-to-liquids			✓	✓					✓		✓		✓			✓	✓		
		Coal-to-liquids			✓	✓				✓					✓				✓		
		Coal-to-gas			✓	✓									✓				✓		
		Bio-to-liquids			✓	✓	✓		✓		✓		✓		✓			✓	✓		
		Bio-to-gas			✓	✓					✓		✓		✓			✓	✓		
		Other / (partially) aggregated*			✓ (5)															✓ (6)	
	Storage	Pumped-hydro			✓						✓		✓						✓		
		Batteries			✓				✓		✓										
		Hydrogen			✓						✓		✓								
		Power-to-gas			✓																
		Other / (partially) aggregated*			✓ (7)										✓						

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SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Industry	Energy demand / Economic output	Iron and steel		√[8]	√	√	√[9]	√	√	√	√		√				√[18]	√	√		√
		Chemicals		√	√[10]	√	√	√	√	√	√		√				√[18]	√	√		√
		Cement		√	√	√	√[9]	√	√	√	√		√		√		√[18]	√[27]	√		√
		Pump and paper		√	√[11]	√	√	√	√	√	√		√				√[18]	√	√		√
		Non-ferrous		√	√[12]	√	√[9]	√	√	√	√		√				√[18]	√	√		√
		Food processing		√		√	√	√								√	√[18]				√
		Agriculture			√	√	√	√	√	√	√		√			√	√		√	√	√
		Textiles and leather		√		√	√	√	√	√											√
		Other		√[25]					√[13]						√[14]	√[15]		√[16]			
		(Partially) aggregated*					√[9]									√[17]				√[19]	
Transportation	Passenger	Airborne			√	√			√	√	√		√		√		√	√[20]	√	√	√
		Seaborne			√	√				√	√[21]		√				√	√[20]		√	√
		Non-motorized													√						
		Rail			√	√			√	√	√		√		√		√	√	√	√	√
		Road	√		√	√			√	√	√		√		√		√	√	√	√	√
		(Partially) aggregated*					√[26]	√								√[22]					√
	Freight	Airborne			√	√			√	√	√		√		√		√	√[20]	√	√	√
		Seaborne			√	√			√	√	√[21]		√		√		√	√[20]	√	√	√
		Rail			√	√		√	√	√	√		√		√		√	√	√	√	√
		Road	√		√	√			√	√	√		√		√		√	√	√	√	√
		(Partially) aggregated*					√[26]	√			√[21]					√[22]					√
Buildings		Residential		√[8]	√	√				√	√		√		√			√	√	√	
		Commercial		√	√[23]	√			√	√	√[23]		√		√			√[23]	√	√	
		Public		√	√[23]	√					√[23]							√[23]			
		Partially aggregated*					√	√								√	√				
Afforestation and other land uses		Crops											√		√	√					
		Animals											√		√	√					
		Bio-energy									√		√		√				√		
		Forestry													√	√[24]		√			
		Partially aggregated*					√					√									

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✓	Represented		Not represented

[1] 3 types of Coal (Brown, Coke and Hard Coal); [2] Other: Biogas, municipal waste and industrial waste; [3] Coal and lignite aggregated; [4] Geothermal and tidal wave aggregated; [5] Others: Coal-to-H_2 and Gas to H_2; [6] Gas-to-liquid, Coal-to-liquid, Bio-to-liquids and Bio-to-gas aggregated; [7] CAES; [8] Results can be further differentiated by energy-carrier and end use; [9] Manufacturing sectors are covered in an aggregated manner; [10] with disaggregation: ammonia, chlorine and other chemical; [11] with subsectors: low quality paper, high quality paper; [12] with disaggregation: aluminium, copper and other non-ferrous; [13] Petrochemicals, Bricks, Fertilisers, Micro, Small and Medium Enterprises; [14] Fertilizer; [15] Transport, Water, R&D, Market Services, Health services, Education services and other public services; [16] Non-metallic, other industries and non-energy uses; [17] Aggregated by heavy and light industry; [18] Aggregated under "Energy Intensive Industry"; [19] Industrial sectors aggregated; [20] Passenger and freight transport aggregated together. Split between domestic and international; [21] Freight and passenger marine transport aggregated together; [22] Passenger and freight transport aggregated together; [23] Commercial and public aggregated together; [24] Evolution of managed forestry; [25] Non-metallic minerals, refineries, engineering and other metal; [26] Aggregated by "Inland transport" and "Sea and air transports"; [27] Included as part of non-metallic minerals

* Model covers overall category, but aggregating various sub-categories

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2.5 Emission granularity

Table 5 shows an overview of the GHGs and pollutants each model is able to cover within their capabilities. The primary focus of most models is on CO_2 emissions from fossil fuels.

Table 5: Emission granularity of the models by type of input

		ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
GHG emissions	CO_2	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	–	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo	Endo
	CH_4	Endo (2)	–	–	Endo	Endo	–	–	–	Endo	–	Endo	–	Endo	Endo	Endo	Endo	Endo	–	Endo
	N_2O	Endo (2)	–	–	Endo	Endo (2)	–	–	–	Endo	–	Endo	–	Endo	Endo	Endo	Endo	–	–	Endo
	F-gases	Endo (2)	–	–	Endo	Endo (3)	–	–	–	Endo	–	–	–	Endo	Endo	Endo	–	–	–	Endo
	Land-use CO_2	–	–	–	–	Exo	–	–	–	–	Exo	Exo	Exo	Endo	Exo (1)	–	–	Exo	–	Exo
Pollutants	PMs (BC, OC, PM2.5)*	–	–	–	Endo	–	–	–	Endo	–	–	–	–	Endo	–	–	–	–	–	Endo
	SO_X	–	–	–	Endo	–	–	–	Endo	–	–	–	–	Endo	–	–	–	–	–	Endo
	NO_X	–	–	–	Endo	–	–	–	Endo	–	–	–	–	Endo	–	–	–	–	–	Endo
	NH_3	–	–	–	Endo	–	–	–	–	–	–	–	–	Endo	–	–	–	–	–	–
	CO/VOC**	–	–	–	Endo	–	–	–	–	–	–	–	–	Endo	–	–	–	–	–	Endo

Endogenous parameter (Endo) | Exogenous parameter (Exo) | Not represented (–)

* PM = Particulate matter; BC = black carbon; OC = Organic carbon
** CO = Carbon monoxide; VOC = Volatile organic compounds

(1) Only for agriculture and managed forestry; (2) Except for LULUC which can be input exogenously; ; (3) Except NF_3

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2.6 Policy granularity

All the models together are able to cover a wide range of policy options as shown in Table 6. Almost all of the models can deal with carbon tax or carbon price (except LEAP and 42) and with annual emissions targets or quotas (except FORECAST and MARKAL) to change the pattern of energy technology uptake (including demand reduction), thereby simulating mitigation. Further capabilities for emission mitigation are regulations, such as emissions standards or financial support, for instance for negative emissions or through the Green Climate Fund.

