PARIS
REINFORCE

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D7.2 INTERLINKAGES OF GLOBAL IAMS WITH THE I^2AM PARIS PLATFORM

WP7 – Model Inter-Comparisons, Global Stocktake & Scientific Assessments

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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 further elaborate on the new I²AM 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 global models 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)

WP7 focuses on global stocktaking of climate efforts, and six global models will be used for a series of extensive model inter-comparisons. The purpose of the first round of global modelling is to provide a global context of where we are heading with current policies and where we are supposed to be heading to comply with the Paris goals for temperature change. Therefore, the global models will be run in a coordinated way, providing the best scientific basis for a model inter-comparison exercise. Key modelling inputs will be harmonised for this exercise, such as socioeconomic and technoeconomic parameters, fossil fuel prices, historical emissions and actual climate policies for countries and regions around the world. The values of parameters to be harmonised in this round are selected based on an extensive process securing reliability and consistency of the assumptions made. After the first modelling round, global models will be constrained with adjusted input assumptions taken from modelling outputs of the regional/national models. Depending on the national/regional modelling outputs and related policy questions that flow into WP7, soft-links between global models can be explored to provide a more robust response from them in the second modelling round. The outcomes from the second global modelling round, whether from one specific model or a robust average result from multiple models, will be important to inform the second and last national/regional modelling exercise. Finally, the I²AM PARIS platform will share and display data, in a stepwise form, a sequence of presenting our processes of harmonisation, interlinkages, and our PARIS REINFORCE scenario data portal.

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 I²AM 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

Work package 7, "Model Inter-Comparisons, Global Stocktake & Scientific Assessments", focuses on global stocktaking of climate efforts, and six global models will be used for a series of extensive model inter-comparisons. The purpose of the first round of global modelling is to provide a global context of where we are heading with current policies and where we are supposed to be heading to comply with the Paris goals for temperature change. Therefore, the global models will be run in a coordinated way, providing the best scientific basis for a model inter-comparison exercise. Key modelling inputs will be harmonised for this exercise, such as socioeconomic and technoeconomic parameters, fossil fuel prices, historical emissions and actual climate policies for countries and regions around the world. The values of parameters that will be harmonised in this round are selected based on an extensive process securing reliability and consistency of the assumptions made. After the first modelling round, the global models will be constrained with adjusted input assumptions taken from modelling outputs of the regional models. Depending on the national/regional modelling outputs and related policy questions that flow into WP7, soft-links between global models can be explored to provide a more robust response from the global models in the second and last modelling round. The outcomes from the second global modelling round, whether from one specific model or a robust average result from multiple models, will be important to inform the second and last national/regional modelling exercise. The I^{2}AM PARIS platform will share and display data, in a stepwise form, a sequence of presenting our processes of harmonisation, interlinkages, and our PARIS REINFORCE scenario data portal. Finally, model validation steps are undertaken to ensure validity and trust in the WP7 models.

The document at hand is the revised version (v1.10R) of deliverable D7.2. 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).

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1 Introduction / Working structure

PARIS REINFORCE is a stakeholder-led project to assess low-carbon transition pathways 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 countries and regions around the globe.

Work package 7, "Model Inter-Comparisons, Global Stocktake & Scientific Assessments", focuses on global stocktaking of climate efforts, and six global models will be used for a series of extensive model inter-comparisons. Table 1 summarises these models, showing a rich diversity in terms of coverage and structure. These models can be roughly categorised in two categories, which is relevant from the perspective of model interlinkage and harmonisation. On the one side we have partial equilibrium models with exogenous economic indicators that focus mainly on long-term trends such as technological progress and human behaviour, while on the other side we have general equilibrium and macroeconometric models with endogenous economic indicators, which focus more on short-to-medium-term trends such as economic and trade effects of climate policies. The energy system model 42 is comparable to partial equilibrium models, in terms of sectoral focus, but looks more at short-term impacts.

Table 1: Overview of global models subject to interlinkage/harmonisation efforts (Source: deliverable 7.1)

		GCAM	TIAM	MUSE	GEMINI-E3	ICES	E3ME	42
Type of model		Partial Equilibrium	Partial Equilibrium	Partial Equilibrium / Agent-based	General Equilibrium	General Equilibrium	Macro-Eco-nometric	Energy system
Team running the model		BC3	Grantham, E4SMA	Grantham	EPFL	CMCC	Cambridge	IEF-RAS
Time horizon (final simulation year)		2100	2100	2100	2050	2050	2050 (2100)	2045
Time steps in solution (years)		5	10	10	1	1	1	1
Sectoral granu-larity	**Macro-economic**	Exogenous	Exogenous	Exogenous	Detailed	Detailed	Detailed	Exogenous
	Agriculture	Detailed	Yes	Yes	Yes	Yes	Yes	Yes
	Energy supply	Detailed	Very detailed	Detailed	Yes	Yes	Detailed	Very detailed
	Industry	Yes	Very detailed	Detailed	Aggregated	Aggregated	Yes	No
	Transport	Detailed	Very detailed	Detailed	Detailed	Aggregated	Detailed	Very detailed
	Buildings	Yes	Very detailed	Detailed	Aggregated	Aggregated	Yes	Detailed
	Land use	Very detailed	Limited	Yes (bioenergy)	No	Yes	Yes	Yes (bioenergy)

The overall work plan for PARIS REINFORCE is summarised in Figure 1. In a first iteration, the global models listed in Table 1 will be used to explore potential futures where we are headed with current policies around the globe,

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with stated Nationally Determined Contributions (NDCs), and where we should head if we wanted to limit global temperature change to levels well below 2 and pursuing 1.5 degrees Celsius, as indicated in the Paris Agreement. Depending on stakeholder inputs, different scenarios will be run for each of those futures. These global scenarios will provide a context, in which national and regional models in WPs 5 and 6 will be used, drawing on stakeholder input. In turn, WP5 and WP6 exercises will provide plausible national and regional scenarios, which together will inform the global models for a second modelling round. For this round, a new interlinkage structure will be designed, making use of the complementarities of the different models in this project.

