PARIS REINFORCE

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Policy Brief

PARIS REINFORCE: What can our models deliver?

Key Points

Detailed policy briefing on:

- **Benefits of modelling**
- **How do the models work?**
- **What can the models do?**
- **What can the models not do?**
- **What have the models done before?**

The PARIS REINFORCE modelling ensemble includes:

- **5 national/regional models for Europe;**
- **9 models covering major and less emitting countries and regions outside of Europe; and**
- **8 global models.**

Thematic area:	Keywords:	Author(s):
Climate Change; Climate Policy; Low-carbon Transitions; Climate-Economy Modelling	Policy brief; Integrated assessment models (IAMs); Climate policy; Climate science; Co-creation; Policy questions	Ben McWilliams, Georg Zachmann (Bruegel) Alevgul Sorman, Ester Galende (BC3) Ajay Gambhir (Imperial College) Alexandros Nikas, Haris Doukas (NTUA)

The PARIS REINFORCE project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 820846.

PARIS REINFORCE: What can our models deliver?

Policy Challenge: PARIS REINFORCE is an EU Horizon 2020 project running from 2019-2022. The project comprises a consortium of thirteen European and five international partners. The fundamental aim of the project is to enhance and improve climate policymaking. In order to do this, the consortium has access to a range of sophisticated climate-economic scientific models. A key novelty of the project is its devotion to 'demand-driven' research. That is, the questions these models will provide insights into and the assumptions they will do this based upon are to be stakeholder-determined through an extensive and exhaustive process. To this end, this policy brief looks to offer an explanation of the modelling capabilities available to PARIS REINFORCE, focussing upon what the models can and cannot do, how they do it, and which areas the models have previously explored.

In order to effectively inform and enhance climate policymaking, PARIS REINFORCE (PR) can rely upon an extensive modelling ensemble comprising:

- 5 national/regional models for Europe,
- 9 models covering major and less emitting regions and countries outside of Europe, and
- 8 global models.

The combination and interaction between different types of models ensures that PR is able to provide a comprehensive level of policy insight that would not be possible with any single modelling exercise.

The purpose of this policy brief is to offer an overview of PR's modelling capabilities in order to help frame a stakeholder-led debate around which relevant policy questions or issues the models should be set to address.

Models provide a testing ground for hypothetical climate policy decisions within structured frameworks. The value they add comes from a better understanding and subsequently more informed implementation of decarbonisation policies.

Policy Brief on:

- ❖ Benefits of modelling
- ❖ How do the models work?
- ❖ What can the models do?
- ❖ What can the models not do?
- ❖ What have the models done before?

Interest in such policies stems from the necessity of reaching Paris Agreement targets, implementing effective Nationally Determined Contributions (NDCs), effective National Economic and Climate Plans (NECPs), as well as desires for further and bolder climate pledges, looking forward to the 2023 Global Stocktake.

Models can offer insight into a vast array of indicators, as well as a range of possible future energy and climate scenarios. The combination of energy, climate and economy representations in many of the models allows for the important assessment of economic and energy system impacts, if any, arising from climate policies. Through such a process of rigorous scientific analysis, policymaking can most efficiently achieve climate targets whilst considering economic returns in terms of employment, GDP and social welfare.

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Benefits of Modelling

Governments and societies together must now make fundamentally important decisions in the drive for decarbonisation that will significantly and structurally alter the shape of economies for decades to come. The effects of climate policies will permeate far beyond the climate sphere into **all aspects of societies**. It is therefore of the utmost importance that these policies are designed to be as socially optimal as possible. For instance, policies must balance desires for rapid decarbonisation with societal concerns of distributive justice.

Apart from offering valuable policy insights, modelling results provide **scientific legitimacy** to policymaking and offer protection for potential policies to survive political scrutiny.

The range of models available to PR have already been successfully used in developing the **fifth IPCC report** as well as **NDCs**.