Several of the presented models are also capable of analysing the results for energy policy instruments, such as taxes, subsidies, energy mix targets, efficiency targets and/or regulations. Almost all of the models without a specific sectoral focus can also represent subsidies for low-carbon technologies, since each model considers the costs of these technologies, as well as energy technology portfolio mix targets and energy efficiency targets. Regulatory instruments (norms and standards)—for instance, thermal regulation in buildings or banning of diesel cars in urban areas—can also be covered to a certain extent by some of the models included in the projects. The implementation of some of these measures, though feasible, requires additional modifications by the modelling teams.

Additionally, specific land policy instruments can also be represented in certain models, such as protected land, production quotas, carbon sink prices or land use change emissions tax and afforestation targets.

Finally, some specific models also allow modellers to make use of trade policy instruments through carbon border tax on imports, on exports and through regulations such as certifications, best-available technologies, and standards.

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Table 6: Policy measures coverage of the models

SECTOR		ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Emissions mitigation policy instruments	Tax	F	F	F	NR	F	FM	F	F	F	FM	F	FM	F	F	F	F	F	NR	F
	Annual target/quota	FM	NR	F	F	F	FM	NR	F (1)	F	FM	F	F	F	F	F	F	F	F	FM
	Cumulative target/quota	FM	FM	F	F	FM	NR	F	FM	F	FM	F	F	NR	NR	FM	F	FM	F	FM
	Regulations*	FM	F	F	F	FM	NR	F	F	F	NR	F	NR	FM	NR	NR	F	NR	F	FM
	Financial supports**	FM	F	F	F	FM	NR	NR	NR	FM	NR	F	NR	NR	FM	FM	F	NR	NR	FM
	Global temperature/ Radiative forcing target	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	F	F	NR	FM	F	NR	NR	NR
Energy policy instruments	Tax	F	F	F	F	F	F	F	F	F	NR	F	NR	F	F	F	F	F	NR	F
	Subsidy	F	F	F	F	F	F	F	F (2)	F	NR	F	NR	F	F	F	F	F	NR	F
	Energy mix target	NR	FM	F	F	FM	FM	F	F	F	NR	F	NR	F	F	FM	F	NR	F	FM
	Efficiency target	FM	FM	F	F	FM	FM	F	F	F	NR	F	NR	FM	F	FM	F	NR	F	FM
	Regulations***	FM	F	F	F	NR	FM	F	F	F	NR	F	NR	NR	NR	NR	F	FM	F	FM
Land policy instruments	Protected lands	NR	NR	NR	NR	NR	FM	NR	NR	NR	FM	NR	NR	F	NR	NR	NR	NR	NR	NR
	Production quotas	NR	NR	NR	NR	NR	FM	NR	NR	NR	NR	NR	FM	F	FM	NR	NR	NR	NR	NR
	Carbon sink pricing / Land use change emissions tax	NR	NR	FM	NR	NR	FM	NR	NR	NR	FM	FM	NR	F	NR	NR	FM	NR	NR	NR
	Afforestation targets	NR	NR	FM	NR	NR	FM	NR	NR	NR	F	FM	FM	FM	NR	NR	FM	NR	NR	NR
Trade policy instruments	Carbon border tax on imports	NR	NR	F	NR	FM	FM	NR	NR	F	NR	FM	NR	NR	F	F	FM	NR	NR	FM
	Carbon border supports on exports	NR	NR	F	NR	FM	FM	NR	NR	F	NR	FM	NR	NR	F	F	FM	NR	NR	FM
	Regulation policies****	FM	NR	FM	NR	FM	FM	NR	NR	F	NR	FM	NR	NR	NR	NR	FM	NR	NR	FM

Feasible (F) | Feasible with modifications (FM) | Not represented (NR)

* Emissions standards, etc; ** Negative emissions, Green Climate Fund; *** Thermal regulation in buildings, banning of diesel cars in urban areas, etc; **** Certifications, Best-available technologies, standards, etc

(1) Feasible for the annual emission target for CO2 and local pollutant emissions; (2) Energy fuels and technology

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2.7 SDG granularity

While the Sustainable Development Goals (SDGs) and their targets were clearly defined and agreed on by the United Nations (UN) Member States, in the 2030 Agenda for Sustainable Development, the choice of indicators used to measure them were, to a large extent, left to the interpretation of each country or institution. Consequently, one SDG may have several metrics and sub-metrics, which are, in turn, influenced by a range of factors. For example, whilst many models can deliver outputs relevant for SDG15 ('Life on Land'), this is in many cases done through the use of a simplified representation of afforestation and land use changes, which may not consider a range of other determinants affecting the quality of life on land. In addition, some of the outputs that can be extracted from the models may have implications on more than one SDGs. Changes in energy costs/prices are not only directly relevant to SDG7 ('Affordable and Clean Energy'), but also to SDG1 ('No Poverty') if interpreted as a driver of poverty. A more specific description of each model's coverage of SDG targets and metrics can be found in the detailed documentation for each model deliverables, D5.1, D6.1, and D7.1.

Table 7 details those SDG measures on which the documented models can inform directly from their outputs. For example, whilst all the models track biofuels and fossil fuel use, from which estimates of particulate matter and thereby respiratory health impacts (a key metric for SDG3, 'Good Health and Well-Being') can be estimated, only four models actually include outputs that directly inform SDG3. In this specific SDG, the relevant metrics may be mortality resulting from air pollutants or an evaluation of health damage based on mortality from air pollutant emissions.