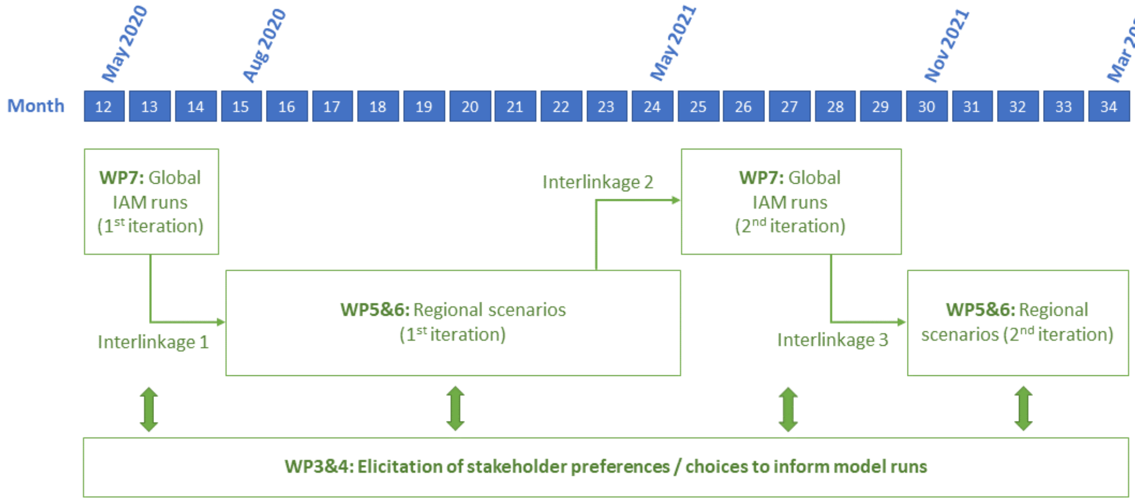

Figure 1: High-level workflow setting out interaction between global and national/regional modelling, informed by stakeholder engagement and stakeholder preference elicitation exercises

It should be noted, from Figure 2, that each stage of modelling 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 to elicit inputs from stakeholders on their particular research questions and views/preferences around modelling assumptions and scenario design. Our first Stakeholder Workshop in November 2019 resulted in stakeholder preferences of global pathways. These focus primarily on lifestyle and behavioural changes, the Green New Deal and Just Transitions, and potential failure of key technologies where possible. Scenario modelling will try to respond to these concerns to the best extent possible.

Work Package 4 ("Robustification and socio-technical analysis toolbox") is used to explore specifics of technological and societal transformations, and to utilise stakeholder inputs to identify pathways that are realistic or robust, in the context of a range of uncertainties about the future. Robustification of national scenarios via WP4 is to add overall coherence to global modelling runs as well. The objectives of WP3 and WP4 are to ensure that the modelling attempts are not done in isolation, but rather orient on what stakeholders deem necessary for analysis via the modelling capabilities and ensembles of the PARIS REINFORCE consortium. WP2, the I²AM PARIS platform, acts as our main knowledge synthesis and dissemination channel. It currently has a detailed interface of all modelling documentation. Future steps on harmonisation and interlinkages (see Section 4) will be detailed within the platform, along with results on modelling runs.

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2 Harmonisation and Interlinkage flows

Based on the harmonisation and interlinkage possibilities of each model (see Appendix for possibilities in WP7, and appendices of D5.2 and D6.2 for WP5 and WP6 respectively), this section outlines a structure for harmonisation and interlinkage efforts in the different modelling rounds of WP7. The following section discusses the hamonised data.

2.1 Modelling round I: Interlinkage through harmonising exogenous variables

The purpose of the first round of global modelling is to provide a global context of where we are heading with current policies and where we are supposed to be heading to comply with the Paris Agreement goals for temperature change. Therefore, all global models will be run simultaneously, providing a model inter-comparison exercise.

To ensure comparability of the results, harmonised data has been used for the most crucial drivers of the global models. The same data is also used in the national/regional models in WPs 5 and 6, to ensure a consistent storyline among the modelling outcomes. Figure 2 shows the overall structure of the first modelling round, in which some outputs of global models will also flow into regional models, predominantly those in WP6. The following section provides the detailed characteristics of the parameters that are subject to harmonisation in this modelling round.

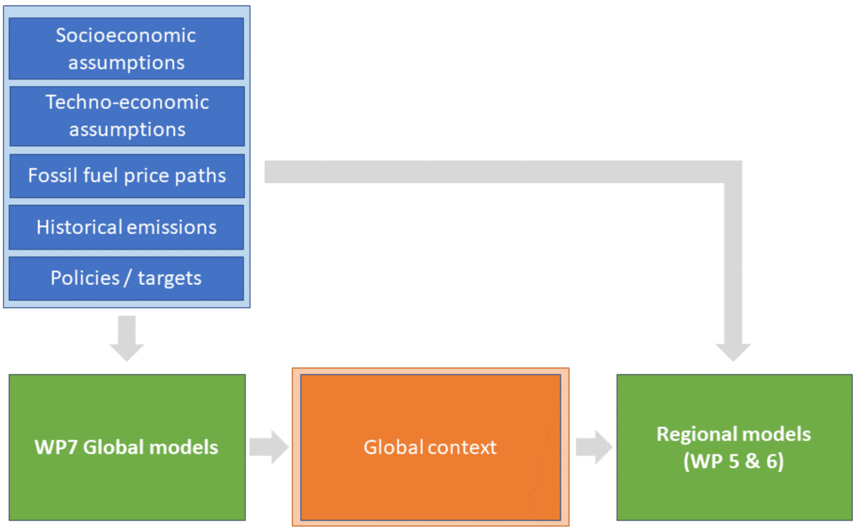

Figure 2: The same modelling assumptions flow into and from WP7 (global) models and national/regional models in WPs 5 and 6 in the first interlinkage exercise, to ensure consistent outputs in all WPs.

2.2 Post-Modelling round I: Feeding regional outputs into global models

For the second interlinkage shown in Figure 3, the main purpose of the interaction between the regional and 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.

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Figure 3: Stakeholder filtered modelling outputs flow from the national/regional models in WPs 5 and 6 to global models in WP7 for second interlinkage exercise

We cannot expect that global models will take into account the precise technological detail, behavioural trends and detailed energy and land policies in the first modelling run, even if we intend to run current policy scenarios that provide some idea of where we are headed. Therefore, the feedback from the national/regional models in WPs 5 and 6 are to serve for fine-tuning the quality of the global scenarios, enabling them to provide a better picture of where we are really headed, and what is necessary to keep global temperatures increase well below 2°C.

2.3 Modelling round II: Exploring soft links between global models

Depending on the national/regional modelling outputs and related policy questions that flow into WP7, soft-links between global models can be explored to provide a more robust response from the global models in the second and last modelling round (see Figure 4).

