PARIS
REINFORCE

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D6.2 INTERLINKAGES OF NATIONAL/REGIONAL MODELS FOR COUNTRIES OUTSIDE EUROPE

WP6 – Promoting sustainable transitions across the globe

Version: 1.10R

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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. The deliverable was submitted on time (May 2020), and then slightly updated, to add two models (MUSE-Brazil and TIMES-India) that will be used to further reinforce the WP6 modelling analysis as well as elaborate on the new I^2AM PARIS harmonisation tables, in September 2020.

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 modelling interlinkages between the national/regional level in countries and regions outside Europe and the global level, within the PARIS REINFORCE consortium. It will also be used by policymakers and other stakeholder groups as a documentation of said interlinkages, serving as a means of facilitating their participation in the co-creation process envisaged in the project.

3. Short summary of results (<250 words)

PARIS REINFORCE will utilise a range of energy and integrated assessments models, as well as sectoral models, to explore in depth the system transformations that can help achieve the Paris Agreement long-term temperature goal of limiting global warming rise to “well below 2°C” and “pursuing efforts towards 1.5°C”.

The sequencing of how these models will be used is to first explore the implications of emissions reduction pathways in global integrated assessment models, which are disaggregated into different major regions, before then exploring regional emissions reduction pathways in greater depth in region-specific modelling exercises. The latter will then help to better specify the global models in a subsequent round of scenarios, to better understand the global emissions and temperature implications of regional emissions reduction efforts, which are closely informed by stakeholders.

Work Package 6, called “Promoting sustainable transitions across the globe”, consists of exploring these regional emissions pathways in major economies outside of Europe. It will be informed by, and in turn inform, the global integrated assessment modelling work of Work Package 7, “Model Inter-Comparisons, Global Stocktake & Scientific Assessments”.

PARIS REINFORCE will ensure that major assumptions driving scenarios are inter-compared across global and regional models and harmonised, where it makes sense to do this and where the model structures and input variables allow this to happen. This document sets out in further details the protocols and procedures, as well as data sources, to be used in this interlinkage and harmonisation process at the various stages of analysis in the project.

4. Evidence of accomplishment

This report.

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^{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.

NTUA - National Technical University of Athens	GR	EPU N·T·U·A
BC3 - Basque Centre for Climate Change	ES	bc3
Bruegel - Bruegel AISBL	BE	bruegel
Cambridge - University of Cambridge	UK	UNIVERSITY OF CAMBRIDGE
CICERO - Cicero Senter Klimaforskning Stiftelse	NO	°CICERO
CMCC - Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici	IT	cmcc
E4SMA - Energy, Engineering, Economic and Environment Systems Modelling Analysis	IT	E4SMA
EPFL - École polytechnique fédérale de Lausanne	CH	EPFL
Fraunhofer ISI - Fraunhofer Institute for Systems and Innovation Research	DE	Fraunhofer ISI
Grantham - Imperial College of Science Technology and Medicine - Grantham Institute	UK	Grantham Institute Climate Change and the Environment
HOLISTIC - Holistic P.C.	GR	HOLISTIC
IEECP - Institute for European Energy and Climate Policy Stichting	NL	IEECP
SEURECO - Société Européenne d'Economie SARL	FR	SEURECO ERAΣME
CDS/UnB - Centre for Sustainable Development of the University of Brasilia	BR	Centro de Desenvolvimento Sustentável UnB
CUP - China University of Petroleum-Beijing	CN	
IEF-RAS - Institute of Economic Forecasting – Russian Academy of Sciences	RU	IEF RAS
IGES - Institute for Global Environmental Strategies	JP	IGES
TERI - The Energy and Resources Institute	IN	teri

Executive Summary

PARIS REINFORCE will utilise a range of energy and integrated assessments models, as well as sectoral models, to explore in depth the system transformations that can help achieve the Paris Agreement long-term temperature goal of limiting global warming rise to "well below 2°C" and "pursuing efforts towards 1.5°C".

The sequencing of how these models will be used is to first explore the implications of emissions reduction pathways in global integrated assessment models, which are disaggregated into different major regions, before then exploring regional emissions reduction pathways in greater depth in region-specific modelling exercises. The latter will then help to better specify the global models in a subsequent round of scenarios, to better understand the global emissions and temperature implications of regional emissions reduction efforts, which are closely informed by stakeholders.

Work Package 6, called "Promoting sustainable transitions across the globe", consists of exploring these regional emissions pathways in major economies outside of Europe. It will be informed by, and in turn inform, the global integrated assessment modelling work of Work Package 7, "Model Inter-Comparisons, Global Stocktake & Scientific Assessments".

In order for these modelling exercises to successfully inform, and derive from, each other, PARIS REINFORCE will ensure that major assumptions driving scenarios are inter-compared across global and regional models and harmonised, where it makes sense to do this and where the model structures and input variable allow this to happen. This document sets out in further details the protocols and procedures, as well as data sources, to be used in this interlinkage and harmonisation process at the various stages of analysis in the project.

The document at hand is the revised version (v1.10R) of deliverable D6.2. The deliverable has been revised with the aim of documenting the validation procedures undertaken to build trust into the models and their results (Section 5), of revising language (to avoid the use of the word 'projection', as models provide what-if analyses), and of facilitating readability (by adding sub-sections to clearly delineate which interlinkage is being discussed in which figure, merging sections, and adding context to figures).

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1 Introduction

PARIS REINFORCE is a stakeholder-led project to assess low-carbon transition pathways that are compliant with the goals of the Paris Agreement. A major focus of the project is to undertake detailed global and country-level energy system and integrated assessment modelling, to understand technically, economically, politically and socially acceptable transition pathways within different major emitting countries.

Work Package 6, "Promoting sustainable transitions across the globe", focuses on non-European energy system and emissions pathways modelling. The suite of models, as shown in Figure 1, covers a number of major emitting economies outside of Europe, including the USA, Canada, China, India, Russia, Brazil and Japan.

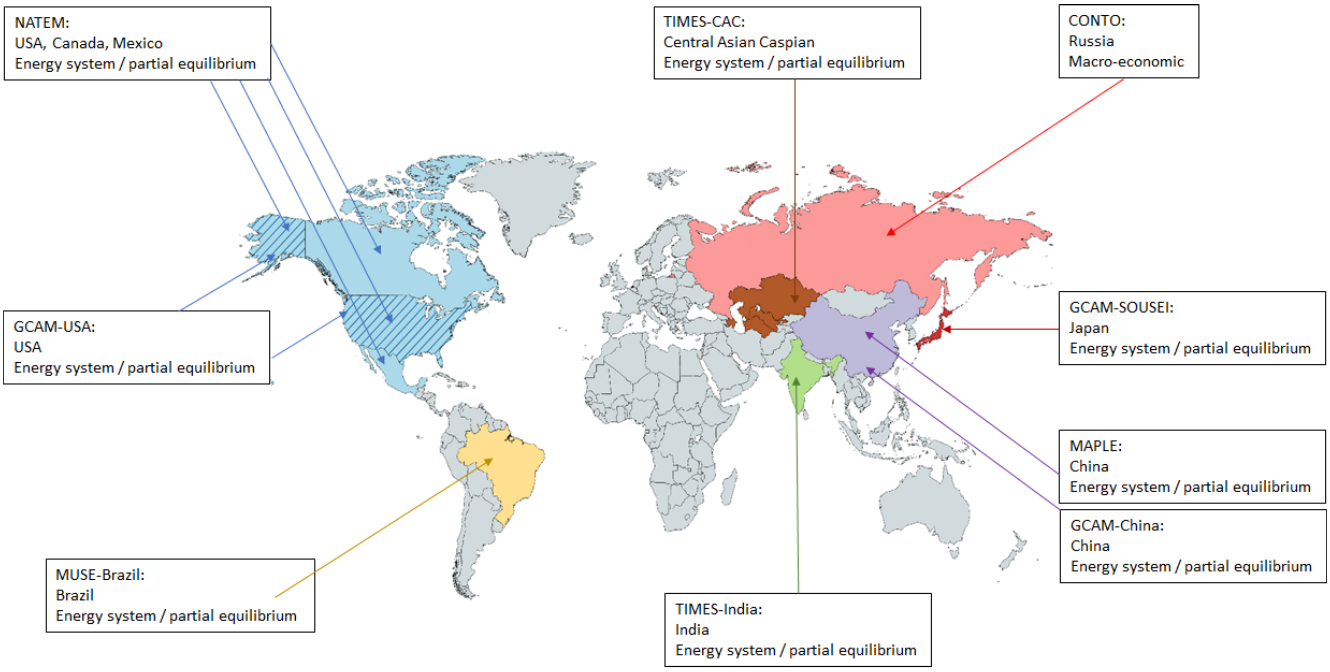

Figure 1: Regional models used in PARIS REINFORCE to simulate transitions in non-European economies