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Table 7: SDGs covered by the models

	1 No poverty	2 Zero hunger	3 Good health and well-being	4 Quality education	5 Gender equality	6 Clean water and sanitation	7 Affordable and clean energy	8 Decent work and economic growth	9 Industry, innovation and infrastructure	10 Reduced inequalities	11 Sustainable cities and communities	12 Responsible consumption and production	13 Climate action	14 Life below water	15 Life on land	16 Peace, justice and strong institutions
ALADIN									✓				✓			
FORECAST							✓		✓			✓	✓			
JET						✓	✓	✓	✓		✓	✓	✓			
LEAP						✓	✓						✓			
NEMESIS							✓	✓	✓	✓			✓			
CONTO	✓		✓	✓			✓						✓			
MARKAL							✓						✓			
MAPLE			✓				✓		✓				✓			
NATEM							✓		✓		✓	✓	✓		✓	
SISGEMA													✓		✓	
TIMES-CAC	✓		✓				✓	✓					✓		✓	
DICE								✓	✓				✓			
GCAM		✓	✓			✓	✓					✓	✓		✓	
ICES	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	
GEMINI-E3		✓					✓	✓	✓				✓			
TIAM			✓				✓	✓	✓				✓			
MUSE							✓		✓				✓			
42							✓						✓			
E3SME	✓	✓	✓		✓		✓	✓	✓	✓						

✓ Represented*   Not represented

*The same SDG can be covered with different indicators, therefore a "✓" in the same SDG by different models doesn't necessarily imply that the same indicators are being used

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2.8 Mitigation and adaptation measures

The models assessed in this document produce outputs to inform mitigation and adaptation planning. Mitigation and adaptation measures can be included in all models' simulations of low-carbon pathways through, for example, the inclusion of renewable energy technologies as alternatives for fossil fuels (mitigation), a shift towards less land use-intensive diets (mitigation and adaptation), or increasing cooling requirements for buildings (adaptation).

Table 8 details what options are available for each model to simulate mitigation and adaptation measures. The changes of input in upstream technologies like hydrogen production and synthetic fuel production are mitigation options available in some models. Additionally, an even larger set of models cover options in the electricity and heat generation sectors; hydro-electricity, solar photovoltaics, onshore and offshore wind turbines, biomass, geothermal, nuclear fission (and sometimes fusion), and carbon capture and sequestration technologies from coal, gas and biomass are some of the alternatives included. In the transport sector, mitigation measures are divided between road, rail, aviation and shipping transport and lastly modal shift and behavioural changes to favour low-carbon transports. The buildings sector allows model users to control the consumption of devices for heating, cooling and lighting purposes, efficiency in appliances and behavioural change as mitigation measures. In the industry sector, the granularity level is also high allowing for independent inputs in the heating process, the fuelling of machines, steam, combined heat and power technologies and at an overall industry level. A few models are also able to capture mitigation measures for agriculture, land use and land use change in terms of energy use, land and animal husbandry practices, afforestation, land protection and biomaterials. Finally, measures for adaptation to climate change can be implemented through the management of land use, water systems and urban environments.

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Table 8: Mitigation and adaptation options in the models

SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Upstream mitigation technologies	Synthetic fuel production	Coal to gas with CCS*			√(2)														√		√
		Coal to liquids with CCS			√(2)										√			√	√		
		Gas to liquids with CCS			√(2)						√								√		
		Biomass to liquids			√						√		√		√			√	√		
		Biomass to liquids with CCS			√(2)						√				√			√	√		
		Others	√(1)																		√(18)
	Hydrogen production	Electrolysis			√			√			√		√		√			√	√		
		Coal to hydrogen with CCS			√			√							√			√	√		
		Gas to hydrogen with CCS			√			√							√			√	√		
		Biomass to hydrogen with CCS			√(2)													√	√		
		Other			√(3)										√(4)						√(19)
Electricity and heat generation mitigation technologies	Electricity generation production Storage	Coal with CCS			√		√			√	√		√		√		√	√	√	√	√
		Gas with CCS			√		√			√	√		√		√		√	√	√	√	
		Nuclear fission			√	√	√	√	√	√	√		√		√		√	√	√	√	√
		Nuclear fusion						√			√							√			
		Hydro			√	√	√	√	√	√	√		√		√	√	√	√	√	√	√
		Biomass	√(1)		√	√	√	√	√	√	√		√		√			√	√	√	√
		Biomass with CCS			√		√			√	√		√		√			√	√		√
		Geothermal			√	√	√	√	√	√	√		√		√			√	√	√	√
		Solar PV			√	√	√	√	√	√	√		√		√	√(5)	√	√	√	√	√
		Solar CSP			√	√	√		√	√	√		√		√			√	√		√
		Onshore Wind			√	√	√	√	√	√	√		√		√	√(6)	√(6)	√	√	√	√
		Offshore Wind			√	√	√	√	√	√	√		√					√	√	√	√
	Heat generation	Coal with CCS									√									√	√
		Gas with CCS									√								√	√	√
		Oil with CCS									√								√	√	√
		Geothermal			√(7)	√		√			√								√	√	√
		Biomass			√	√		√			√		√		√			√	√	√	√
		Biomass with CCS									√								√		√

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SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Mitigation: transport	Road	Gas vehicles (CNG/LNG)**	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓	
		Hybrid electric vehicles	✓		✓		✓		✓	✓	✓		✓		✓			✓	✓	✓	
		Fully electric vehicles	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
		Hydrogen fuel cell vehicles	✓		✓			✓	✓	✓	✓		✓		✓			✓	✓		
		Biofuels in fuel mix	✓[8]		✓	✓	✓		✓	✓	✓		✓		✓			✓	✓	✓	
		Efficiency	✓		✓	✓	✓[9]	✓	✓	✓	✓		✓					✓		✓	
		Other	✓																		
	Rail	Electric rail			✓	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
		Hydrogen fuel cell rail									✓								✓		
		Efficiency			✓	✓	✓	✓	✓	✓	✓				✓			✓		✓	
		Other																			
	Aviation	Biofuels in fuel mix			✓	✓	✓		✓	✓	✓		✓		✓			✓	✓	✓	
		Hydrogen planes																✓			
		Electric planes				✓		✓											✓		
		Efficiency			✓	✓	✓[9]	✓	✓	✓	✓							✓		✓	
		Specify																			
	Shipping	Gas (CNG/LNG)				✓		✓			✓								✓	✓	
		Hydrogen									✓							✓	✓		
		Biofuels in fuel mix			✓	✓	✓		✓	✓	✓				✓			✓	✓	✓	
		Electric				✓		✓													
		Efficiency			✓	✓	✓	✓	✓	✓	✓							✓		✓	
		Other																			
	Modal shifts				✓[9]		✓[17]		✓	✓			✓[9]		✓		✓	✓[9]			
	Others: (e.g. travelling less)				✓[10]		✓				✓[10]		✓[10]		✓	✓[11]	✓	✓[10]			