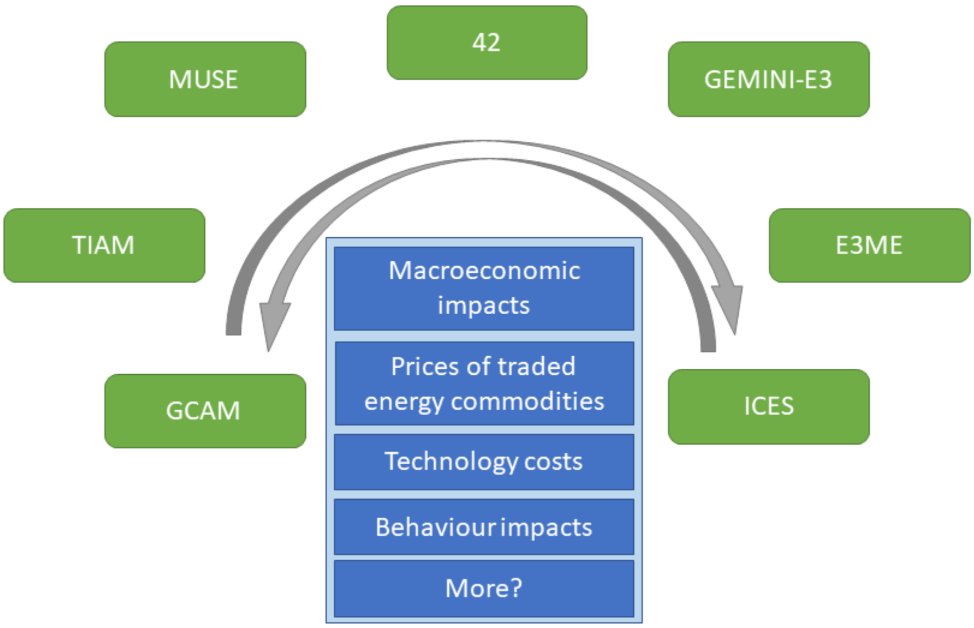

Figure 4: Based on national/regional inputs to WP7, soft links between global models can be explored to improve the consistency of the global outputs in the second and last modelling round.

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Table A1 in the Appendix provides an overview of the outputs and harmonisable inputs for each of the global models, as identified by each of the modelling teams. It shows clear differences between the models, and in most cases symmetries between the partial equilibrium and general equilibrium/macroeconomic models. For example, partial equilibrium models can adapt their drivers for energy demand, while such drivers are outputs for general equilibrium and macroeconomic models. Similarly, partial equilibrium models require inputs for technoeconomic parameters and are willing to adapt those, while ICES and E3ME cannot adapt them. Here, the general equilibrium model GEMINI-E3 is an exception, as it can also adapt external values for such parameters. On the other hand, international prices for tradable energy goods, such as fossil fuels and bioenergy, tend to be outputs from partial equilibrium models, but inputs to general equilibrium and macroeconomic models.

This information, in combination with the interchanged experience among WP7 modellers in the first round will help foster mutual understanding and highlight the qualities and dependencies of each of the global models, which is crucial when creating soft-links between these models. For example, the mix of projected national/regional energy demand and behaviour trends that come out of WPs 5 and 6 might have significant impacts on economic growth, while also affecting global technology costs and energy prices. All global models in WP7 have different qualities, which can be linked to one another to construct the most robust global response to the national/regional modelling and stakeholder outcomes in the first round.

2.4 Modelling round II: Feeding global outputs into regional inputs

The outcomes from the second global modelling round, whether from one specific model or a robust average resulting from multiple models, will be important to inform the second and final national/regional modelling exercise. Importantly, the global models need to check whether the policies and ambitions that come out of the first European modelling round are sufficient to keep global temperature increase well below 2°C, while also being in line with other global policy goals, such as the Sustainable Development Goals (SDGs). It is expected that this may not be a sufficiently ambitious pathway and this second iteration of global modelling will set the European models up for the final round of modelling, while identifying the gap between what is provided in the first modelling round and what is needed to reach the Paris Agreement and SD goals. The combination of outputs from the global models, in terms of global context variables such as fossil fuel prices, and the identified global policy gaps, should provide a good base for the European models to design Paris-compatible pathways that limit global temperature increase to well-below 2°C, while also meeting other local and global policy goals.

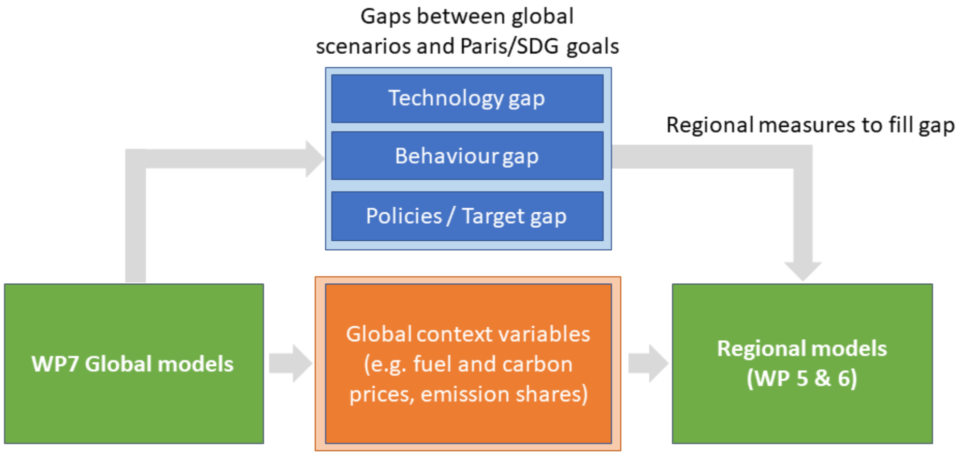

Figure 5: Modelling assumptions flow from WP7 (global) models to the national/regional models in WPs 5 and 6 for a final interlinkage exercise

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3 Parameter assumptions used in the global models

3.1 Harmonised modelling inputs

As mentioned in Section 2.1, the first modelling round uses harmonised external assumptions for key modelling variables. Based on the outcomes of a questionnaire identifying the role of different modelling parameters in each model (see outcome in Appendix) and on internal discussions on which assumptions constitute the most important drivers for modelling outcomes, an overview of the selected assumptions and their details are presented in Table 2. This overview also considers other factors such as the availability of reliable input data and the homogeneity in which a certain parameter is represented in different models.

