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D7.4 1st Report on model inter-comparisons: Informing scientific assessments and the GST

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 with a delay of two months, agreed upon with the Project Advisor.

2. Dissemination and uptake

This deliverable highlights the format that will be used throughout the PARIS REINFORCE project to inter-compare model results when several models are used to explore the same research question. In the particular case of this exercise, the question at hand is "where are global and regional greenhouse gas emissions heading?". This is a complex (yet vitally important) question, which is informed by a transparent and systematic consideration of the current policies and measures, as well as pledges, that each country has put in place to tackle climate change.

3. Short summary of results (<250 words)

PARIS REINFORCE is utilising 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 7, called "Model Inter-Comparisons, Global Stocktake & Scientific Assessments", consists of designing and performing global modelled scenarios of future emissions pathways, using an array of global integrated assessment models and energy system models.

This report shows that the first global model inter-comparison, using a mix of Computable General Equilibrium (CGE), macro-econometric, bottom-up energy system and partial equilibrium models results in a broad range of emissions futures under "reference" scenarios, which account for current policy efforts and current Paris pledge targets. This range is produced despite of a high degree of modelling input and scenario design harmonisation, highlighting the importance of underlying model structure in determining the results.

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
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

Executive Summary

There are hundreds of different modelled carbon dioxide (CO_2) and greenhouse gas (GHG) emissions pathways in the academic literature, focusing on cases with no or relatively low levels of mitigation action (often called "business-as-usual"), as well as cases with much higher levels of mitigation action aimed at achieving specified emissions or climate targets, often in line with international goals such as the Paris Agreement's well-below-2°C target.

However, there has been a relative dearth of scenarios that address the question "where are emissions heading?" at this point in time, taking into account the reality of current levels of mitigation ambition and related policy actions and near-term goals in the world's different countries and regions. This report, encompassing the first global model inter-comparison in the PARIS REINFORCE project, aims to address this question.

The report uses a range of seven global energy system and integrated assessment models (IAMs), spanning a wide range of solution objectives and underlying model structures, to focus on future pathways of CO_2 emissions from energy and industrial processes, which form the majority of all anthropogenic GHG emissions, and which provide a strong signal of future temperature change.

The exercise includes a high degree of harmonisation of socio-economic, techno-economic and policy assumptions across models, reflecting up-to-date assumptions on future economic and population growth paths, low-carbon technology cost reduction trajectories, as well as the most current mitigation policies. Furthermore, it includes two clear and explicitly stated methodologies to extrapolate current levels of mitigation effort into the future, taking on board where both current policies and nationally determined contributions (NDCs) take regional and global emissions by 2030. The first of these extrapolation methods uses a continuation of 2020-2030 emissions intensity of GDP trends in each region. The second method uses an equivalent carbon price that on its own would deliver the level of effort implied by current policies and NDCs in 2030, before extending this carbon price into the future at a growth rate in line with regional per capita incomes.

The results from this analysis are that global energy-related CO_2 emissions, which are currently ~33 $GtCO_2$, are heading to a range of 30-35 $GtCO_2$ by 2030, thereby indicating that emissions are unlikely to either grow or fall significantly in the coming decade, based on current levels of ambition. By 2050, current ambitions indicate a much broader range of potential emissions futures, in the range of 20-40 $GtCO_2$. In other words, it is uncertain whether current ambitions are commensurate with rising, falling or flatlining emissions in the coming three decades. Nevertheless, emissions are unlikely to rise to levels tracking the highest emissions-growth representative concentration pathways, such as RCP8.5 and RCP7.0, which typically see emissions in the range of 50-80 $GtCO_2$ by 2050. Whilst to some extent this is good news from a climate change perspective, it also highlights the significant extent of further effort required to pull emissions levels down towards the net-zero levels that many scenarios show them reaching by mid-century in Paris-compliant scenarios.