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SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Mitigation: buildings	Heating	Gas replacing oil / coal		✓	✓	✓	✓			✓	✓		✓		✓		✓(12)	✓	✓	✓	
		Biofuels		✓	✓	✓				✓	✓		✓		✓			✓	✓	✓	
		Electricity		✓	✓	✓	✓	✓		✓	✓		✓		✓		✓(12)	✓	✓	✓	
		Hydrogen			✓						✓		✓					✓	✓	✓	
		Solar thermal		✓	✓	✓	✓	✓		✓	✓		✓					✓	✓	✓	
		Building shell efficiency		✓	✓	✓					✓		✓				✓(12)			✓	
		Other																			
	Lighting	Efficient lighting		✓	✓	✓			✓	✓	✓		✓				✓	✓	✓		
	Appliances	Efficient appliances		✓	✓	✓			✓	✓	✓		✓				✓	✓	✓		
	Cooling	Electricity		✓	✓	✓			✓	✓	✓		✓		✓	✓(13)					
		Building shell efficiency		✓		✓					✓		✓								
	Behavioural change	Less energy service demand		✓	✓(9)		✓				✓(9)		✓(9)		✓	✓(13)					
Mitigation: industry	Process heat	Gas replacing oil / coal		✓(14)	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓(12)	✓	✓	✓	
		Biomass		✓	✓	✓	✓	✓		✓	✓		✓		✓			✓	✓	✓	
		Hydrogen		✓		✓					✓		✓		✓			✓	✓		
		Electricity		✓	✓	✓	✓	✓		✓	✓		✓		✓		✓(12)	✓	✓	✓	
	Machine drives	Gas replacing oil / coal		✓	✓		✓				✓		✓					✓	✓	✓	
		Electricity		✓	✓		✓				✓		✓				✓(12)	✓	✓	✓	
	Steam	Gas replacing oil / coal		✓	✓	✓	✓			✓	✓		✓				✓(12)	✓	✓		
		Electricity		✓	✓	✓	✓			✓	✓		✓					✓	✓		
	CHP***	Gas replacing oil / coal		✓	✓	✓			✓	✓	✓		✓		✓		✓(12)	✓		✓	
		Biomass		✓	✓	✓			✓	✓	✓		✓		✓		✓(12)	✓	✓	✓	
	Overall industry	Carbon Capture Storage		✓	✓(14)	✓					✓		✓					✓	✓		
		CDR/NET****																✓			
	Behavioural change	Lower material consumption		✓	✓(10)		✓				✓(10)		✓			✓(15)	✓(12)	✓(10)			

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SECTOR			ALADIN	FORECAST	JET	LEAP	NEMESIS	CONTO	MARKAL	MAPLE	NATEM	SISGEMA	TIMES-CAC	DICE	GCAM	ICES	GEMINI-E3	TIAM	MUSE	42	E3ME
Mitigation: agriculture	Energy use	Gas replacing oil / coal				✓	✓	✓			✓		✓				✓	✓	✓	✓	
		Biomass				✓	✓	✓			✓		✓					✓	✓	✓	
		Electricity				✓	✓	✓	✓		✓		✓				✓	✓	✓	✓	
	Land practices	Land yield maximisation													✓						
		Organic fertilizer use																			
		No tillage																			
		Agroforestry																			
	Animal husbandry practices	Improved feeding practices									✓				✓						
		Manure management									✓										
		Feed additives									✓										
	Behavioural change	Less product demand			✓(10)						✓(10)		✓(9)		✓	✓	✓	✓(10)			
Mitigation: land use, land use change and forestry		Afforestation			✓							✓	✓		✓				✓		
		Land protection										✓			✓			✓	✓		
		Biomaterials													✓						
Adaptation measures	Land	Land use adaptation/planning													✓						
		Water use restrictions			✓								✓(16)			✓					
		Forest fire management																			
	Water bodies	Coastal protection																			
		River restoration/rehabilitation																			
		Flood management																			
		Retreat/elevated infrastructure																			
	Urban	Additional cooling of buildings			✓								✓		✓						
		Early warning systems																			
		Green spaces in cities																			
		Building material choices			✓																

[*] CCS = Carbon Capture and Storage; [**] LCNG = Compressed Natural Gas, LNG= Liquefied Natural Gas; [***] CHP = Combined heat and power; [****] CDR = Carbon Dioxide Removal

(1) Way of production is represented by fuel costs (exogenous); (2) Available without CCS; (3) Nuclear to hydrogen; (4) Thermal splitting (nuclear); (5) Sectors aggregated; (6) Wind sector aggregated; (7) Geothermal heat pumps attached to district heating only; (8) Implemented through fuel price; (9) Exogenously determined; (10) Demand reduction through price elasticities; (11) Exogenous behavioural shift on transport sector; (12) Energy uses aggregated together; (13) Exogenous shift in energy demanded by households; (14) More granularity is also possible; (15) Exogenous shift energy efficiency and other materials; (16) Only for Kazakhstan; ; (17) Only for households; (18) Biomass Integrated gasification combined cycle (BIGCC) and BIGCC with CCS; (19) Fuel cells

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3 Policy scenarios

As presented in the previous section, there is an extensive array of integrated models aimed at underpinning climate and energy policies, each of them designed to respond to a great variety of different policy questions (Nikas et al., 2019; Doukas and Nikas, 2020). These policy questions vary from poverty levels to the share of fossil fuels in energy generation in 2050, and some of the models can answer questions related to the SDGs as well. However, no single model can consider all questions in such a complex domain (Doukas et al., 2018) and, at the same time, some relevant topics are not considered in any of the models (e.g. gender equality).

In order to provide more in-depth information on the question of what our models can and cannot deliver, the next paragraphs present a wide variety of questions that the models can approach, related to mitigation and adaptation policies and SDGs; as well as multiple examples on how these models have contributed to relevant policies and decisions.

3.1 Mitigation and adaptation measures

The capabilities of the models in the PARIS REINFORCE portfolio allow for handling questions including but not limited to the examples provided in this section. Here, we highlight a series of (hypothetical) policy questions that our modelling ensemble of tools can answer. At a later stage of the project, in terms of *inclusive policy making* and *co-creating knowledge* with practitioners, policymakers, academics and all other relevant stakeholders—the core component of the PARIS REINFORCE project—policy questions will be co-designed with the stakeholders that will thereafter drive the scenario design and initial modelling runs.

This attempt is to characterise the range and diversity of questions that can be handled with our modelling ensemble within the consortium as well as to provide an opportunity to raise questions, share knowledge and interact with peers and stakeholders. As can be observed, most of the questions are related to mitigation, addressing both the demand and the supply side so the policy questions may emerge as critical insights regarding the energy production and the consumption chain. However, the diversity of questions is vast, depending on the priority of action areas that emerge from the dialogue with stakeholders. Policy questions may concern behavioural changes/individual action; or more systemic changes regarding policy instruments and "just" transitions and labour implications, agricultural production, trade patterns and many more.