Not all these harmonisation parameters are applied in each model since some model structures do not allow the harmonisation of certain inputs (see Section 2). Also, for some models, the required effort for harmonising variables was too large compared to the value added from harmonisation, because some parameters were already well up-to-date and/or the harmonisation of these parameters was complicated. In such cases, the consistency of the default inputs in these models was checked with the parameters provided in Table 2 to ensure they do not diverge strongly. The last column in Table 2 shows which global models are either updating or checking their outputs for which harmonised variables. This list shows that socioeconomic data is harmonised across all models, as well as CO_2 emissions. However, other parameters, such as technoeconomic parameters or fossil fuel prices, are only harmonised or cross-checked by those models that use these as inputs.

The data in Table 2 has been put together considering an optimal balance between reliability and consistency. Consistency has been ensured where applicable, by using the same data source. For example, in socioeconomics, the same source has been used for population and GDP for each country during the same time period, as these are strongly interrelated. Similarly, the source for historical GHG and non-GHG emissions by country is the same, as both types of emissions depend on combustion activities. Reliability has been enforced by expert judgement within different modelling teams cooperating in PARIS REINFORCE. Discussions leading to the selection of the assumptions in Table 2 can be summarised as follows:

- Socioeconomics: Consistency considerations have been crucial for the elaboration of a set of socioeconomic assumptions, first because GDP and (working age) population are highly correlated and should therefore come from the same source for each individual country, and second because GDP and population are subject to serial correlation, as the values in one year are expected to affect the values in subsequent years. While the SSP database (Dellink et al., 2017; KC and Lutz, 2017) is the only identified source that provides both GDP and population projections until 2100 for all countries (which is required as some models run until 2100, see Table 1), the estimates are slightly outdated, and short-term projections (<2020) have proven not to fit well with real-world developments. Therefore, for reliability purposes, different sources have been identified for short-term projections and extended to the medium term to secure serial consistency: OECD projections (Economic Outlook (EO) 106 for short-term GDP, EO 103 for medium-term GDP, and updated population projections) have been applied for non-EU OECD

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and various non-OECD countries[1]. Since OECD projections go until 2060, a switch year has been selected individually for each country, at which OECD growth rates for both population and GDP come simultaneously very close to SSP2 growth rates. From this point onwards, SSP2 growth rates have been assumed until 2100. For EU countries, EUROPOP (Eurostat, 2018) has been used for population projections until 2100, while the Ageing Report (EC, 2017; which is based on EUROPOP population projections, but less updated in the short-term) has been identified as the most reliable projection for both GDP per (working age) capita growth rates until 2070, and SSP2 growth rates have been assumed from 2070 onwards. For non-OECD countries not in the OECD database[2], a lack of both reliable and consistent data sources forced us to prefer short-term reliability over serial consistency. For these countries, population growth rates published by the United Nations and GDP growth rates from the IMF have been assumed until 2020, and SSP2 growth rates for population and GDP are assumed from 2021 onwards, which could result in an inconsistency between estimates until 2020 and beyond 2020, as the post-2020 growth population and GDP growth rates stemming from SSP2 are serially correlated with pre-2020 estimates by design. However, the use of growth rates for both population and GDP prevents time series breaks between 2020 and 2021.

- Technoeconomic parameters: Main reliability concerns have been weighted for choosing the main source for technoeconomic assumptions. Since technology plays a major role in PARIS REINFORCE, an up-to-date source for these parameters is of high importance for the modelling activities. For power generation and transport technologies, estimates from Napp et al (2019) have been shared, which is based on a relatively recent literature review and used by default in TIAM. For consistency, the technoeconomic assumptions for the industry, residential and commercial sectors have also been shared to be harmonised in other models, although different representation of these sectors in the different models complicates harmonisation of these assumptions, and less weight is given to them compared to the assumptions for power generation and transport technologies. Assumptions of EU NECPs, based on Mantzos et al (2017), are provided as an alternative to TIAM-based assumptions and are mainly used by WP5 models.
- Fossil fuel prices: The projections provided by the IEA in the World Energy Outlook 2019 for oil, coal and natural gas prices are considered the most up-to-date source for such estimates. The "Current Policies" projections are well in line with the objectives in the first modelling round of this project, which are largely based on the modelling of current climate policies around the world. Also, the regional disaggregation of coal and natural gas prices allows for realistic and consistent estimates among models that operate at different geographical scales. A comparison has been done with estimates provided by the European NECPs, but the latter seemed to be relatively outdated compared to the IEA estimates. These prices are only adopted by models in which fossil fuel prices are exogenous, which are typically the general equilibrium and macro-economic models.
- Exchange and interest rates: As projections from OECDs' EO 103 have been used for medium-term economic growth projections in the major economies (62.8% of global GDP in 2018), projections for exchange and interest rates have been extracted from the same source for consistency considerations.
- Historical emissions: While different datasets have been considered for streamlining historical emissions

[1] Countries for which OECD projections are used, are: Australia, Canada, Chile, Iceland, Israel, Japan, Korea, Mexico, New Zealand, Switserland, Turkey, United States (OECD), Argentina, Brazil, China, Colombia, Costa Rica, India, Indonesia, Saudi Arabia and South Africa (non-OECD). Together, these countries represented 62.8% of global GDP and 57.8% of global population by 2018.

[2] All non-OECD countries not listed in Footnote 1. These countries represented around 34% of global population and 20% of global GDP in 2018.

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within the different models of the consortium, the CEDS database (Hoesly et al, 2018; van Marle et al, 2017) also used in the CMIP6 project has been used as it includes emissions for most GHGs and pollutants, separately for each country and sector, within the same database, so guaranteeing consistency as much as possible. The database does not include data for N_2O and F-gases, and the PRIMAPHIST database (Gütschow et al, 2016) has been chosen for streamlining N_2O emissions and F-gases are based on global data in the WMO Ozone Assessment of 2018. The use of the EDGAR database (Janssens-Maenhout et al, 2017) has also been considered, as it includes data on all GHGs, including N_2O and F-gases. However, EDGAR databases do not include estimates for all pollutants, and estimates from EDGAR v4.2 were considered outdated and only go until 2012, while estimates from EDGAR v5.0 do not include emissions from biomass burning and land use change. Therefore, the need for alternative datasets to complete the EDGAR data, was considered more complicated and less consistent than completing the CEDS database with data from PRIMAPHIST and the WMO assessment.