Table 1 describes some of the key attributes of the models. A fuller description, including key references, is available in PARIS REINFORCE deliverable 6.1: "Documentation of national/ regional models for countries outside Europe".

Table 1: Details of models to be used in Work Package 6 on non-EU country mitigation analysis

Model		CONTO	GCAM-China	GCAM-SOUSEI	GCAM-USA	TIMES-India	MAPLE	NATEM	MUSE-Brazil	TIMES-CAC
Type		Inter-industry	Partial equilibr.	Partial equilibr.	Partial equilibr.	Energy system	Energy system	Energy system	Energy system	Energy system
Country / Region		Russia	China	Japan	USA	India	China	USA, Canada, Mexico	Brazil (5 States)	Central Asian Caspian
Country Partner		IEF-RAS	BC3	IGES	BC3	Grantham	CUP	IEECP	Grantham	E4SMA
Time horizon		2040	2100	2100	2100	2050	2050	2050	2100	2050
Time step intervals (years)		10	5	5	5	5	5	5	5	10*
Sectoral level of representation	Upstream	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed
	Electricity	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed
	Heat	Detailed	Detailed	Detailed	Detailed	N/a	Detailed	Detailed	Detailed	Detailed
	Transport	Detailed (road)	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed
	Buildings	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed
	Industry	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed
	Agri-culture	Detailed (energy)	Detailed (energy)	Detailed (energy)	Detailed (energy)	N/a	Detailed (energy)	Detailed (energy)	Detailed	Detailed (energy)
	Land use	N/a	Detailed	Detailed	Detailed	N/a	N/a	N/a	Basic	Basic

*Notes: *Flexible to run with shorter time periods*

The overall work plan for PARIS REINFORCE is to first run the suite of global energy system and integrated assessment models to understand both reference scenarios (i.e. those without a high degree of mitigation over and above current levels of ambition) as well as those that consider mitigation in line with the Paris Agreement goal to limit global warming to "well below 2°C" above pre-industrial levels. This is the focus of Work Package 7 ("Model inter-comparisons, global stocktake & scientific assessments"). The global modelling exercise, and its results, will then be used to provide inputs into the country and regional level modelling contained within Work Package 6, as well as its sister Work Package 5 ("Transforming Europe), which focuses on European modelling.

One further iteration of global and regional modelling will then be undertaken during the project, to more fully explore how regional modelling affects the possibilities around the global models, and what the second iteration of global model runs (now fully informed by the regional models) then indicate about the need for greater ambition in a second set of regional model runs. A high-level schema for the modelling in PARIS REINFORCE, based on the detailed, whole-project workflow (see Figure 7 of the PARIS REINFORCE Grant Agreement) is shown in Figure 2.

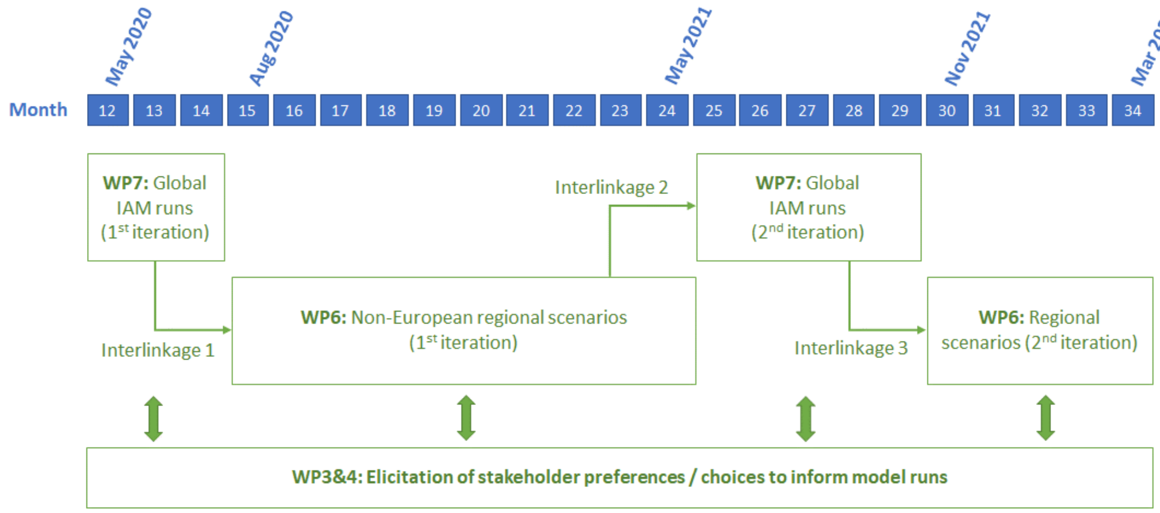

Figure 2: High-level workflow of interactions between global and non-European regional modelling

It should be noted that each stage of modelling depicted in Figure 2 is fed by inputs from stakeholders consisting of policy and decision makers from a range of countries relevant to the modelling exercises. An "Ongoing stakeholder dialogue" Work Package (WP3) is used to organise meetings, discussions and polls with stakeholders in order to facilitate a two-way exchange of information around modelling practices, assumptions and limitations, as well as elicit inputs from stakeholders on their particular modelling questions and views/preferences around modelling assumptions and scenario design. A specific Work Package (WP4: "Robustification and socio-technical analysis toolbox") is used to explore specifics of technological and societal transformations, and to utilise stakeholder inputs to identify preferences and pathways that are preferred, or robust, in the context of a range of uncertainties about the future.

Together, WP3 and WP4 are intended to ensure that the modelling analysis around transition pathways is not undertaken in an analytical "vacuum" but rather co-created with stakeholders, to arrive at robust transition pathways. As the project proceeds, this interaction with stakeholders will be facilitated by use of a transparent and user-friendly modelling platform, "I^{2}AM PARIS", which has already been designed and developed.

The next Section describes in further detail each of the three interlinkages denoted in Figure 2 above, with the specific objective of describing which assumptions and variables will be used in the different global and regional modelling phases.

2 General principles of model interlinkages

This section describes in turn the three interlinkages introduced in Section 1, and specifically the information flow for each interlinkage, to maximise consistency between the global and regional modelling.

2.1 First interlinkage of global and regional models

Figure 3 provides an overview of how the global and regional models are related, through both the use of shared exogenous assumptions, as well as through outputs from the global modelling that inform the regional modelling. For the first interlinkage (see "Interlinkage 1" in Figure 2 in Section 1 above), this will happen by means of a number of shared assumptions and/or outputs from the global models, as shown both in Figure 3 and further detailed in Table 2.