3.1.1 Mitigation

Energy Production:

- *What is the persistence of nuclear energy in 2030/2050 under current tendencies and policies?*
- *How would a 100% renewable electricity mix in Europe look like in 2050?*
- *What would the energy mix in the EU be after a complete phase-out on coal?*
- *How would a moratorium on new fossil installations look like? What would this mean in terms of scaling up with renewable technologies?*
- *What is the role and weight of CCS in IAMs? Can a future without CCS be possible?*

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Transport:

- *How can bans on diesel cars in urban areas or quotas outdated car fleet/vehicles impact emissions?*
- *How will the share of electric vehicles in 2030/2050 impact emissions in different regions?*
- *How can short-distance electric aviation potentially affect the emissions in 2050?*
- *How will the elimination of certain flight routes affect emissions at the European level?*

Land:

- *How would an increase in protected land impact negative emission rates?*
- *How would production quotas on monoculture crops impact emission rates?*
- *What is the impact on emissions between long and short food chains? How can shortening food production systems affect reduction of emissions?*

Trade:

- *How can shipping trade be accounted for? How would new trade routes impact emissions?*

Labour:

- *How can a shift from fossil industries to renewables impact labour conditions? How can these scenarios be used in "just" transition scenarios?*

Behavioural changes:

- *What are the effects on emissions of a modal shift in personal transport? How can certain subsidies or societal shifts (like "flight shaming") facilitate train travel and impact emissions respectively?*
- *What is the effect on emissions of a reduction of meat demand?*
- *How will a 20% reduction on individual household energy demand affect emissions in 2030? How can this be achieved: via efficiency or via demand reduction?*

Energy efficiency:

- *How can smart meters and «time of use» tariffs impact consumer choices and efficiency?*
- *How much room for improvement is there for energy efficiency in final energy use in appliances?*

Buildings:

- *How will a shift from gas to electrification in the buildings' heating affect emissions in 2030?*
- *How much can investment in "passive housing" save in terms of emissions?*

Industry:

- *What will the emissions of the industry sector be in 2050?*
- *How will a coal-to-gas shift affect emissions of the industry sector in 2030?*
- *How can the promotion of self-generation and self-consumption impact industrial emissions?*
- *How can greater reuse (upcycling) and efficiency of materials and processes impact industrial emissions?*

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- *Will electrification of the low-temperature industry (example: textile sector, processing of foods) be possible? How much reduction of emissions can this result in?*

Policy Instruments:

- *How will the removal of fossil fuel subsidies affect respective prices?*
- *How will moving away subsidising fossil gas infrastructure and gas as a transitory fuel impact sectors?*
- *How can a carbon tax impact the uptake of renewables?*
- *How can a tax on CO_2 in the sectors (not included in the Emissions Trading System) impact the economy?*

3.1.2 Adaptation

As these models were originally thought for mitigation, they are very vague when addressing adaptation issues, but still manage to respond to some questions, such as the ones regarding afforestation, land-use change and/or negative technologies (if any), for example:

- *What are the consequences of afforestation levels in land-use change?*
- *How can thermal regulation of buildings (and retrofitting) impact efficiency and consequent emissions?*

3.2 SDG Agenda

Despite most models not having originally been designed to handle the SDG targets (ICES includes a focused module on SDGs) and especially not the ones addressing societal issues, a number of the models in the PARIS REINFORCE portfolio can provide great insights into the progress towards their achievement.

What will the poverty levels be in 2040?

- ICES is able to give information on the poverty prevalence (% population) (target 1.2.).

Other questions that cannot be answered by our models:

- Extreme poverty levels (target 1.1.) and how climate change will affect them.

What will the hunger levels be in 2030?

- ICES is able to give information on the prevalence of undernourishment (% population) (target 2.1.).
- GEMINI-E3 and GCAM are able to calculate agricultural prices and food prices by region respectively, providing some information related to the topic, but not specifically on hunger. Additionally, GCAM is able to provide some information on the production of twenty different crops.

Other questions that cannot be answered by our models:

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- Access to land, related to target 2.3.
- Crops productivity, related to target 2.4., and how climate change is going to affect it.

How many premature deaths are due to air pollutants?

- ICES, GCAM and MAPLE are able to calculate the mortality rate due to air pollutants (target 3.9.).

What will the health coverage be in 2030?

- ICES can calculate the physician density, but models cannot calculate real access to health for the population, as it depends in other factors i.e. affordability, doctors training, infrastructure etc.

What will the education levels be in 2040?

- ICES is able to provide the literacy rate (% population). However, more qualitative data regarding access to free and quality education (target 4.1.) or the level of gender disparities in education (target 4.5.) cannot be addressed by our models.

What will be the difference in income between men and women?

- E3ME is able to project the income distribution by gender

However, other forms of discrimination against women and girls cannot be captured by any of the models

What is the level of access to safe and affordable drinking water in 2030?

- Our models are able to provide information on variables such as water consumption per capita (JET and LEAP), but fail to calculate the levels of access to water among the population.

How will water scarcity threaten specific regions by 2030 and beyond?

- GCAM is able to assess future water scarcity as a function of water basin characteristics, agricultural, industrial and municipal water use, and future temperature levels.

What will be the level of energy access in 2030?

- ICES is able to estimate the access to electricity (% population) and, at the same time, calculate the percentage of renewable sources in the energy mix.
- Other models such as GCAM, TIAM, GEMINI-E3 or MARKAL-India can provide information on the penetration of renewable energy, but fail in providing information about access.

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What will be the levels of access to decent work in 2040?

- Various models can provide inputs on this answer. GEMINI-E3 and ICES are able to provide information on GDP growth and GDP per capita, and ICES is also able to calculate the percentage of people employed (% population).
- However, other qualitative aspects related to what a “decent work” means cannot be captured in our models.

Our models can handle the level of financing for different investments: ICES and NEMESIS can measure R&D expenditure, MUSE can offer information on investment by sector, and ALADIN considers innovation in technology and infrastructure.

What will be the level of inequality in 2025?

- ICES is able to calculate the Palma ratio within a country, i.e. the ratio of the richest 10% of the population’s share of gross national income (GNI) divided by the poorest 40%’s share.

ICES can calculate the CO_2 intensity of the residential and transport sectors, being able to address some issues regarding the impact of cities and their transport systems, but other variables related to the topic such as access to adequate, safe and affordable housing cannot be calculated.

GCAM is able to calculate the footprint impact of consumption, and TIAM and JR-EU-TIMES is able to provide information on energy consumption and production patterns.

All models are inherently related to climate action at large.

None of our models provides information on aquatic ecosystems.

JET and TIAM provide simplified information on afforestation and GCAM on land-use change; while SISGEMA is able to estimate the deforestation rates, as well as the conservation and restoration cost in each of the Brazilian municipalities.

However, other variables such as desertification level, ecosystems conservation and restoration cannot be addressed.

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16 PEACE, JUSTICE AND STRONG INSTITUTIONS

None of our models provides explicit information on peace, justice and strength of the institutions. However, they can indirectly tackle justice issues via other SDGs such as SDG 8 or SDG 10.