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3.2 Current policies (CPs) and Nationally Determined Contributions (NDCs)

As well as the socioeconomic, technoeconomic and other parameters described above, all models in the PARIS REINFORCE consortium have been set up to include reference scenarios which reflect current levels of climate policy ambition in different world regions. This will include a reference scenario reflecting the implementation of current policies (CPs) at a national or regional level, as well as a distinct reference scenario including the implementation of Nationally Determined Contributions (NDCs). In both cases, this ambition was implemented until 2030 (the period for which NDCs are most frequently stated and for which current policy impact can reasonably be projected), but with assumptions made around how these levels of current policy and NDC "efforts" are extended beyond 2030.

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

3.2.1 Current policies and NDCs until 2030

3.2.1.1 Current policies until 2030

Greenhouse gas emissions are directly and indirectly regulated by a vast number of public policies directly targeting climate, but also non-climate related issues in most if not all sectors in the economy across scales of time, space, and political constituencies. It is therefore important to represent them in models used to develop low-carbon pathways representing current trends in emissions, energy system configurations, demand profiles and so on. This can be challenging as public policies vary widely in their scope, detail and criteria. A wide variety of policy types exist across geographic scales (cities, nations) so it is not a trivial matter to accurately model policies at a national level as there may be interaction between different policies across sub-national constituencies and across sectors. This problem is exacerbated at the global level, especially as global models tend to include varying levels of regional aggregation.

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Table 2: Characteristics of harmonised parameters and use in WP 7 models

	Variable	Definition	Time span	Source	Units	Comments	Used in models (Update / *check differences*)
Socio-economics	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 depending by country, ensuring smooth transitions between projected growth levels, and consistency between (working) population and GDP growth rates.	GCAM, TIAM, MUSE, GEMINI-E3, ICES, E3ME, 42
	Working 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		MUSE, ICES, E3ME
	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		GCAM, TIAM, MUSE, GEMINI-E3, ICES, E3ME, 42
Power generation costs	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$2010/kW, Lifetime in years	Technologies included are wind, solar, nuclear, geothermal, hydro, coal, gas, biomass	GCAM, TIAM, MUSE, GEMINI-E3, E3ME
	Key technological attributes of renewable and non-renewable technologies	Costs of investment, fixed and variable O&M, conversion efficiencies, self-consumption share, capacity factors, technical lifetimes and O&M costs growth	2020 - 2050	NECPs (Mantzos et al, 2017)	Costs in EUR'13/MWh, Lifetime in years	No global coverage. Costs are estimated for Europe. No regional disaggregation	*TIAM*
Transport costs	Key technological attributes of cars, buses and trucks	Costs of investment, fixed O&M, efficiencies and technical lifetimes	2006 - 2050	TIAM (Napp et al, 2019)	Costs in M 2010 US$/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	*GCAM, TIAM, MUSE, GEMINI-E3, E3ME*
	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	

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Residential and commercial costs	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	TIAM, GCAM, MUSE, E3ME
	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	
Industry costs	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	TIAM, GCAM, MUSE, E3ME
	Key technological attributes by type of process	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	
Fossil fuel prices	Fossil fuel price paths	Price projections in the main regions for oil, gas and coal	2010-2050	2019 World Energy Outlook by International Energy Agency	Oil: $2018USD per barrel/per GJ Gas: $2018USD per Mbtu/per GJ Coal: $2018USD per tonne GJ	Figures available at global level and for 4 regions: EU, USA, China and Japan	GEMINI-E3, ICES, E3ME
Exchange rates	Exchange rates	Exchange rates between US$ and national currency	2000-2100	Economic Outlook No. 103 (July 2018) by OECD	US$/National currency	Long-term baseline projections + constant after 2060 except Bulgaria, Cyprus, Croatia, Malta and Romania from Eurostat	E3ME
Interest rates	Interest rates	Short- and long-term interest rates			%		E3ME
Emissions	Historical emissions	CO_2, CH_4, BC, OC, CO, NH_3, NO_x, VOC, SO_2	1970-2015	CMIP6 (Hoesly et al, 2018; van Marle et al, 2017)	Mt	222 countries, 19 sectors	All: GCAM, GEMINI-E3, ICES, E3ME, TIAM; Only CO_2: 42, MUSE
		N_2O	1990-2017	PRIMAP (Gütschow et al, 2016)		216 countries (and aggregated regions), 14 sectors	GEMINI-E3, ICES, GCAM
		HFC, SF_6, C_2F_6, CF_4	1978-2016	NOAA: WMO Ozone Assessment 2018		Global totals, no regions or sectors, 1978-2016	GCAM

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In addition, the language used to describe an official policy ranges from vague and difficult to quantify to be based on quantitative indicators. Therefore, some degree of interpretation is needed. For example, some policies set targets relative to a base year or to a business-as-usual (BAU) scenario in the future. Others are based on complex indices like energy or carbon intensity of GDP. Implementing such policies requires access to historical data or calculating targets based on counterfactual no-policy or BAU scenario runs. A working document was prepared with a list of current energy and climate policies in G20 (+EU) countries stemming from the CD-Links policies database to serve as an implementation guideline for modelling teams (Roelfsema et al., 2020). Additionally, this information has been complemented with consortium expertise on new or updated national policies of countries both included and excluded from the CD-Links database.

Models differ in their structure, so the set of policies that can be put in place vary across models. Modelling teams decided which policies can be implemented and applied some degree of creativity to help circumvent the implementation challenges.

3.2.1.2 NDCs until 2030

Under the 2015 Paris Agreement, virtually all countries around the globe submitted their NDC, stating their ambition level with respect to GHG emission reductions. All officially submitted NDCs are publicly available[3], but the language used to describe a climate ambition ranges, similarly to the case of current policies, from very vaguely formulated to very specific and expressed through quantitative targets. Therefore, also for this implementation exercise, some degree of interpretation has been required. Some emission reduction policies set targets relative to a base year or to a pre-calculated business-as-usual (BAU) scenario in the future. Others may be based on carbon intensity of GDP. Some only include CO_2 emissions from energy and industry, while others include other GHGs and CO_2 from Land use, land-use change and forestry (LULUCF). Implementing such policies required access to disaggregated historical emissions data and calculating the expected share of e.g. CO2 in a pre-calculated BAU scenario for GHG emissions.