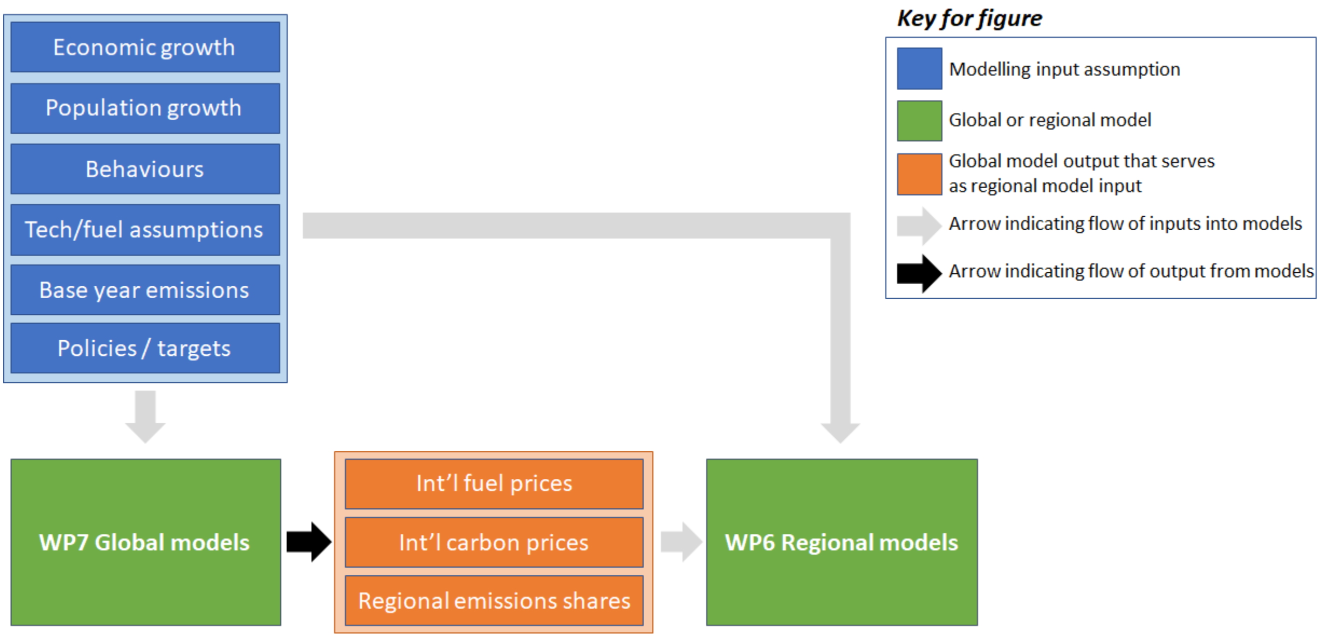

Figure 3: Modelling assumptions flow into and from global (WP7) models to regional (WP6) models for first interlinkage exercise

Note: This flow outlines the main assumption interlinkages common to most models. Certain models will need additional, more model-specific inputs, such as international prices and demands of goods and services so as to fully specify their trade sectors.

Figure 3 sets out that there are nine main categories of input assumptions into, or output from, the global models that can be considered as harmonising variable sets to ensure broad consistency between the global and regional modelled scenarios. The first six of these categories (economic growth; population growth; behaviours that govern the growth of energy and other service demands as populations and economies grow; technology cost and performance data; base year emissions; and implementation of current policies and targets) are shown in the blue boxes in Figure 3. These are primarily input assumptions into both the global and regional models. As such, the primary purpose of these input assumptions will as a common set to be used in both the global models and regional models, since the objective will be to use the same broad assumptions across models.

However, when more detailed assumptions such as elasticities are considered, then the region-specific modelling data may be deemed more relevant than the global modelling data. A full comparison analysis will be necessary to understand the specific protocol for choosing whether—and if so how—to update the regional modelling data with the assumptions feeding into the global models in this case. Another exception to this sharing of assumptions between the global and regional models is the CONTO model for Russia, which generates endogenously its own macroeconomic growth path as part of its objective function.

The remaining three categories of assumptions for the regional modelling (international fossil fuel prices; international carbon prices; and region-specific emissions reductions consistent with global targets) will be obtained by considering the outputs from the global model scenarios, generated by the global models themselves. These three categories of assumptions are denoted by the orange boxes in Figure 3. It should be noted that it is expected that the global models will produce a potentially wide range of values for each of these outputs that should serve as inputs, so a key question is which of these values to choose to serve as regional model inputs. In practice this will be case-specific, with medians and—if necessary—ranges (excluding outliers) used to specify the regional model inputs. Here, a degree of expert consideration will be required to judge which inputs are most suitable for the regional models.

Table 2 summarises the direction of flow of assumptions from the global to regional models in this first interlinkage of global and regional modelling.

Table 2: Assumptions linking global models and non-European regional models

Assumptions	Direction of flow	Details and Rationale
Economic growth (country and regional GDP)	Off-model (exogenous) assumptions into both global IAMs and regional models (to calibrate their initial, reference scenarios*).	In almost all models, GDP growth is an exogenous assumption for reference scenarios*.
Population growth	Off-model (exogenous) assumptions into both global IAMs and regional models	In almost all models*, population growth is an exogenous assumption.
Energy, agriculture, land services demand (behavioural factors which relate socio-economic drivers to energy and other services demand)	Two-way (global model assumptions compared to regional models to decide which is more credible)	Models have different legacy assumptions on service demand behaviours so soft linking and harmonisation is a two-way process.
Technology cost and performance data	From global to regional models	Global model technology cost and performance data reviewed and updated as part of 1st global model scenarios exercise.
Base year emissions	Both global and regional models will be "calibrated" to base year emissions data.	Global model emissions will be calibrated to recent outturn emissions data, as will subsequent regional modelling.
Current policies and targets in regions	From global to regional models	Global model regions updated with current policies, NDCs and other representations of policies and targets as part of 1st global model scenarios exercise.
International fossil fuel prices	From global to regional models	Global models generate international fossil fuel prices endogenously based on underlying fuel supply-cost curves for each major region represented. However, many different models will generate different prices for each scenario, based on technology deployment choices, so a central case and range will be taken and where necessary key public sources like IEA World Energy Outlook also considered.
Global and regional carbon prices	From global to regional models	Global models generate international carbon prices endogenously based on underlying technology and fuel costs and substitution dynamics. However, these can vary greatly across models, so a central case and range will be considered.
Regional emissions in mitigation scenarios	From global to regional models, with reference to other sources such as IPCC scenarios databases	Global models generate regional split of emissions reduction effort for global targets, as a result of cost-optimal emissions reduction assumptions. These distributions can vary by model; hence a central case and range will be considered.

**Macroeconomic models will generate their own growth path in response to climate policy but can be calibrated for their reference cases. The exception is CONTO, which generates its own macroeconomic growth path for all scenarios*

2.2 Second interlinkage of global and regional models

For the second interlinkage shown in Figure 2, the main purpose of the interaction between the regional models and the global models will be to constrain the global models with adjusted input assumptions into, and results from, the regional models. This is a critical element of the PARIS REINFORCE work programme, since it specifically reflects stakeholder choices and preferences around those inputs and resulting pathways that they deem to be most realistic and consistent with given national contexts.

Figure 4 illustrates the categories of variables that we expect to emerge from the regional modelling exercise that will be relevant to the second iteration of global modelling. Of critical note is the role of stakeholder preferences in informing the inputs into the regional models, which will feed through into the second iteration of global modelling.