17 PARTNERSHIPS FOR THE GOALS

None of our models can measure the projected level of commitment and partnerships for the goals.

3.3 Key policy questions already addressed by the models

The PARIS REINFORCE portfolio of models has already been used in very different contexts in the past, demonstrating their capabilities to address very relevant policy questions. These include but are not limited to the examples below.

Decarbonisation of industry in the EU:

- FORECAST: Used in the "A Clean Planet for all" EU 2050 strategy to model the decarbonisation of the EU industry sector.
- FORECAST: Simulated the transition to a low-carbon energy system for the industrial sector in an integrated manner – SetNav H2020 project.

Impacts of different mitigations measures:

- NEMESIS: Estimated the impact of RES deployment on employment in the EU.
- CONTO: Explored the macroeconomic impacts of a 1.5°C scenario in Russia.
- GEMINI-E3: Analysed the energy and economic impacts of a deep reduction on emissions per capita (e.g. Switzerland, transition to only 1 ton CO2 per capita in 2050).

Electric vehicles deployment:

- ALADIN: Studied the market evolution of plug-in electric vehicles (PEVs) in Germany.

Carbon market and carbon prices:

- GEMINI-E3: Estimated the magnitudes of carbon taxes that would be needed to meet strong CO_2 emissions reductions targets in Switzerland by 2020 and 2050, and assessed the economic impacts of meeting those targets through carbon taxes.

Impacts of climate change or climate change policies on SDGs:

- GEMINI-E3: Analysed the consequences of climate scenarios on health, buildings/infrastructure, energy, water, agriculture, tourism, and the spill-overs to other sectors.
- ICES, GCAM: Evaluated synergies and trade-offs between emission reduction policies and SDGs.

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Other policy questions:

- GEMINI-E3: Analysed the impacts of Brexit on the EU climate policy.

3.4 Potential of policy questions to be addressed in the future

As has been shown, models can handle a wide variety of issues, and despite their legitimate criticisms, they have been extremely useful in designing and planning climate policies and targets. However, this analysis has highlighted some limitations, and therefore some improvements to be done in the future, especially with regards to considering qualitative information.

Regarding the effects of climate change on different ecosystems, there is barely any information on aquatic ecosystems and how climate change will affect them —and therefore the communities relying on them— as well as some important variables of SDG15, such as desertification.

Looking at social issues, only one model can provide limited information on gender equality (SDG5), a key piece in implementing mitigation and adaptation measures worldwide; while others barely capture some information on education (SDG4). Additionally, they tend to fail when providing data on "access to" (e.g. access to health services, access to water, access to clean energy, etc.). Some models can provide the availability of the resource, but not the accessibility *per se*, which is a more complex issue.

Finally, no model can handle the last two SDGs, related to peace, justice, and strong partnerships for the goals. All this qualitative information should not be missed when planning energy and climate policies, complementing the data provided by the models.

To conclude, when dealing with complex challenges, none of these models or tools alone is capable of meeting such societal challenges. Hence, stakeholder co-creation processes are increasingly promoted to create collaborative roadmaps for future energy transition pathways (Mourik et al., 2017).

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4 Model validation

Regarding the use of the models described in Section 2, a legitimate question has been raised, both in the literature and in the policy world, around the levels of trust that people (whether scientists, policymakers or other stakeholders) should have in these models and their outputs (Doukas and Nikas, 2020). That is, especially, considering the underlying assumptions driving them (Kelly and Kolstad, 1999) and uncertainty ranges (Doukas et al., 2018), as well as the extent to which these are communicated alongside the results.

It is unavoidable that the models used in PARIS REINFORCE cannot provide a complete representation of the world, owing to the fact that in many ways the future is unknown, and furthermore there is incomplete knowledge of past dynamics governing energy, agricultural, land and environmental systems that are represented by these models.

In spite of this challenge, the models used in PARIS REINFORCE are intended to be trusted, and seen as useful and valid, by both the scientific community and—equally if not more importantly—stakeholders such as policy- and decision-makers, who will plan low-carbon strategies on their basis. Here we detail the steps both that have been applied in developing and using the models, as well those that will be applied in the context of the project, in order that such trust and validation is achieved.

The workflow to be followed in PARIS REINFORCE includes the following steps, as also presented in Figure 2, based on the relevant literature on evaluation and validation of integrated assessment models and drawing from the primary elements of (Schwanitz, 2013):

- **Documentation** of models' capabilities, in terms of geographic, policy, sectoral, technological, emissions, and socioeconomic coverage, in technical and non-expert-friendly language, for both the academic community to evaluate and other stakeholder groups to comprehend and appreciate the extent to which models can be used to respond to policy questions and concerns. A major part of this documentation step is this deliverable itself, and its representation on the I^{2}AM PARIS platform.
- **Communication** of these capabilities, as well as of the extent to which these models are validated, referenced, benchmarked, and evaluated, and therefore trustworthy. This includes a process of presenting the modelling approaches and preliminary results to stakeholders, a discussion of the types of inputs and outputs the models produce as well as of how they produce these outputs, and a co-design of the entire research process to ensure transparency and policy demand orientation.
- **Benchmarking and harmonisation** of inputs, as part of validity checks of the employed models, with the aim to ensure that they are in line with the most up-to-date verified information as well as harmonised in the multi-model analyses and inter-comparisons envisaged in the project, so as to allow mapping the resulting ranges exclusively onto the models' diversity (see Giarola et al., which explicitly reports on this harmonisation process, and Sognnaes et al., which explores inter-model differences in scenarios).
- **Diagnostics** runs, to check that each model's responses to key input variable changes are in line with common expectations and compared to other results and global models and/or a priori defined 'stylised' behaviours (see Giarola et al.).
- **Iteration** of this workflow, with experts and non-expert stakeholders, to document and discuss

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results with them, allowing them to appreciate the behaviours of the models under increasingly stringent mitigation scenarios, and why the models respond in the way that they do.