Modelling Types

PR has access to a broad range of modelling types differing in the ways and levels of detail in which they assume economies behave, e.g. how they represent economic behaviour and the sectors to which they devote particular attention. Each modelling type has its advantages and limitations. Therefore, models are often able to offer the most powerful insights in combination or via comparison on the same issue.

PR’s **modelling ensemble** comprises energy system, partial and general equilibrium, macro-econometric, and other sectoral models, available at the national, regional, and global scale. Many of the models have integrated climate modules, effectively making them integrated assessment models.

***Brief description** of the modelling types available to PARIS REINFORCE:*

Energy System models have detailed representations of energy sector processes. These essentially include fuel extraction, transformation into useful energy forms (e.g. electricity), delivery of this energy to end users, and finally consumption of this energy to provide consumer services (e.g. transportation, and heating).

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

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

Macro-econometric models also offer multiple-sector representations of the economy, as with CGE models. However, they do not assume optimising behaviour or market equilibrium in the short-term. Sectors across the economy are modelled based upon historical data and econometrically estimated parameters.

Other sectoral models simulate specific sectors of the economy, such as land use, transport, or inter-industry. These models do not necessarily have as detailed links between energy, economy, environment and climate feedbacks as integrated assessment models.

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Models can work together by either being set to address the same questions separately or by being linked together to provide a more detailed analysis on one particular policy area. In terms of linkages, one of the most important to arise from PR’s modelling capabilities is that of the detailed, technologically rich, sectoral models producing output that can be fed into broader macroeconomic, integrated assessment modelling tools. This combination can provide a deeper understanding of both how policies can have an effect within particular technology and/or sectoral areas as well as how these changes may then interact with other economic sectors, leading to broader economic consequences.

How do the models work?

Models do not all operate in the same way but share some overarching methodologies. Most importantly, all models depend upon **socioeconomic**, **technological**, and **other assumptions** to drive results. For instance, energy models take data on the demand for and supply of different fuels from the world as of today, and then model how energy technologies and fuel mixes are likely to evolve over time. The models are run based upon calibration to a base year, whilst changing exogenous variables according to the latest scientific predictions (e.g. population growth). Other models take data on different economic goods and input variables beyond fuels before performing similar analysis.

Exogenous variables have their value determined outside of a model and are then input into the model.
Endogenous variables have their value determined within the model. Their value will therefore change in line with other modelled variables.

Models decompose economies into multiple constituent sectors. Within these sectors, socioeconomic inputs drive demands for energy and other services. For example, in those models representing the agricultural sector, demand for agricultural services (including food and fibre) is determined by factors such as population and income growth. The evolution of these factors over time is therefore a very important building block for models.

Socioeconomic Assumptions

Technological Assumptions

Political Sentiment

Policy Evaluation

Scenario Analysis

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Models can be used in different ways to evaluate climate policies and targets:

Policy implementation – investigating the effects of particular policies through changing a range of assumptions (e.g. on socioeconomic growth, technology availability, and costs) and observing how the models respond, in terms of technology, fuel mixes, and economic outputs. For example, an energy system model could investigate the effects of a policy providing subsidies for household solar PV installations on household energy demand, energy supply, and the balancing of electricity markets. Broader analysis using a macroeconomic model could then investigate household income effects, and the changing consumer demands across sectors.

Models allow for user-customisation of the policy mix, such that a new set of policies can be fed into models and estimated changes to economic, energy system, and climate indicators can be calculated. Changes can be applied to both policies and underlying exogenous assumptions relating to socioeconomic and technological parameters.

Different models would be selected to evaluate policies based upon their specialisations and the particular effects a user is interested in.

Scenario analysis – rather than implementing a particular set of explicit policies within a single framework, models can also assess the likely evolution of economies and energy systems according to a range of different scenarios. These could consist of different assumptions regarding areas such as consumer preferences, technological evolution and political sentiment.