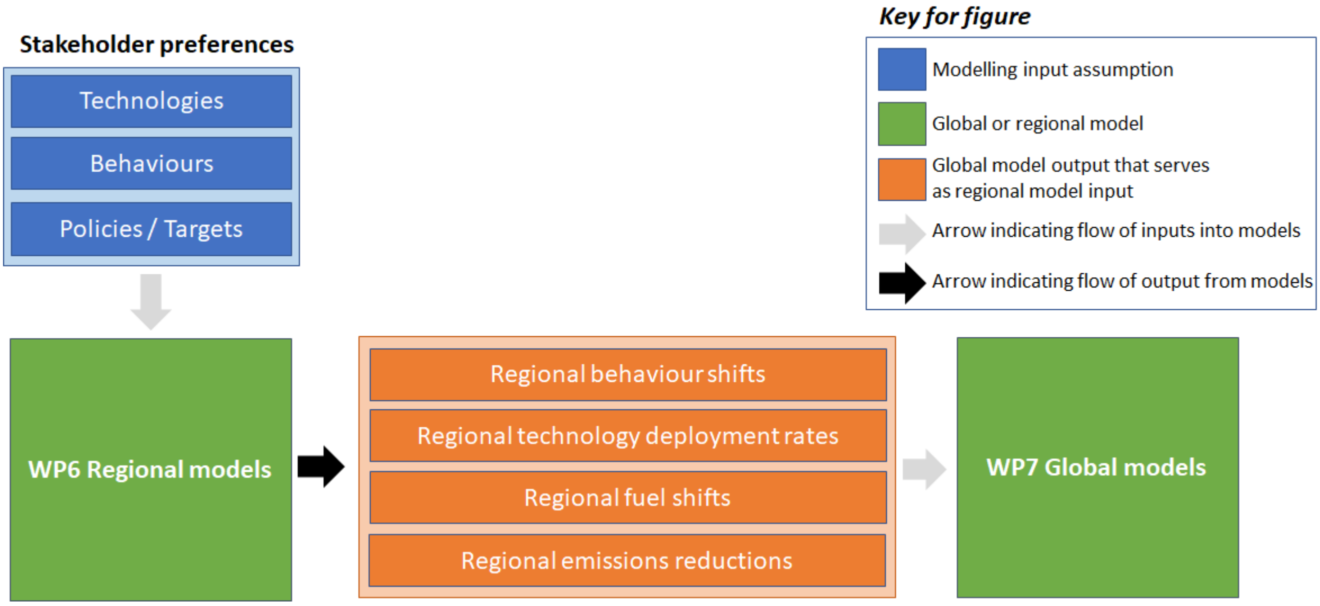

Figure 4: Modelling assumptions flow into and from regional (WP6) models to global (WP7) models for second interlinkage exercise

This second interlinkage exercise will set up a second round of global and regional modelling, so as to further explore how the Paris Agreement goals could be met in light of stakeholder inputs and any adjustments that they imply for regional mitigation pathways. These stakeholder preferences are denoted in the blue boxes in Figure 4, and include technology preferences and constraints, behavioural changes and barriers, and specific policies and targets that may have emerged since the first global modelling runs. The regional modelling that will be informed by these stakeholder preferences will result in a series of regional modelling outputs, which will serve as inputs into the second global modelling exercises. These outputs from the regional modelling are denoted by the orange boxes in Figure 4. They will include constraints and adjustments around regional behavioural changes not fully captured in the initial global modelling, as well as regional technological and fuel transformations that are more closely informed by stakeholder preferences than in the first global modelling iteration. This will result in specific regional emissions reduction levels that are likely to be different from those determined within the first global modelling iteration, which will form a further potential set of constraints for inputting into the global models, as shown in Figure 4.

2.3 Third interlinkage of global and regional models

The second round of global modelling runs, now fully informed by the regional modelling exercise, will determine the level of global emissions reductions possible and the temperature change that this emissions reduction pathway leads to. It is expected that this may not be a sufficiently ambitious pathway to meet the Paris Agreement's goal of limiting global temperature increase to well below 2ºC and if possible 1.5ºC above pre-industrial levels. As such, the second round of global modelling will set the regional models up for the final round of modelling, in a third and final interlinkage of modelling assumptions.

This will explore—in further close cooperation with stakeholders—the extent to which different regions can "close the gap" between the resulting level of ambition from the global models, and a level that those models indicate is more consistent with the Paris Agreement. This will require a third, final interlinkage between the global and regional models, as shown in Figure 5.

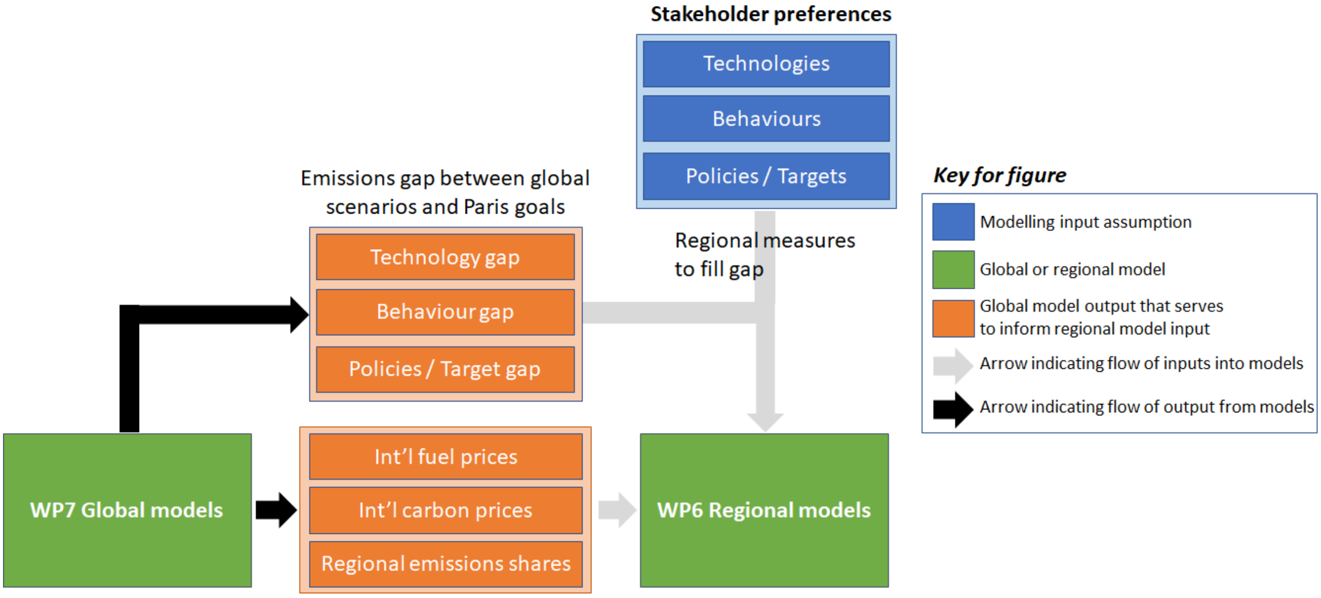

Figure 5: Modelling assumptions flow from global (WP7) to regional (WP6) models for third interlinkage exercise

The global modelling will produce a range of outputs which will serve as inputs to inform the regional modelling. In addition to the three categories of outputs discussed in Section 2.1, for the first interlinkage (international fuel prices, international carbon prices, regional emissions shares), the global models will also produce outputs that detail the gap between technology deployment, and /or behaviour change, and / or policies, that needs to be closed to ensure that each region's contribution to a Paris-compliant pathway can be achieved. We expect there will be gaps in near-term policy and emissions levels, as well as overall technological and behavioural change levels as produced by the global models, when compared to the action needed to achieve the long-term Paris Agreement goals. Furthermore, the mitigation pathways produced may lead to gaps or shortfalls in the attainment of key sustainable development goals, which are critical to specific regions. These gaps will be discussed with regional stakeholders to understand whether—and if so how—they can be closed, so as to achieve a set of regional emissions reduction pathways that lead to global emissions consistent with the Paris Agreement goals. The stakeholder discussions will thus form a final set of inputs into the regional modelling, as denoted by the blue boxes in Figure 5.

3 Specific assumptions used in global and regional modelling

The different iterations of modelling discussed in Sections 1 and 2 will use a harmonised set of input assumptions around socioeconomic and technology cost and performance parameters. Each of these groups of assumptions is detailed further in this section.