A working document was also elaborated with a list of interpreted NDCs of the majority of countries and regions stemming from the CD-Links policies database (Roelfsema et al., 2020). Since each model has a different regional disaggregation and different capabilities through which non-CO2 gases constraints can be implemented, the exact modelling of these NDCs depended on the interpretation of each modelling team. Given the uncertainties related to NDCs, the least ambitious NDC target has been selected (lower end) in those cases where a range was given, or, alternatively, the unconditional target by country. In addition, for countries or regions where the regional disaggregation was similar to the guidelines given in the working document, the same targets have been used for consistency purposes. Finally, a document has been prepared where each team explained the policy interpretations through the assumed quantitative targets.

[3] https://www4.unfccc.int/sites/submissions/indc/Submission%20Pages/submissions.aspx

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3.2.2 Extension of current policies and NDCs beyond 2030

The Paris Agreement states that each Party must communicate successive NDCs that "represent a progression beyond the Party's then current nationally determined contribution and reflect its highest possible ambition, reflecting its common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (UNFCCC, 2015). There are, however, several ways in which to define 'progression' and 'ambition'. While numerous studies have followed CPs or NDCs to 2030, there has been very little analysis of post-2030 pathways. CD-LINKS assumed that the "equivalent effort relative to the *No Policy* scenario after 2030" was applied, which essentially means there is no ratcheting of ambition post-2030. ADVANCE used an "extrapolation of implied effort beyond 2030", which was based on emission intensity, though those results have not been analysed (only published in the database). The CD-LINKS and ADVANCE scenarios show that some level of policy after 2030 in line with CPs and NDCs leads to lower temperatures levels than no policy, but they are not sufficient for achieving the 2ºC target. CD-LINKS estimates a temperature range across models of 3ºC - 3.5ºC in 2100, while ADVANCE projects a range of 2.3ºC - 3.3ºC. Nearly all other scenario exercises look at pathways to 1.5ºC or 2ºC. The effort done by the PR consortium is therefore aimed at filling the literature gap on "where we are heading" if climate policy continues to be ratcheted modestly over time. In addition, costs of mitigation may be systematically overestimated if 1.5ºC - 2ºC scenarios are constantly compared to scenarios with little or no mitigation.

From a modelling perspective, there are many potential ways of extending CPs and NDCs beyond 2030 based on some form of 'continued ambition'. Questions arise firstly because many different metrics can be used to measure the ambition implied by CPs and NDCs to 2030, including (but not limited to) the carbon price, emissions intensity, and absolute emissions. All of these can be used for extending the scenarios forward in time. The choice matters because it reflects different assumptions regarding how we believe climate policy is likely to progress and this will lead to different pathways. Further challenges arise as different models will respond differently to different metrics. Constant emissions reductions might for example require exponentially increasing carbon prices in one model, but not in another. Constant emissions intensity reductions may or may not imply a decrease in emissions, depending on population and economic growth assumptions. It is also possible that different metrics to measure ambition make sense for different countries. Secondly, there are questions as to how exactly a chosen metric should be extended forward in time. Do we assume a constant rate of change or constant absolute reduction (or increase)? Do we base this on the average value of the metric in 2020-2030, the value in 2030, or do we consider acceleration over time?

Thus, the concept of continuously increasing ambition leaves us with many interesting research questions, which challenge our understanding of how policy may change over time and the understanding of how models respond to different implementations of raised ambition. While the objective is not to predict future policies or technologies, the "where are we headed" scenarios represent a more systematic analysis of possible emissions pathways based on extending current trends with realistic policy and technology trajectories. This analysis provides an improved basis for identifying how ambitions will need to be accelerated in order to limit global warming to well-below 2^{0}C, and thus for informing the ratcheting up of ambition inherent to the Paris Agreement.
In addition to representing plausible trajectories forward, the choice of how to extend CPs and NDCs beyond 2030 must be meaningful and work for all models in the consortium. Different approaches for extrapolation climate efforts beyond 2030 have therefore been adopted also with the objective of

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gauging whether the different options result in sensible-looking emissions and energy system changes going forward.

A stepwise and iterative process was designed (Figure 6) and divided into two stages where Stage 1 represents the implementation of CPs and NDCs up to 2030 and Stage 2 represents the post 2030 extension, which is meant to be iterative as modelling groups explore different implementations of post-2030 ambition.