As an **illustrative example**, in energy markets, one scenario could consider the emergence of highly engaged consumers (prosumers) who rapidly invest in distributed electricity generation compared with another scenario of rather disengaged consumers who continue to prefer to purchase electricity directly from central generation sources.

Models investigate the effects of different global/national scenarios by changing the socioeconomic assumptions they rely upon, e.g. high/low population growth, high/low energy demand, etc. Examples of different scenarios based upon socioeconomic assumptions are those from the Shared Socioeconomic Pathways.

A common indicator, used by the IPCC, is the evolution of economies consistent with limiting temperature changes, or greenhouse gas (GHG) emissions, to certain values.

Exogenous shocks can also be considered as part of different scenarios, such as significant behavioural change leading to reduced energy demand, perhaps due to shifts in diets, material consumption, or aviation demand. Shocks to established agreements, such as a Member State leaving the European Union, or a country abandoning the Paris Agreement, could also potentially be analysed through changing exogenous variables.

In combination – it is also common and perhaps most informative to take both approaches together, e.g. to provide an understanding of policy effects under a range of different scenarios. Policy measures can be examined under a reference scenario and then further so under user-customised hypothetical scenarios. For example, under different globally determined oil prices, what are the effects, or indeed requirements, for policy measures to discourage gasoline-powered vehicles?

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What can the models do?

The diversity of the models allows them to cover a large set of mitigation options and policy instruments. Models have been developed in particular to assess the impacts of a broad range of mitigation measures that policymakers may choose to undertake.

Here, some examples of measures that models could quantify are listed, followed by output variables that are typically provided by models:

Policy Options

Both mitigation and adaption policy options can be considered. **Mitigation** concerns measures that look to directly reduce emissions whereas **adaption** considers measures that may be implemented in order to maintain established standards of living in a changing climate. Models have historically focussed predominantly upon mitigation measures; however, adaption capabilities are being steadily introduced in line with their increasing relevance given ongoing climate change.

Mitigation measures

Macro-measures

Certain models investigate policies implemented at the macro-level. Such policies can be expected to have wide-ranging effects throughout the economy. Examples include:

- Carbon (emission) taxation. This can be international, nation-wide, and/or regional, e.g. a carbon border tax on imports in one region, as well as the imposition of carbon taxes by neighbouring countries.
- Tradable carbon permits.
- Annual emission targets or quotas.

Sectoral/technology-specific policies

Models are also able to assess the impacts of policies specific to an individual sector or technology. The impact of such measures can be evaluated at the sectoral level *(in energy system and partial equilibrium models*) whilst also at the broader national and regional level (*in general equilibrium or macro-econometric models*). Some examples include:

- Efficiency targets (for certain industries) or minimum energy performance standards.
- Regulations (standards) – the imposition of specific regulations limiting the use of certain technologies or energy generation within a chosen sector.
- Financial support, for individual technology mixes through R&D or direct subsidies for investments into low-carbon areas such as renewable energy capacity or hydrogen production.
- Energy mix targets.
- Capacity factor limits on certain generation plants, e.g. closing coal plants by a certain year.
- Particular energy taxes for end users.

Sectoral/technological-policy options can be applied into a range of sectors. One can investigate the effects of interventions into sectors in isolation or as part of a broad-ranging economy-wide 'Green Deal'. Models represent economies in detailed sectoral depth. Listed below are some examples of sectors that may be considered important for investigation:

- Upstream technologies (e.g. Synthetic fuel production, such as Coal to Gas; Hydrogen production).

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- Electricity and heat generation (e.g. Coal/Gas with CCS, Nuclear fission, Solar PV, Offshore wind).
- Electricity storage.
- Transport (Road, such as Gas vehicles, Hybrids, Hydrogen fuel cells; Rail; Aviation; Shipping, such as LNG, Biofuels).
- Buildings (Heating, such as gas replacing oil, electricity, hydrogen; lighting, efficiency; Appliances, efficiency; cooling).
- Industry (Process heat; machine drives; steam; CHP).
- Agriculture (Energy use; Land practices; Animal husbandry).
- Land use (payments to landowners for holding carbon stocks, e.g. trees)

Adaption measures

Specific adaptation measures can be implemented for some sectors, particularly relating to the management of land use, water systems, and urban environments. An example could consider the consequences of afforestation levels on land-use change.