3.1 Socioeconomics

A key consideration for the set-up of the global and regional models concerns the most appropriate projections to use for population and economic growth, since these variables are key drivers in future demand for energy and other services such as agriculture and land, which are instrumental in driving future greenhouse gas emissions.

There are several potential socioeconomic pathways that could be implemented in the models, including from the Shared Socioeconomic Pathways (SSPs) produced by the international modelling communities involved in global climate change scenario analysis (O'Neill et al., 2014). For PARIS REINFORCE, we use a bespoken data set constructed primarily from the second SSP (the "middle of the road") pathway, since this is the least normative in terms of structural changes from historical trends. However, we make a number of adjustments to this data set, to reflect more up-to-date sources for the European Union in particular, given its importance in the PARIS REINFORCE project, as well as to account for historical deviations (specifically over the period 2010-2020) between the SSP2 population and economic growth projections (which start from 2010) and outturn data. Table 3 summarises the key sources and methods used to construct the population and economic growth data set.

Table 3: Details of regional population and GDP data sources used in first modelling phase

Variable	Definition	Time span	Source	Units	Comments
Population	Total country population	2010-2100	EUROPOP, OECD and UN (short- & mid-term) SSP2 (long-term; KC & Lutz 2017)	Million people Growth rate	Switch from short- & mid-term to long-term projections by country, ensuring smooth transitions between projected growth levels, and consistency between (working) population and GDP growth rates.
Working age Population	Total population between 15 and 64 years old	2010-2100	Ageing Report (EC, 2017), OECD and UN (short- & mid-term) SSP2 (long-term; KC & Lutz 2017)	Million people Growth rate	
GDP	Gross domestic product based on purchasing-power-parity valuation	2010-2100	Ageing Report (EC, 2017), OECD (Economic Outlook No. 103 and 106) (short- & mid-term), IMF (short-term), SSP2 (long-term Dellink et al, 2017)	PPP (constant billion 2010 International $) PPP (constant billion 2010 €) Growth rate	

3.2 Energy and other service demand behaviours

In most model types, population and economic growth drives growth in energy demands. This is done by choosing variables called elasticities of demands to their respective drivers, in each region, using the following general formula:

$$\text{Demand} = \text{Driver}^{\text{Elasticity}}$$

For example, the number of billion vehicle km travelled by automobiles, bv-km, grows by a factor that is the growth in GDP per capita in a region to the power of a pre-defined elasticity:

$$\text{Bv-km} = (\text{GDP/capita})^{\text{Elasticity}}$$

Many of the models also have the capability of estimating the price-based response of these energy service demands to the changing conditions of scenarios, in which mitigation occurs. For example, if the cost of energy increases as fossil fuels are replaced by renewables, then the demand for energy services would decrease. To do this, models make use of another set of inputs, namely the price elasticities of the demands for each energy service considered. Together, these elasticities inform the behaviours of people and households to increasing wealth and changes in energy prices.

The specification of these elasticities is highly detailed and time-intensive, and it may be that the elasticities in the global models are different to those in the regional models, as well as across the global/regional models. In terms of a meaningful interlinkage exercise, therefore, we will compare the energy demands in each sector of the economy that occur in the regional models and the corresponding regions of the global models, to understand if there are significant differences even when the same population and economic drivers are used. In the case of such differences, the protocol is to further explore the drivers in the specific region with a view to deciding whether, and if so to what extent, to adjust the regional models' elasticities using the values from the global models. It should be noted that this is a much less exact format of harmonisation than the precise harmonisation sought for socioeconomic drivers (as described in Section 3.1) because the large range of global models used in WP7 have different structures, different degrees of disaggregation of sectoral energy demand into different energy services, and thus non-comparable elasticity values. The key objective here is thus to ensure that the regional models' projected energy demand for the harmonised population and economic growth inputs are within the broad range of energy demands in the corresponding regions of the global models.

3.3 Base year emissions

Each of the global and regional models will be used to project emissions under different scenarios until at least 2040, with some models going beyond, to 2100 (this is the case for three regional models based on the global GCAM model – GCAM-SOUSEI for Japan, GCAM-China and GCAM-USA).

In order for the emissions at the start of the projection period for both the regional models and the global models to be in line with each other, it is important that both the global and regional models' base year emissions are closely aligned.

The PARIS REINFORCE consortium is using a consistent global, country-level disaggregated dataset for historical emissions of major greenhouse gases, based on the Community Emissions Data System (CEDS) for Historical

Emissions (Hoesly et al., 2018). All WP7 global models' base years will be compared to this emissions dataset to ensure they are closely aligned to the latest available CEDS data, which at this time is to 2015, though (as at mid-May 2020) an update to 2018 data is expected in the next few weeks.

For WP6 models, their base year emissions will also be cross-checked against this CEDS data set to ensure close alignment. In many cases (for example NATEM, TIMES-CAC, CONTO) the regional models' base year emissions are linked to national inventories. In addition, there are sometimes significant deviations between different datasets for emissions, owing to underlying uncertainties in energy and other balances of emissions-causing activities. As such, it is not intended that the harmonisation of base year emissions will be an exact exercise, but rather a comparison and further investigation of any significant differences.

3.4 Technoeconomic parameters

A major aspect of PARIS REINFORCE will be the close comparison of the costs and performance of major technologies in the low-carbon transition. This is because there is increasing focus on the role that technology costs are having on the real-world transition, exemplified above all by rapid cost reductions in solar PV electricity generation. Other examples include electric vehicles and offshore wind electricity, whose cost reductions have confounded many analysts and forecasters in recent years.

In PARIS REINFORCE, we are focusing the technoeconomic parameter harmonisation process primarily on ensuring that all global (WP7) and regional (WP6) modelling groups are using data that reflects the most notable costs in the power and transport sectors, as these sectors are the most easily comparable across models. However, where possible, through sufficient comparability of input parameter types, assumptions across buildings and industrial sectors will also be compared and harmonised. Table 4 summarises the key data sources for technoeconomic parameter harmonisation.

Table 4: Summary of key attributes of technoeconomic harmonisation data

Variable	Definition	Time span	Source	Units	Comments
Key technological attributes of renewable and non-renewable technologies	Costs of investment, fixed and variable operation & maintenance (O&M), capacity factors, conversion efficiencies and technical lifetimes	2003 - 2048	TIAM (Napp et al, 2019)	Costs in US$2010/kW Lifetime in years	Technologies included are wind, solar, nuclear, geothermal, hydro, coal, gas, biomass
Key technological attributes of renewable and non-renewable technologies	Costs of investment, fixed and variable O&M, conversion efficiencies, self-consumption share, capacity factors, technical lifetimes and O&M costs growth	2020 - 2050	NECPs (Mantzos et al, 2017)	Costs in EUR'13/MWh Lifetime in years	No global coverage. Costs are estimated for Europe. No regional disaggregation
Key technological attributes of cars, buses and trucks	Costs of investment, fixed O&M, efficiencies and technical lifetimes	2006 - 2050	TIAM (Napp et al, 2019)	Costs in M 2010 US$/Billion vehicle km Efficiency in B vehicle km/PJ Lifetime in years	Attributes available by fuel technology (diesel, fuel, electric, hydrogen, hybrid, natural gas) and by efficiency categories
Key technological attributes of cars, trucks, trains and planes	Costs of investment and efficiency ratio	-	NECPs (Mantzos et al, 2017)	Costs in EUR'13/MWh Efficiency in liters/100 vehicle km	No global coverage. Costs are estimated for Europe. No regional disaggregation Fuel technology disaggregation
Key technological attributes of main household appliances, lighting, heating and cooling	Costs of investment, fixed O&M, capacity factors and efficiencies.	2006 - 2048	TIAM	Costs in Million US$2010/PJ	Attributes available by fuel technology (bio, coal, diesel, electric, kerosene, LPG, Natural gas, solar) and by efficiency categories
Key technological attributes of main household appliances, heating and cooling	Costs of investment and efficiency ratios.	-	NECPs (Mantzos et al, 2017)	Costs in EUR'13/MWh	No global coverage. Costs are estimated for Europe. No regional disaggregation
Key technological attributes of steel and cement industries	Costs of investment, fixed and variable O&M, capacity factor, technical lifetime and input material requirements	2006-2030	TIAM	Costs in $2010USD/Mt Lifetime in years, Input requirements in PJ/Mt and t/t	Attributes available by process type

3.5 Current policies and NDCs

As well as the socioeconomic, techno-economic and other parameters described above, all models in the PARIS REINFORCE consortium are intended to be set up in such a way that their reference scenarios reflect current levels of climate policy ambition in different world regions. This will include a reference scenario reflecting the implementation of current policies at a regional level, as well as a distinct reference scenario including the implementation of Nationally Determined Contributions (NDCs). In both cases this implementation of ambition will be input to 2030 (the period for which NDCs are most frequently stated and for which current policies' impact can reasonably be projected), but with assumptions made around how these levels of current policy and NDC "effort" are extended beyond 2030.