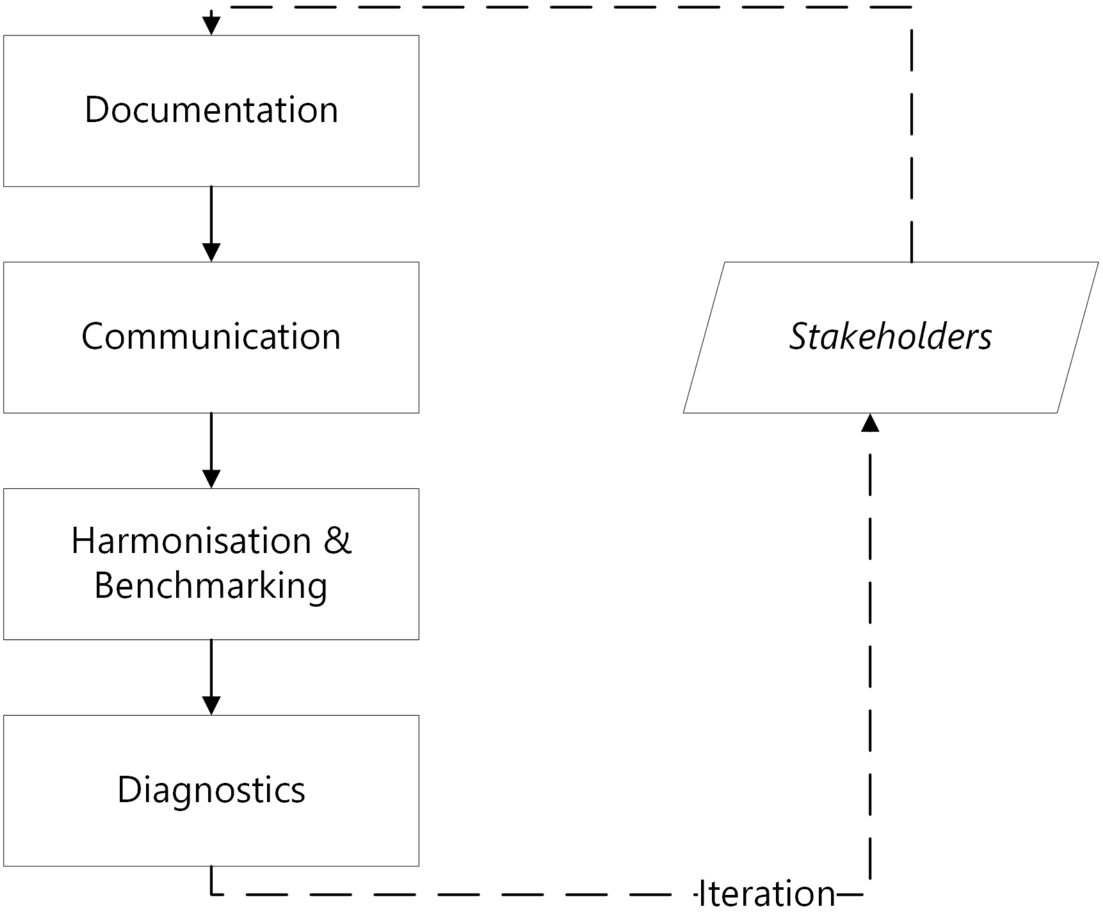

Figure 2: Model validation process in PARIS REINFORCE

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5 Stakeholder knowledge

Stakeholder engagement and co-creation lies at the core of PARIS REINFORCE, aiming to include stakeholders' knowledge and expertise in the research process. This places the project directly in line with the Talanoa facilitative dialogue, which established the need for a more collaborative and cooperative approach toward climate research and policy implementation.

This section directly links with D3.1., offering more detail on the importance of stakeholder involvement, as well as concretising how stakeholder knowledge will be used within the project.

5.1 Relevance and legitimacy for co-creation

The involvement of stakeholders in the research process is an increasing trend, especially when dealing with complex topics that touch social, economic and political interests, such as the energy transition (Mielke et al., 2016). The main objective of this process in this context is to tackle the complexity, uncertainty and variety of perceptions on mitigation and adaptation to climate change by combining expert knowledge with views from all stakeholders, including the civil society (Kasemir et al., 2000).

The advantages of stakeholder involvement are multiple, having demonstrated capacity to increase the degree of political relevance (Spangenberg, 2011), to enhance the legitimacy and credibility (Cash et al., 2003; Lang et al., 2012), to create ownership of the problems (Lang et al., 2012), and to improve the accountability of the research (Welp et al., 2006). The dialogue among stakeholders ensures that a wide range of interests is reflected in the research, improving scientists' policy recommendations and therefore the interconnection and exchange process among science and policy, i.e. the science-policy interface (Mielke et al., 2016).

However, despite the proved benefits, the most extended practice in the model-based research in support of climate policy is to limitedly engage stakeholders (Doukas et al., 2018). In fact, one of the most common criticisms of IAMs is the lack of transparency on the assumptions that drive the models, causing a lack of trust among policymakers on the modelling results and the associated recommendations (Doukas et al., 2018; Gambhir et al., 2019; Kelly and Kolstad, 1998). There are nevertheless some efforts happening to integrate stakeholders into modelling (see Huppmann 2019), and other H2020 projects such as TRANSrisk, Deeds or Shape Energy Initiatives have successfully consulted multiple actors, but the practice is far from being mainstream.

On the contrary, PARIS REINFORCE employs an innovative approach in the modelling activities, where stakeholders are involved from the very beginning of the process and co-create, together with the scientists, the different policy questions, seeking to intertwine science and policymaking, incorporating into the research process the knowledge, experience, expertise and expectations of stakeholders. This inclusiveness is in line with the Talanoa dialogue in COP23, giving voice in the climate change dialogue to literately everyone, experts or otherwise.

Therefore, the stakeholders considered in this project are not only policymakers, but also the private industry, national governments, the research community, non-governmental organisations (NGOs), labour and trade unions and associations, representatives from other relevant institutions, and the civil society. All of the them are the driving forces of the transition to transform our economies and our societies and should be at the centre of policy support—including modelling—processes, especially in the context of an ongoing and systematic review and reshaping of climate action.

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5.2 Stakeholder knowledge mapping

The main stakeholder engagement process takes place within WP3 as a part of the Ongoing Stakeholder Dialogue. Here, it has been specified that a dynamic and nuanced approach will be undertaken to include demand driven ongoing conversations with all relevant stakeholder groups to engage their demands for plausible climate concerns prior to the modelling runs of the consortium.

A vast array of stakeholder groups is to be identified (lead by Bruegel and all partners in the consortium), ranging from different regional and thematic focuses.

The foremost domains of stakeholder knowledge have been defined as:

- Core policymakers group
- Co-designers
- Thematic focus groups
- Self-identified stakeholders
- Scientific Advisory Board (SAB) guiding the consortium

The core policymakers group, identified as a small group of high-level decision makers (5-10 individuals), will serve as a first driver for determining and compiling foremost concerns and for sharing the consortium's research for ensuring policy-relevance of work undertaken.

The co-designers are a large group of stakeholders that will consist of experts covering national and regional policymakers, members of academia, representatives of industries, trade unions, NGOs, financial entities as well as the civil society to include views and concerns of lay citizens, adding legitimacy to our work and ownership of the scientific/research outcomes.