Output Variables

The effects of any policy or scenario change will result in many changes to economic and climate indicators. Models record these adjustments and provide a range of output. Examples include:

- **Energy indicators**: how does energy demand change? How is the energy supply mix likely to be altered in order to meet changing energy demand, under different climate policies?

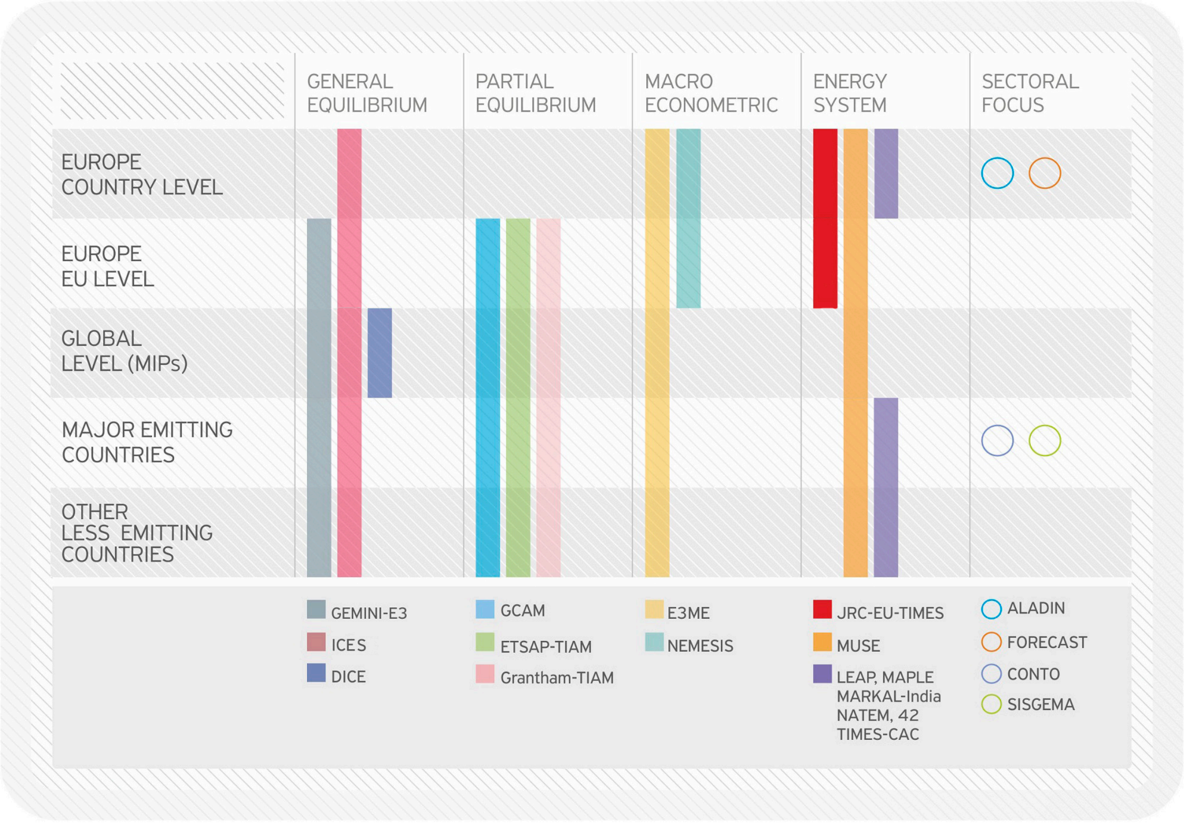

Figure 1: Geographic scope of each model

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- **Economic indicators**: what will the predicted effects be on GDP, employment, and income?
- How will a specific technological policy affect deployment of that technology?
- How will investment spill over into complementary technologies or industries (e.g. what will the effects of investment into electric charging infrastructure be on consumer EV demand)?
- Trade flows: how does the volume and composition of imports/exports vary?