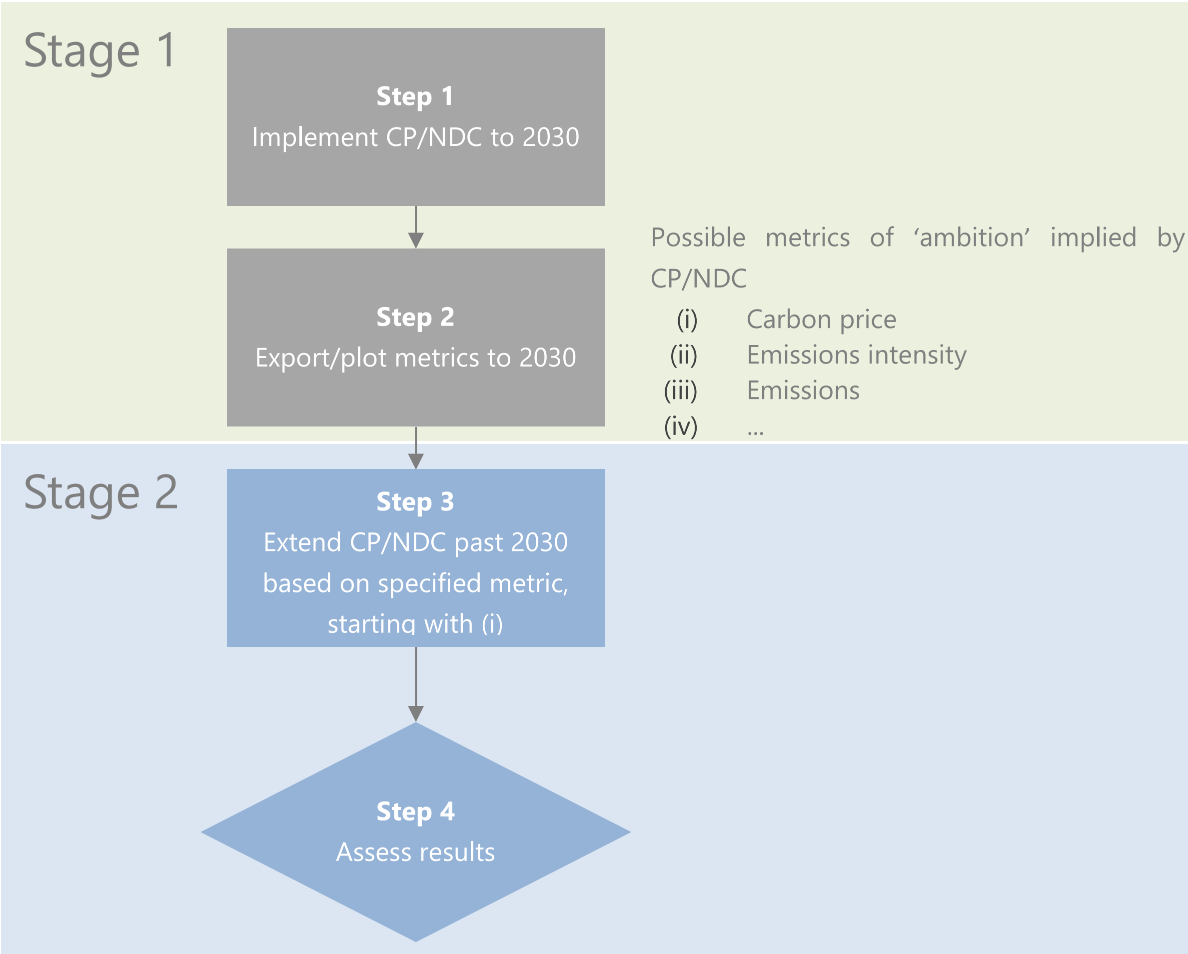

Figure 6: Steps for deciding on post 2030 extensions of CP and NDC scenarios

Step 1 involved first to harmonize the parameters described in section 3.1 (socio-economics, technology costs, etc.) to make sure models' 2018-2020 emissions are broadly in line with outturn data and near-term emissions projections. Once this was completed, modelling teams were required to implement climate policies and NDCs to 2030. The results of Step 1 representing ambition implied by CPs and NDCs in terms of carbon prices, emissions and emission intensities are then exported for Step 2. These metrics were then used to extend CPs and NDCs beyond 2030 for the calculations in Step 3.

Amongst the list of alternatives, two metrics were recognised as identifiers of climate ambition for priority runs:

1. **Implicit carbon price extended with regional GDP growth per capita**: By extending the internally calculated carbon price - necessary to achieve the measured GHG savings in 2030 with applied CPs and NDCs - into the future, forecasting capabilities were used to explore where the extrapolation of stated climate ambitions will get us in the long term.

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For those regions in which the implicit carbon price in 2030 is zero (either due to the absence of CPs or non-ambitious stated NDCs), a price of 1 $/tCO2 was assumed for the inflation towards future periods.

2. **Carbon intensity extending ambition based on 2020-2030 effort**: First, it was calculated how CPs and NDCs affected the carbon intensity and the total emissions in each region from each model's base year until 2030. Then, using the backcasting capabilities of our models this trend – which was based on a mix of stated ambitions and overall socioeconomic and technological trends - was extrapolated into the future.

Building upon the results of these initial scenarios, more ways to extrapolate post-2030 climate ambitions might be explored, based on the same indicators for 2030 gathered in Step 2.

The motivation behind these scenarios is to have a comprehensive mix of forecasting and backcasting approaches to project climate change mitigation scenarios into the future. See Table 3 for a layout of pre- and post-2030 scenarios that will be applied within the proposed structure.

Table 3: Overview *of modelling approaches applied in the first global modelling round.*

		Global models (WP 7)
Current policies	*Until 2030*	*Forecasting:* exploring the effect of current policies on emissions
	Beyond 2030	*Forecasting* based on carbon price extrapolation; *Backcasting* based on projected emissions intensity up to 2030 (see method 2 above for details)
NDCs	*Until 2030*	*Backcasting:* exploring the region-specific requirements to meet a certain NDC goal
	Beyond 2030	*Backcasting* based on projected emissions intensity up to 2030; *Forecasting* based on extrapolation of implicit carbon price

In Step 4, upon observing the results from all partners, the realism of resulting modelled pathways will be assessed. Among other things, groups will look at key technology deployments (e.g. renewables, CCS) to get a sense of whether this is credible given the policies applied. As the results are analysed, it might make sense to implement "alternative metrics" or to adjust relevant parameters to determine what metrics choice give the most plausible results.

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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[4].

Additionally, the platform will count with 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 7), 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

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

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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.