The thematic focus groups will be a subsample of the co-designers, that will have more specific thematic focus discussions particular to emerging sector-specific or case-specific concerns.

Self-identified stakeholders will be a form of inclusive engagement where interested parties or people will be allowed to become a stakeholder in the project, through self-registration during any point of the project.

Lastly, the Scientific Advisory Board (SAB) will be our complementary stakeholder entity that will collaborate with the PARIS REINFORCE consortium with their expertise, guiding the engagement and execution of the project throughout the three years.

5.3 Engagement methods

The engagement and co-creation process will be conducted through different methods all along the research process as specified in D3.1 Stakeholder Engagement Plan. These methods will vary depending on the different types of stakeholders considered (see Section 4.2.) with the objective of gathering different types of knowledge and expertise from all stakeholders.

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Table 9: Engagement methods and techniques

Engagement methods	Most appropriate application of technique
Bilateral or multilateral interviews	• Solicit views and opinions • Enable stakeholders to speak freely and confidentially about controversial and sensitive issues • Build personal relations with stakeholders
Formal meetings	• Present project information to a group of stakeholders • Allow the group of stakeholders to provide their views and opinions • Build impersonal relations with high-level stakeholders
Public events & workshops	• Present project information to a large audience of stakeholders, and in particular communities • Allow a group of stakeholders to provide their views and opinions • Build relationships with local communities • Use participatory exercises to facilitate group discussions, brainstorm issues, analyse information, and develop recommendations and strategies
Focus group meetings	• Allow a smaller group (e.g. of between 8 and 15 people) to provide their views and opinions of targeted baseline information on a specific thematic/regional issue • Build relationships with local communities or sectoral networks
Survey, questionnaire	• Gather opinions and views from individual stakeholders on a large scale.

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6 The I²AM PARIS platform

The I²AM PARIS platform will act as the main channel of all modelling documentation where all the features of the modelling ensemble present within the PARIS REINFORCE consortium will be streamlined.

In similar vein, it will be the "go-to" reference source for the public, policymakers and the scientific community, for gathering insights on the capabilities of our models in relevance to the most pertinent climate-related policy concerns they may have.

6.1 Why do we need a Platform?

In the most recent IPCC 1.5 °C Special Report, it has been noted that:

"…[e]xploratory knowledge generation about future pathways cannot be completely isolated from societal discourse, value formation and decision making and therefore needs to be reflective of its performative character (Edenhofer and Kowarsch, 2015; Beck and Mahony, 2017). This suggests an interactive approach which engages societal values and user perspectives in the pathway production process. It also requires transparent documentation of IAM frameworks and applications to enable users to contextualise pathway results in the assessment process." [Forster et al., 2018, 2SM-pp9][1]

Therefore, there has been a plea to re-integrate social considerations and priorities into the thinking, which extends beyond business-as-usual modelling attempts (Byrne et al., 2006; Goldthau and Sovacool, 2012). The novelty of the PARIS REINFORCE project centres around stakeholders driving all modelling and policy support processes, where they actively participate in all stages of the project.

For doing so, the three main driving questions of the Talanoa Dialogue will guide design of the platform:

Where are we now?

This guiding question will serve as a ***diagnostic*** and will include responses to where the world, policy and science currently stand, by means of model stocktake, documentation and specifications that will include detailed information on mitigation and adaptation measures, geographic coverage, socioeconomic dimensions, sectoral, emission, policy and SDG granularity; as well as of highlighting assumptions behind all models used in the PARIS REINFORCE consortium, while also acknowledging what our models cannot deliver with their respective limitations.

Where are we going?

This guiding question will respond to the PARIS REINFORCE modelling ensemble capabilities including a compilation of relevant **policy questions determined through a co-definition process** with the relevant stakeholders, and a set of responses to which models within the modelling portfolio can answer these concerns.

How do we get there?

This guiding question will serve as a basis for the model runs (envisaged to be carried out in two

[1] From SR 1.5

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iterations/rounds), as an attempt to answer stakeholders' policy questions and resulting scenario outputs of **how models respond** to these.

6.2 What is the Objective of the I^{2}AM PARIS platform?

The objective of the platform is to take the stocktaking task beyond the state of the art of already existing modelling documentation platforms, such as the EU ADVANCE project[2] or other attempts of reporting harmonised baselines, such as the AMPERE Project[3], by serving as an **arena** where **concerns** on achieving post-Paris pledges are inquired and **responses** to how our modelling consortia handle these concerns can be found.

The platform will initially be used as a common reference point for all analyses as well as serving as a basis for undertaking harmonisation attempts and making model inter-comparisons more meaningful.

The platform will also serve as a glossary and/or reference document to be used for both experts and non-experts to familiarise themselves with the *scope, capabilities* and *results* of model runs and their *assumptions*.

Moreover, the I^{2}AM PARIS platform will be used as a tool for communicative purposes and will encourage further stakeholder engagement by bridging traditional gaps between science and the relevant stakeholder base.

6.3 Who is the Target Audience of the Platform?

The I^{2}AM PARIS platform will have two principle user interfaces, corresponding to two target groups:

- *Policymaking/public interface:* aimed at policymakers and all other relevant stakeholders, who will be able, via this interface, to inquire about relevant policy questions. The policy questions will be queried within the system regarding the capabilities of the modelling ensemble and correspond to:
    - What do stakeholders perceive as a problem?
    - How do stakeholders formulate sustainability problems, policy questions and priority areas of action?
    - How can the modelling ensemble of the PARIS REINFORCE consortium respond to some of these pertinent areas of concern for giving way for informed decision making and taking?
    - The core aims of this interface will be documentation, dissemination and exploitation, transparency, ownership, and informed decision making.

- *Science/modelling interface:* consisting of the detailed modelling stocktake, on endogenous and exogenous variables and a detailed level of granularity of sectors, mitigation and adaptation indicators and assumptions behind the model runs, as well as all scenario outputs. The core

[2] http://www.fp7-advance.eu/
[3] https://cordis.europa.eu/project/rcn/98809/reporting/en

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aims of this interface will be academic/scientific dissemination and exploitation, legitimacy, and reproducibility.

6.4 Timeline

The preparation of the open access I^2AM PARIS platform is an ex-post process to deliverables D5.1, D6.1 and D7.1, which provide information on model features, capacities and specifications; as well as deliverable D3.1, on the stakeholder engagement plan.

Mock-ups of the platform have started and an initial presentation of the platform's capabilities are to be presented at the First Stakeholder Council Dialogue, in Brussels, on the 21st of November, 2019.

The gradual improvement of the platform is to be undertaken and fine-tuning adjustments will take place from M13 (June 2020) till M36 (May 2022) of the PARIS REINFORCE project.

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