Moreover, the effects on a range of **GHG emissions** and **other pollutants** are also calculated. This allows for a better understanding of how a particular policy can contribute towards NDCs, for example, and of what further measures must be taken beyond such policies to ensure full Paris compliance, as well as complementary benefits in reducing air pollution. Across the broad range of PR’s modelling ensemble, the GHGs considered include carbon dioxide (**CO_2**), methane (**CH_4**), nitrous oxide (**N_2O**), and fluorinated gases (**HFCs**, **PFCs**, **SF_6** and **NF_3**); while the pollutants considered include particulate matter (**PMs**), sulphur oxides (**SO_x**), nitrogen oxides (**NO_x**), ammonia (**NH_3**), and others (e.g. **CO**, **VOC**).

Models can also analyse the *sensitivity of transition pathways* and mitigation costs to particular technological assumptions, e.g. how realistic GHG reductions in the steel industry are, under a range of assumptions as to when CCS will become technologically mature.

The entire modelling ensemble of the PR project can work at the global level with aggregate predictions but is further able to be dissected to the national level, covering 76 disaggregated countries. Figure 1 highlights the geographic scope of each model and the number of models available per region is illustrated in the map below (Figure 2).

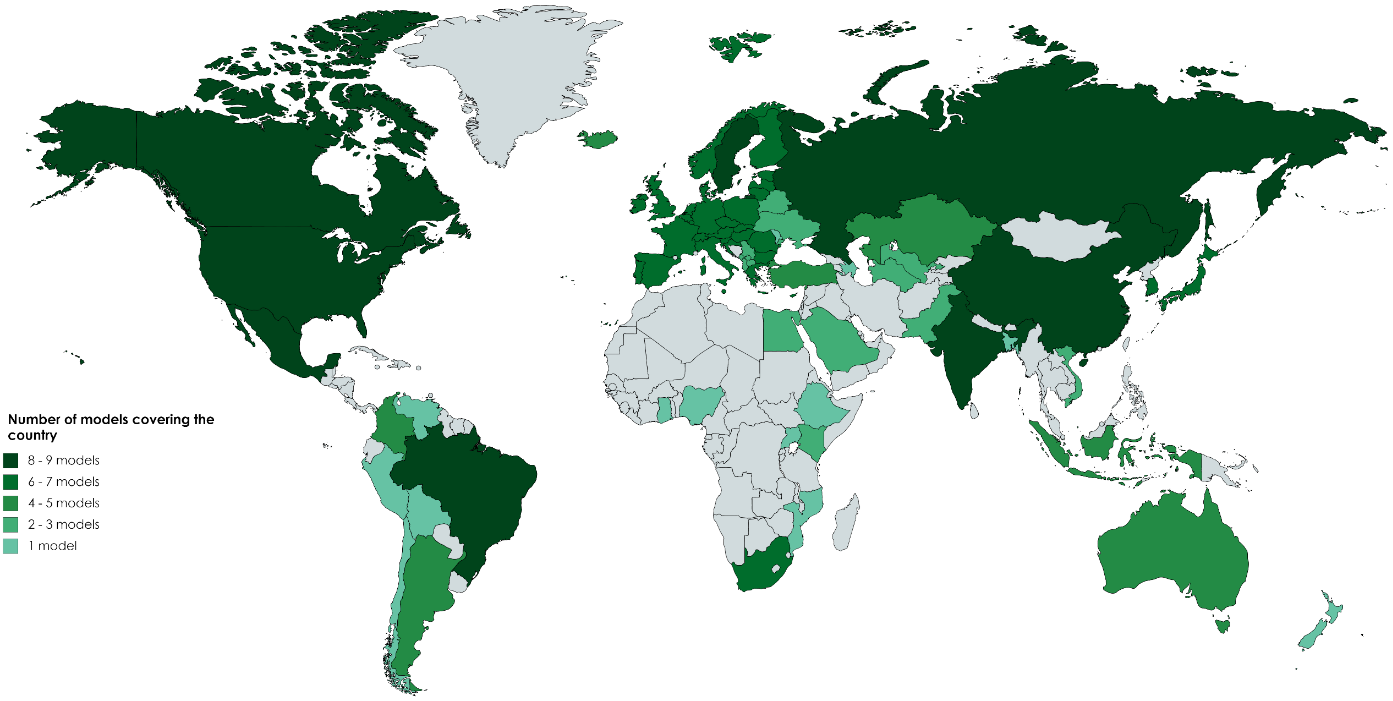

Figure 2: Geographic coverage of the PR modelling armoury

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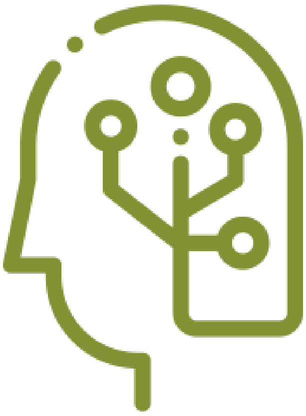
What don’t the models do?

Models are a **broad approximation** to reality and are only as good as the assumptions fed into them. These assumptions range from socioeconomic factors (e.g. population growth) to energy technology parameters (e.g. cost and efficiency). Assumptions drive modelling outputs, and hence an evaluation of multiple different scenarios, based upon different assumptions, is potentially appealing.

This is why a significant element of the PR process consists of consultation and co-creation with a wide range of relevant stakeholders. Through an extensive discussion process, and the creation of a Stakeholder Council and Scientific Advisory Board, PR will be working with as large and diverse a stakeholder base as possible to develop a deeper understanding of the assumptions on which models are built, as well as plausible scenarios for them to investigate. This protocol aims to effectively incorporate stakeholder experience and expertise into scientific modelling.