NDCs are implemented according to a direct interpretation of countries' Paris Agreement pledges. Current policies are implemented according to the database of such policies by region, as detailed in the CD-Links policies database (Roelfsema et al., 2020).

3.6 Additional considerations for global and regional model interlinkages

Aside from the major input and output interlinkages described in Sections 3.1-3.5, it is also necessary to consider additional information that the global modelling runs can provide as useful inputs into the regional modelling, and vice versa. In particular, the global model runs are expected to be able to inform regional modelling runs through the following parameters at the first and third interlinkage stages shown in Figure 2:

- **Technology availability**: Decisions made for the global modelling exercises will affect the regional modelling exercises as well. For example, if global modelling excluded Direct Air Capture (DAC), or other advanced/ speculative technology availability from its scenarios, then for consistency this technology should also be excluded from the regional modelling. Similarly, key resource constraints such as around regional biomass availability should be harmonised between global and regional modelling exercises.

- **Technology deployment rates:** A key output from the global models will be major low-carbon energy technology deployment patterns across regions. In many cases these rates will be constrained at maximum possible levels in order to represent realistic deployment patterns. Indeed, this is a critical input element into scenario modelling. Such technology capacity deployment rates tend not to be decided ex ante, since it is not clear before undertaking detailed modelling runs which technologies will be deployed to what extent. As such, any imposed technology deployment rates are likely to form a further set of input assumptions into the regional modelling exercises, to avoid overly optimistic technology deployments in specific regions in these exercises.

- **Global levels of decarbonisation ambition:** As the PARIS REINFORCE project proceeds, there may be changes to global levels of ambition to tackle climate change, reflecting changes in international efforts towards meeting NDCs, particularly in preparation for the Global Stocktake, or new information on the need to reduce emissions to meet the Agreement's 1.5°C goal. This could, for example, require an acceleration in mitigation effort at a global level, so as to more quickly decarbonise, if it is deemed that there should be less reliance on negative emissions technologies. Any implications these efforts have on the global-level ambition of tackling climate change may be necessary to feed into the regional modelling as the project proceeds.

- **Non-CO_2 greenhouse gases (GHGs) not covered by regional models:** Where the regional models have limited coverage of GHGs or sectors, the regional elements of global models that do cover these sectors/gases can be used to supplement the regional modelling.

3.7 Detailing the common assumptions to models and links between them

To ensure a clear and consistent approach to assumptions interlinking between models, each modelling team has indicated for a list of variables and whether these variables are outputs, inputs or not represented in their model. In the case of an input, each have indicated whether they are able or not to adapt this variable to outputs from other models in the consortium, or with harmonised inputs. Table 5 shows the outcome of this questionnaire for the regional models in WP6.

Table 5: WP6 models' ability to harmonise to a common set of input assumptions

		CONTO	GCAM-China	GCAM-SOUSEI	GCAM-USA	MAPLE	NATEM	TIMES-CAC	MUSE-Brazil	TIMES-India
Demography	Population	2	2	2	2	2	2	2	2	2
	Urbanisation	2	4	4	4	4	4	2	2	2
	Household size	2	4	4	4	4	4	2	2	2
	Age	4	4	4	4	4	4	4	2	4
	Education level	4	4	4	4	4	4	4	2	4
Macro-economic	GDP / total income (reference)	1	2	2	2	2	2	2	2	2
	Employment (reference)	1	3	4	3	4	4	4	4	4
	Real households disposable inc.	1	4	4	4	4	4	4	4	4
	Sectoral value added	1	4	4	4	4	4	2	4	2
	Discount rate	4	2	2	2	2	2	2	4	2
	Interest rate	2	4	4	4	4	4	4	4	4
	Exchange rates	2	4	4	4	4	4	2	4	2
Demand drivers	Industrial goods	1	2	1	2	2	2	2	2	2
	Domestic Building serv. demand	2	2	1	2	2	2	2	2	2
	Commercial building serv. demand	2	2	1	2	2	2	2	2	2
	Passenger transport demand	2	2	1	2	2	2	2	2	2
	Freight transport demand	4	2	1	2	2	2	2	2	2
	Food demand	4	2	1	2	4	2	4	2	4
Techno-economic parameters										
Energy industry	*Synthetic fuel production*	4	2	2	2	4	2	2	2	2
	Hydrogen production	2	2	2	2	4	2	2	2	2
	Electricity generation	2	2	2	2	2	2	2	2	2
	Storage	4	2	2	2	4	2	2	2	4
	Heat generation	3	2	2	2	4	2	2	2	4
Transport	*Road: light duty*	2	2	2	2	2	2	2	2	2
	Road: heavy duty	2	2	2	2	2	2	2	2	2
	Rail	3	2	2	2	2	2	2	2	2
	Aviation	3	2	2	2	2	2	2	2	2
Buildings	*Heating*	4	2	2	2	2	2	2	2	4
	Cooling	4	2	2	2	2	2	2	2	2
	Appliances	4	2	2	2	2	2	2	2	2
Industry	*Process heat*	4	2	3	2	2	3	2	3	4
	Machine drives	4	4	3	4	4	3	2	3	4
	Steam	4	4	3	4	4	3	2	3	3
	CHP	4	2	3	2	2	3	2	3	2
	CCS/NETs	4	4	3	4	4	3	2	2	2
Energy price projections	Coal market/import prices	4	2	2	2	2	2	2	1	2
	Oil market/import prices	2	2	2	2	2	2	2	1	2
	Gas market/import prices	2	2	2	2	2	2	2	1	2
	Bio-energy market/import prices	4	2	3	2	2	2	2	1	2
Renewable energy potential (e.g. physical maximum)		4	2	2	2	4	2	3	2	2
Land use change emissions		3	1	1	1	4	4	3	4	4
Sectoral energy mix		1	1	1	1	1	1	1	1	1

Key: 1 = Model output; 2 = Model input that can be harmonised;
3 = Model input that cannot be harmonised; 4 = variable not represented in the model

4 Links with the I²AM PARIS platform

The I²AM PARIS platform will share and display data, in a stepwise form, a sequence of presenting our processes of a) harmonisation, b) interlinkages, and c) our PARIS REINFORCE scenario data portal.

4.1 Platform interfaces

The I²AM PARIS platform aims to have two interfaces:

- The *public interface* is directed/targeted to non-modelling expert stakeholders, such as policymakers, or non-profit organisations. Through this interface, the user will be able to learn about the capabilities of the models, and the list of variables behind them, as well as the different scenarios that have been considered.

- The *advanced user (or scientific) interface* will present data in a more detailed manner, where access to the databases themselves will be illustrated. All harmonised datasets will be gathered in the platform online and these will eventually be presented in a format that is, over time, built towards the IPCC scenario templates[1].

Additionally, the platform will have a video presentation of the capabilities of the platform and how to use it.