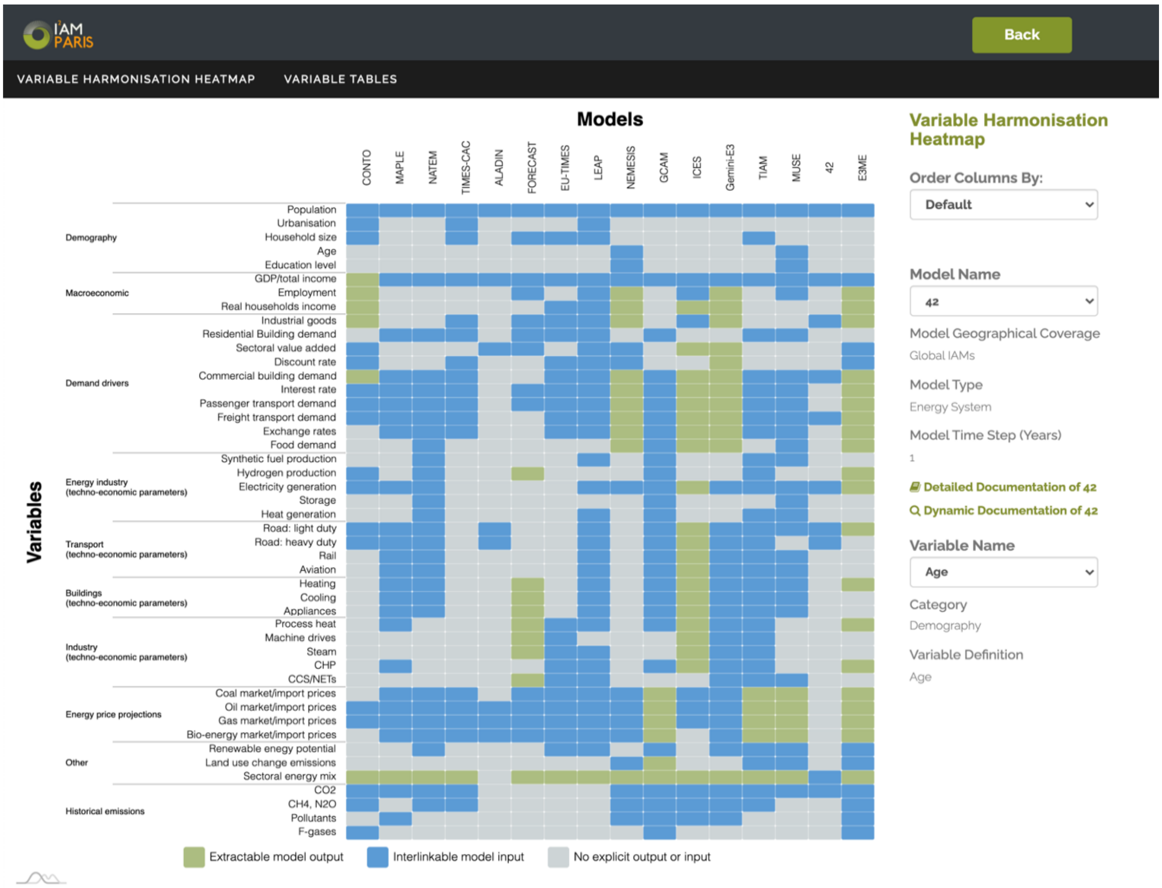

Figure 7: Variable Harmonisation Heatmap

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 might be included reflecting COVID-19 implications and the Green New Deal. Those scenarios, as well as the variables, will be named in a simple and accessible manner so non-experts could 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[5] or the SENSES toolkit[6].

[5] https://themasites.pbl.nl/global-stocktake-indicators/
[6] https://climatescenarios.org/

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5 Ensuring validity and trust in the models

As noted in deliverable D7.1, 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 D7.1, 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 WP7 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 WP7 models). As part of this step, the project released and shared with stakeholders a policy brief on 'what can our models do?' (link).

Secondly, as with WP5 and WP6 for European and non-European national modelling respectively, WP7 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 active engagement with global stakeholders 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. This interaction will therefore provide an opportunity to place our models' results in the context of previous results from other global low-carbon pathways modelling activities. 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 globally, before discussing the realism, feasibility and validity of such results with both global and regional stakeholders. In this way, WP7 models can undertake scenarios informed by national stakeholders in various regions around the world, improving the real-world relevance of their outputs.

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

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updating these inputs is detailed in this deliverable, Section 3.1, and the underlying detailed protocol for achieving this has been documented (and submitted for academic publication) in Giarola et al.

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 WP7 models, this includes comparing the resulting ranges of the inter-comparison exercises to those of similar studies in the scientific or grey literature; for example, in building a robust reference scenario looking at current policy efforts (Sognnaes et al.), comparisons have been drawn against recent similar scientific endeavours like (Roelfsema et al., 2020) or high-impact reports like the International Energy Agency's 2019 World Energy Outlook (IEA, 2019). Such diagnostics will be undertaken as part of the WP7 global 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 I²AM 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.

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Appendix – Ability for Interlinkage and harmonisation of global models in WP7

Since each model in the consortium has a different overall structure, the set of variables that can be harmonised or interlinked (e.g. with regional models, see D5.2 and D6.2) also differs for each model. For this purpose, each modelling team has indicated, for a list of variables, whether these variables are outputs, inputs or not represented in their model. In the case of an input, each team have indicated whether they are able/willing or not to adapt this variable to outputs from other models in the consortium or with harmonised inputs. Table A1 shows the outcome of this process for the models in WP7.

Table A1: WP7 models' ability to harmonise/interlink to a central set of assumptions

		Model name:						
		GCAM	*ICES*	*Gemini-E3*	*TIAM*	*MUSE*	*42*	*E3ME*
Demography	Population	2	2	2	2	2	2	2
	Urbanisation	4	4	4	4	4	4	4
	Household size	4	4	4	2	4	4	4
	Age	4	4	4	4	2	4	3
	Education level	4	4	4	4	2	4	4
Macro-economic	GDP / total income (reference)	2	2	2	2	2	2	2
	Employment (reference)	3	2	1	4	2	4	1
	Real household disposable income	4	1	1	4	4	4	1
	Sectoral value added	4	2	1	4	4	2	1
	Discount rate	2	4	4	2	2	4	4
	Interest rate	4	1	1	4	4	4	2
	Exchange rates	4	4	1	4	4	4	2
Demand drivers	Industrial goods	2	1	1	2	2	2	1
	Domestic Building services demand	2	1	1	2	2	4	1
	Commercial building serv. dem	2	1	1	2	2	4	1
	Passenger transport demand	2	1	1	2	2	2	1
	Freight transport demand	2	1	1	2	2	4	1
	Food demand	2	1	1	4	2	4	1
Techno-economic parameters								
	Synthetic fuel production	2	4	4	2	2	4	4
Energy industry	*Hydrogen production*	2	4	4	2	2	4	1
	Electricity generation	2	1	2	2	2	2	1
	Storage	2	4	4	4	2	4	4
	Heat generation	2	4	4	2	2	3	4
Transport	*Road: light duty*	2	1	2	2	2	2	1
	Road: heavy duty	2	1	2	2	2	2	4
	Rail	2	1	2	2	2	4	4
	Aviation	2	1	2	2	2	4	4
Buildings	*Heating*	2	1	2	2	2	4	1
	Cooling	2	1	2	2	2	4	4
	Appliances	2	1	2	2	2	4	4
Industry	*Process heat*	2	1	2	2	3	4	1
	Machine drives	4	1	2	2	3	4	4
	Steam	4	1	2	2	3	4	4
	CHP	2	1	2	2	3	4	1
	CCS/NETs	4	4	2	2	2	4	4
Energy price projections	Coal market/import prices	1	2	2	1	1	4	1
	Oil market/import prices	1	2	2	1	1	4	1
	Gas market/import prices	1	2	2	1	1	4	1
	Bio-energy market/import prices	1	4	2	1	1	4	1
Renewable energy potential (e.g. physical maximum)		2	4	2	2	2	4	2
Land use change emissions		1	4	4	2	2	4	2
Sectoral energy mix		1	1	1	1	1	2	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

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