Such a process will still only arrive at a closer approximation to reality. Indeed, there are no fundamentally ‘true’ values for assumptions that models run on and models cannot be expected to produce fundamentally ‘true’ policy insights. A significant part of the **value from modelling** therefore arises from **constructive dialogues** regarding the inputs into the model, as well as why models output the results that they do.

Through extensive stakeholder collaboration, PR aims to increase awareness and understanding of the different policy options available; highlighting how these interact and may result in economic change. For these reasons, PR considers the discussions centred on modelling activities as a pivotal part of the project and its core goal of contributing to more informed and effective climate policymaking.



Moreover, models are limited in their ability to simulate behavioural changes, such as transport modal shifts, from cars to buses or bicycles. Some models can represent agents’ choices to make such shifts in response, for example, to changing prices, but large-scale behavioural changes such as shifts to vegan diets or energy conservation are most commonly modelled through implementing exogenous changes.

Models also cannot quantify changes resulting from political sentiment (e.g. how the 2020 US election results might influence global energy policy). In the context of such limitations, scenario analysis is a useful tool for exploring different possible economic environments.

Finally, the range of models were not initially designed to give insight into the Sustainable Development Goals (SDGs). A number of models do still have capabilities for some of the SDGs, e.g. health issues from air pollutants and clean water access. However, the models should not be considered as offering a holistic overview of all SDGs; for example education, gender equality and justice issues are not explicitly considered.

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What have the models done before?