4.2 Model variable linkages

The potential linkages between model variables are presented through two features in the platform:

i) A harmonisation heatmap is included with different model variables on the rows (e.g. demographic, macroeconomic or technoeconomic) and the different models of the PARIS REINFORCE consortium on the columns (with the possibility to add other models in the future). The different colour codes, as presented in the legend, indicate if the variables are an extractable model output, a harmonisable model input or non-explicit output or input for each model (see Figure 6). This heatmap is thought to be a relatively simple tool to see at a glance what variables have the potential to be harmonised across the different PARIS REINFORCE models.

   The user may select ad hoc which models they would like, for illustrative purposes, to compare against one another.

ii) For each modelling project/exercise, a separate heatmap is included, with information on which parameters have actually been harmonised or interlinked in each model. The design is similar to the heatmap discussed above (Figure 6), but the blue cells will be divided in different blue shades, separating variables that have been harmonised in that specific modelling exercise, and those that are not. Similarly, extractable model outputs will be divided into different green shades, separating those outputs to be used as inputs to other models, and those that are not.

iii) For each modelling project/exercise, tables with harmonised variables (see e.g. Table 2 in this deliverable) corresponding to the three different subgroups of models of the PARIS REINFORCE consortium (i.e. European models, non-European models and global models). These tables show the characteristics of the harmonised parameters in detail, including the description of the parameter, the timespan, the source and in which models they have been applied.

[1] https://data.ene.iiasa.ac.at/ar6-scenario-submission/#/about

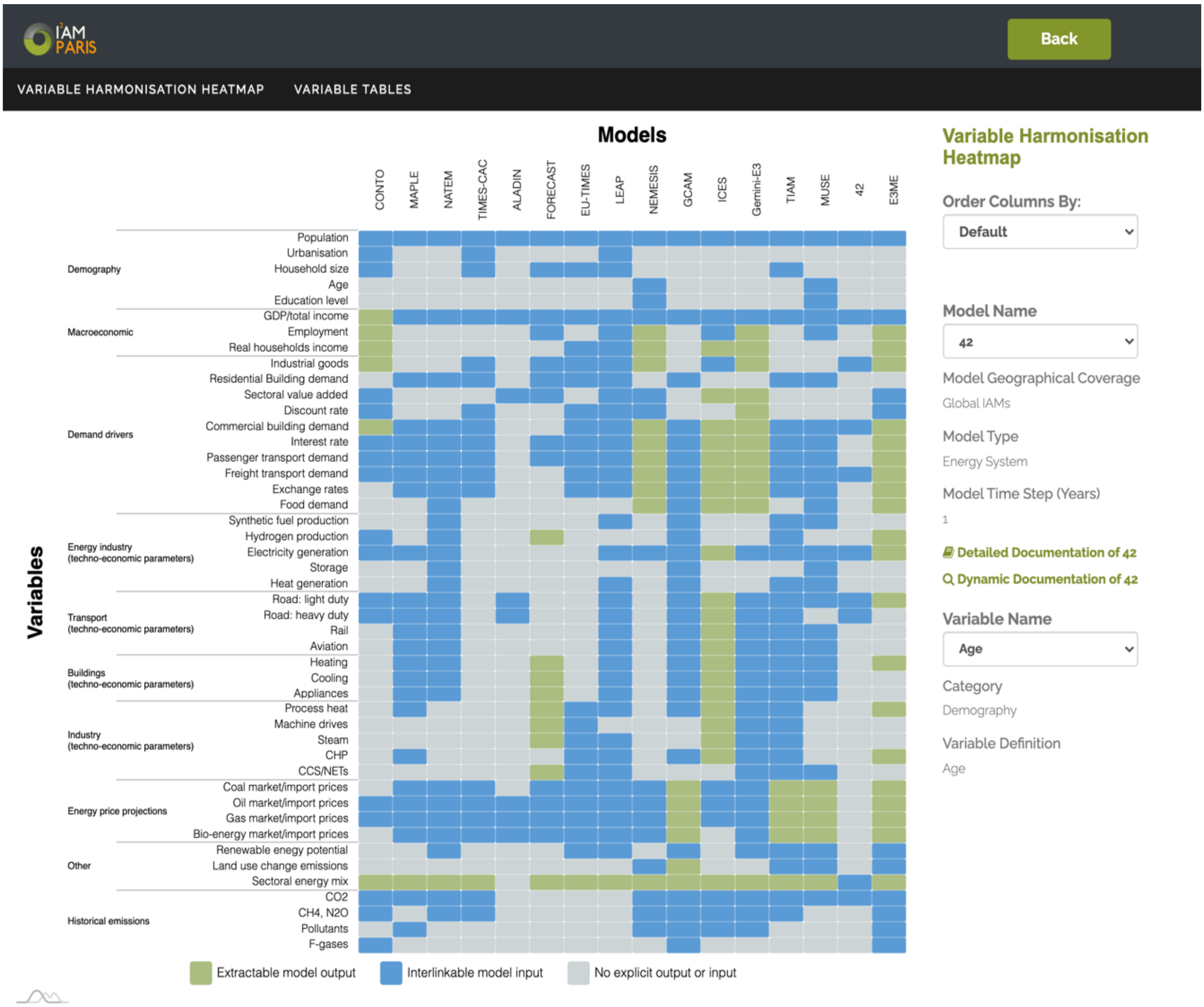

Figure 6. Variable Harmonisation Heatmap

4.3 Futures scenario data portal

Once the PARIS REINFORCE consortium finalise reference scenarios, we then will display modelling runs based on potential elaborations and visualisations of Current policies (CPs) and Nationally Determined Contributions (NDCs). In the second round of modelling, different projections may be included reflecting COVID-19 implications (perturbations) and impacts related to the Green New Deal. Those scenarios, as well as the variables, will be named in a simple and accessible manner so non-experts may also understand and extract key insights. For instance, scenario names could be clear-cut questions such as "Where are we heading?".

Finally, the visualisation of the results will be done using different graphs and infographics. Several webpages have served as an inspiration; see for example the Global Stocktake[2] or the SENSES toolkit[3].

[2] https://themasites.pbl.nl/global-stocktake-indicators/
[3] https://climatescenarios.org/

5 Ensuring validity and trust in the models

As noted in deliverable D6.1, a critical requirement of mitigation pathways modelling, particularly when using a co-creation approach with stakeholders, is to ensure trust and validity of the models used. This section highlights the different steps through which this process is being undertaken in WP6 of the PARIS REINFORCE project.

First, as reflected in deliverable D6.1, very early in the project the consortium has put significant effort in ***documenting*** each of the employed models' capabilities, in terms of geographic disaggregation, sectoral representation, types of greenhouse gas and pollutant emissions accounted for, technological detail, policy representation, socioeconomic inputs and outputs, and representation of metrics relevant to non-climate SDG indicators. It has done so for every model in the consortium, (a) in detailed and technical format for experts' consideration (see here for WP6 models), (b) in a dynamic interface and easy-to-digest language for non-experts to comprehend and map their requirements onto (see here for all models, in detailed, descriptive layout), and (c) in a comparative setting, allowing all stakeholders to understand which models should be employed for which policy questions (see here for WP6 models). As part of this step, the project released and shared with stakeholders a policy brief on 'what can our models do?' (link).