These models have been developed and fine-tuned over many years. Some examples of the work they have previously carried out are listed below:

Authors	Description	Model
Gnann et al. (2015)	Investigated market evolution of plug-in electric vehicles in Germany.	ALADIN
Shirov & Kolpakov (2019)	Explored macroeconomic impacts of a 1.5-degree scenario in Russia.	CONTO
Wood et al. (2019)	Investigated emission transfers from developing to developed countries. The share of national footprint embodied in imports, at least for developed countries with ambitious decarbonisation policies, will likely increase.	E3ME
REFLEX: Available in 2020	Detailed analysis of residential, tertiary, and industrial mitigation pathways under both centralised and decentralised systems with the consideration of flexibility options (e.g. EVs, hydrogen) for the EU28.	FORECAST
Yu et al. (2019)	Examined the role of carbon capture, utilisation and storage (CCUS) in China's climate mitigation plans. GCAM was disaggregated to 31 Chinese provinces in order to investigate where, in terms of geography and sector, CCUS deployment in China may take place.	GCAM
Babonneau et al. (2018)	Analysed the impacts of Brexit on EU Climate Policy under different scenarios of cooperation within European Effort Sharing.	GEMINI-E3
Sgobbi et al. (2016)	Assessed the role of hydrogen in a future, decarbonised Europe under key climate scenarios. Hydrogen could become a viable option by 2030 however a long-term CO_2 cap would be needed to realise this.	JRC-EU-TIMES
Emodi et al. (2017)	Explored Nigeria's future energy demand, supply, and associated GHG emissions from 2010 to 2040. Four different energy scenarios were considered and the most efficient way (cost, GHGs) to meet such demands was analysed.	LEAP
Kerdan et al. (2019)	A soft modelling link with GINO (a technically focussed gas model) was used to investigate the evolution of natural gas demand and infrastructure in Brazil. Scenario analysis was performed with respect to volumes of gas flows through the Bolivian-Brazilian gas pipeline.	MUSE
Realmonte et al. (2019)	Investigated the role of Direct Air Capture (DAC) in meeting global 1.5- and 2-degree pathways; and concluded that DAC can reduce mitigation costs in the short run but there still exist many uncertainties over its scale-up potential.	TIAM (TIMES)
Duscha et al. (2016)	Investigated ambitious 2030 renewable energy deployment scenarios in Europe: they can result in positive employment and GDP effects.	NEMESIS
Young et al. (2016)	Provided estimates of costs and benefits of a possible Payment for Environmental Services system in Brazil.	SISGEMA
Uzyakov et al. (2016)	Described the evolution of the pricing mechanism in the world oil market. The conditions and parameters of relatively high/low oil prices were described.	42
Camagnolo & Davide (2019)	Investigated synergies between global SDGs and NDCs. Full implementation of current NDCs was projected to slow down efforts to reduce poverty by 2030.	ICES

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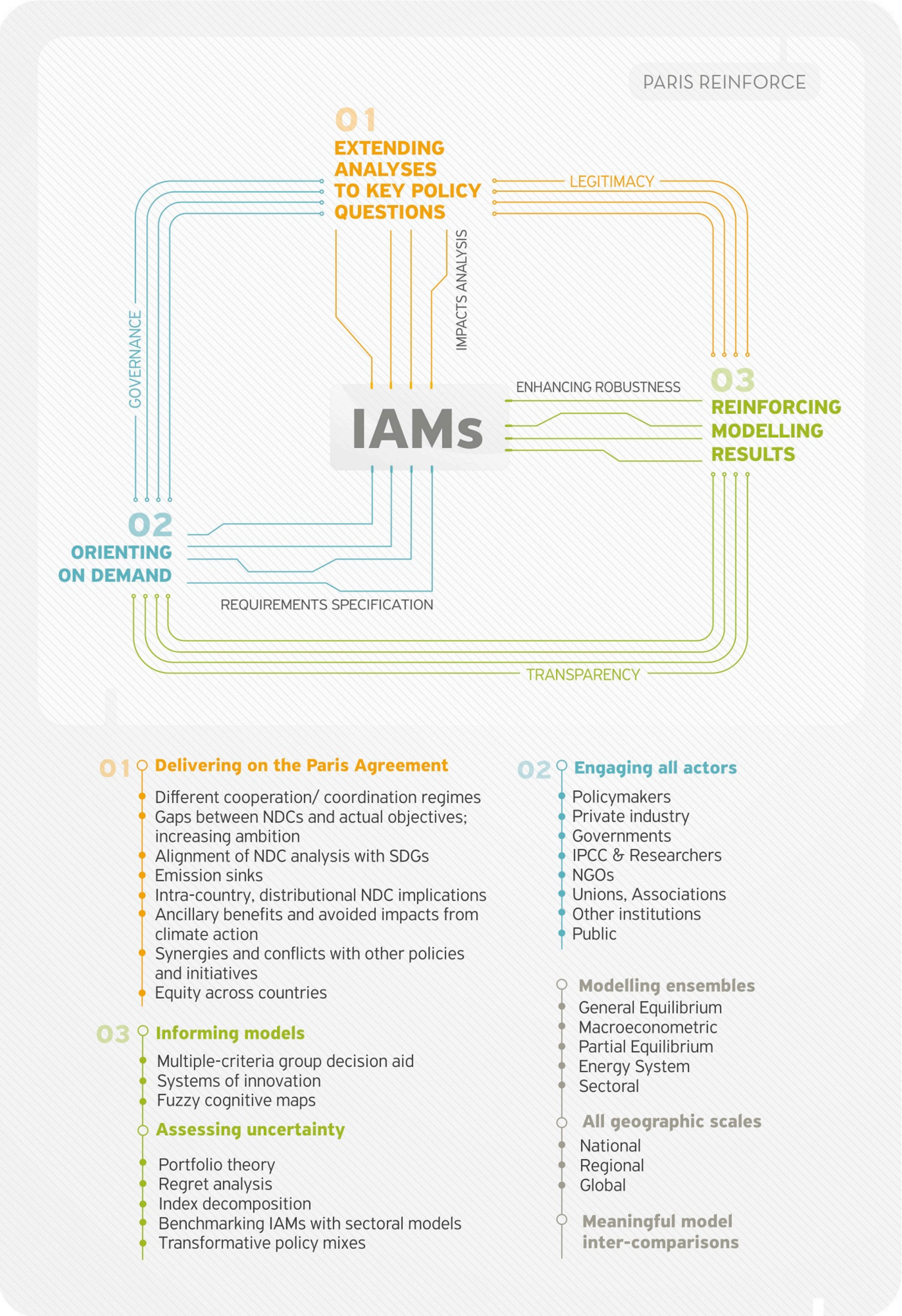

01 **Delivering on the Paris Agreement**

- Different cooperation/ coordination regimes
- Gaps between NDCs and actual objectives; increasing ambition
- Alignment of NDC analysis with SDGs
- Emission sinks
- Intra-country, distributional NDC implications
- Ancillary benefits and avoided impacts from climate action
- Synergies and conflicts with other policies and initiatives
- Equity across countries

03 **Informing models**

- Multiple-criteria group decision aid
- Systems of innovation
- Fuzzy cognitive maps

Assessing uncertainty

- Portfolio theory
- Regret analysis
- Index decomposition
- Benchmarking IAMs with sectoral models
- Transformative policy mixes

02 **Engaging all actors**

- Policymakers
- Private industry
- Governments
- IPCC & Researchers
- NGOs
- Unions, Associations
- Other institutions
- Public

Modelling ensembles

- General Equilibrium
- Macroeconometric
- Partial Equilibrium
- Energy System
- Sectoral

All geographic scales

- National
- Regional
- Global

Meaningful model inter-comparisons

Figure 3: The PARIS REINFORCE overall concept

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Policy Briefs

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PARIS REINFORCE: What can our models deliver?

In a nutshell

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^{2}AM 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.

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