Second, as with WP5 and WP7 for European and global modelling respectively, WP6 is undertaking an approach in line with the "prolonged nature of model validation" (Barlas, 1996). This approach integrates opinions from the scientific community with the perspectives of stakeholders and external experts that will ultimately use the model results. The project will, in this respect, undertake a series of stakeholder workshops for each region covered in WP6 aimed at ***communicating*** what the models are, as well as what they can do, including a presentation of the modelling approach, preliminary results, and a discussion of the types of inputs and outputs the models produce and how they do this. These workshops will therefore provide an opportunity to place our models' results in the context of previous results, from other low-carbon pathways modelling in the regions of focus, as well as any relevant regional results from global modelling. They will also allow the project, not only to clearly communicate the modelling capabilities, features, and questions they have been asked to address in the past, but also to co-create the most pertinent questions stakeholders would like the models to address in the context of PARIS REINFORCE, in light of this well-informed stakeholder perspective. As shown in Figure 2, the workflow of PARIS REINFORCE involves first undertaking global, regionally-disaggregated modelling to explore the regional dynamics of emissions and energy / agricultural / land system transitions in the regions of interest, before discussing the realism, feasibility and validity of such results with regional stakeholders. In this way, the more detailed region-specific modelling that will be undertaken using the WP6 models can be made more real-world relevant.

Third, a central aspect of achieving real-world relevance is to undertake basic ***harmonisation/benchmarking*** of the models, via targeted validity checks. This includes ensuring that base-year emissions, socio-economic assumptions, policies, and energy / agricultural / land system representations are in line with the most up-to-date verified information, and that such inputs are to the extent possible harmonised across the models used in a multi-model analysis; this is not to strip models of their invaluable diversity in the way they behave in response to specific stimuli as well as the theoretical foundations underpinning them, but quite the contrary to allow the consortium to later map the resulting ranges onto this diversity rather than uncertainties associated with ad hoc inputs assumed for each model. This also includes technology costs and performance variables. The full process for updating these inputs are detailed in this deliverable, Section 3, and the underlying detailed protocol for achieving this has been documented (and submitted for academic publication) in Giarola et al. (2021).

Fourth, "***diagnostic***" tests will be run for each model, to check that its responses to key input variable changes, such as stringency of climate policy (as represented by emissions targets, carbon prices, or combinations thereof), are in line with common expectations and compared to other results and models covering the same/similar regions and/or a priori defined stylised behaviours. For WP6, this includes (a) comparing the resulting ranges of the multi-model exercises to those of recent and similar studies looking at the regions of focus, for example Safonov et al., 2020 for Russia, or Wang et al., 2020 for China; and (b) comparing the resulting ranges of the multi-model exercises to those of the global model inter-comparisons carried out as part of WP7 with appropriate disaggregation at the regions of WP6 focus, e.g. Sognnaes et al. Such diagnostics will be undertaken as part of the WP6 non-European modelling exercise. These checks will build on the normal standard practice undertaken by each modelling group to regularly check the model code and ensure that errors/bugs are identified and eliminated, and to report the model's performance and results of this exercise alongside its results.

Finally, this evaluation process will be carried out in an ***iterative process*** throughout the project. It will be documented to ensure that models perform without unexplained dynamics in both reference and mitigation cases. A key element of this will be in taking documented modelling results back to stakeholders in the second half of the project, when they will be able to understand the behaviours of the models under increasingly stringent mitigation scenarios, and to ask why the models respond in the way that they do.

In combination, these evaluation steps cover the primary elements of the workflow suggested by Schwanitz (2013) on model validation. The models' conceptual framework has to a large extent already been evaluated (and will be clearly communicated with stakeholders) as following from a principle of identifying least-cost pathways to low-carbon futures given the technological inputs and other input assumptions (which may be technology constraints, socio-economic dynamics, and representations of policies). This document (and the I^{2}AM PARIS platform that it feeds into) is intended to represent a major advance in communicating in a clear, accessible and attractive way the features, objectives, coverage, capabilities and limitations of the models. Such documentation, both here and in the platform, will accompany stakeholder interactions. Model structure and responses will be tested through both diagnostics as well as comparison with other published low-carbon and reference case pathways. Whilst most modelling groups explicitly draw on a vast range of literature and comparative studies to understand the extent to which their results are similar or different from others, and if so why, in PARIS REINFORCE we will explicitly undertake and present such comparisons throughout our modelling, to help better build trust in the results and the models themselves.

References

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review: The Journal of the System Dynamics Society*, *12*(3), 183-210.

Capros, P., Paroussos, L., Fragkos, P., Tsani, S., Boitier, B., Wagner, F., ... & Bollen, J. (2014). European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis. *Energy Strategy Reviews*, *2*(3-4), 231-245.

Dellink, R., Chateau, J., Lanzi, E., & Magné, B. 2017. Long-term economic growth projections in the Shared Socioeconomic Pathways. *Global Environmental Change*, 42, 200-214. doi:10.1016/j.gloenvcha.2015.06.004

European Commission, 2016, "Energy, transport and GHG emissions: trends to 2050". Doi: 10.2833/001137

European Commission, 2017, "The 2018 Ageing Report – Underlying assumptions & projections methodologies", European Economy Institutional Papers n°065. doi: 10.2765/286359

Giarola, S., Mittal, S., Vielle, M., Perdana, S., Campagnolo, L., Delpiazzo, E., Bui, H., Anger-Kraavi, A., Kolpakov, A., Sognnaes, I., Peters, G.P., Hawkes, A., Koberle, A., Grant, N., Gambhir, A., Nikas, A., Doukas, H., Moreno, J., & Van de Ven, D.J. (2021). Challenges in the harmonisation of global integrated assessment models: a comprehensive methodology to reduce model response heterogeneity. *Science of the Total Environment*.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod, N., Kurokawa, J.-I., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and Zhang, Q.: Historical (1750-2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), *Geoscientific Model Development*, 11, 369-408, 2018. DOI:10.5194/gmd-11-369-2018

KC, S., & Lutz, W. 2017. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change*, 42, 181-192. doi:10.1016/j.gloenvcha.2014.06.004

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustain. Sci.* 7, 25–43. https://doi.org/10.1007/s11625-011-0149-x

Mantzos, L., Wiesenthal, T., Matei, N. A., Tchung-Ming, S., Rozsai, M., Russ, P., & Ramirez, A. S. (2017). JRC-IDEES: Integrated Database of the European Energy Sector: Methodological note (No. JRC108244). Joint Research Centre (Seville site).

Napp, T. A., Few, S., Sood, A., Bernie, D., Hawkes, A., & Gambhir, A. (2019). The role of advanced demand-sector technologies and energy demand reduction in achieving ambitious carbon budgets. *Applied energy*, 238, 351-367. DOI: https://doi.org/10.1016/j.apenergy.2019.01.033

O'Neill, B.C.; Kriegler, E.; Riahi, K.; Ebi, K.L.; Hallegatte, S.; Carter, T.R.; Mathur, R.; Vuuren, D.P. van (2014) A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic. Change*, 122, 387–400. https://doi.org/10.1007/s10584-013-0905-2

Roelfsema, M., et al. (2020). Taking stock of national climate policies to evaluate implementation of the Paris Agreement. *Nature Communications*, 11, 2096. DOI: https://doi.org/10.1038/s41467-020-15414-6

Safonov, G., Potashnikov, V., Lugovoy, O., Safonov, M., Dorina, A., & Bolotov, A. (2020). The low carbon development options for Russia. *Climatic Change*, *162*(4), 1929-1945.

Schwanitz, V. J. (2013). Evaluating integrated assessment models of global climate change. *Environmental modelling & software*, 50, 120-131.

Sognnaes, I., Gambhir, A., Van de Ven, D.-J., Nikas, A., Anger-Kraavi, A., Bui, H., Campagnolo, L., Delpiazzo, E., Doukas, H., Giarola, S., Grant, N., Hawkes, A., Koberle, A., Kolpakov, A., Mittal, S., Moreno, J., Perdana, S., Rogelj, J., Vielle, M., & Peters, G.P. (in revision). A multi-model analysis of long-term emissions and warming implications of current mitigation efforts. *Nature Climate Change*.

Wang, H., Chen, W., Zhang, H., & Li, N. (2020). Modeling of power sector decarbonization in China: comparisons of early and delayed mitigation towards 2-degree target. *Climatic Change, 162*, 1843-1856.