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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 7, called "Model Inter-Comparisons, Global Stocktake & Scientific Assessments", consists of designing and performing global modelled scenarios of future emissions pathways, using an array of global integrated assessment models and energy system models. Table 1 describes some of the key attributes of the models used in this work package. A fuller description, including key references, is available in PARIS REINFORCE deliverable D7.1 *('Documentation of global IAMs')*.

Table 1: Overview of global models subject to interlinkage/harmonisation efforts

		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 (GDP)**	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	Limited (bioenergy)	No	Yes	No (exogenous)	Yes (bioenergy)

Source: Deliverable D7.1

The overall work plan for PARIS REINFORCE is to first run this 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. The global modelling exercise, and its results, will then be used to provide inputs into two regional modelling work packages - Work Package 5

("Transforming Europe"), which focuses on European modelling, and Work Package 6 ("Promoting sustainable transitions across the globe"), which focuses on non-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 is shown in Figure 1.

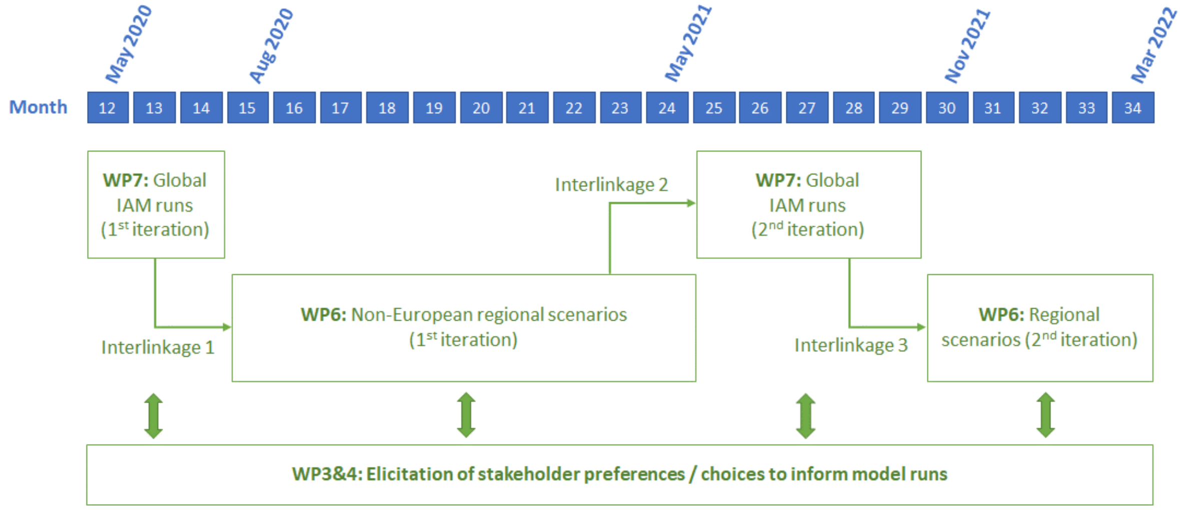

Figure 1: High-level workflow of interactions between global and non-European regional modelling

It should be noted that each stage of modelling depicted in Figure 1 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.

At the time of preparing this Deliverable (i.e. November 2020), PARIS REINFORCE has developed a detailed set of global IAM modelled scenarios to address the question "Where are global and regional greenhouse gas emissions heading?". The purpose of this modelling exercises is two-fold:

- To use as context for a series of European and non-European stakeholder workshops, to understand where and how different countries and regions can "close the emissions" gap between pathways that represent current levels of mitigation ambition and effort;

- To provide a novel and critical input into the scientific literature, ideally in time for inclusion in the Intergovernmental Panel on Climate Change's Sixth Assessment Report (to be published in 2022), on an area that has so far been relatively under-explored in recent years; namely, now that it is widely believed that the world is not on a "business as usual" pathway towards greater than 4°C of global warming (above pre-industrial levels) by 2100, where is it more likely to be heading (Hausfather and Peters, 2019)?

The method used, to inter-compare emissions and related outputs across a range of models, is at its heart not new. Model inter-comparisons have formed the basis of several IAM exercises in recent years, including in EU-funded projects such as AMPERE, LIMITS, ADVANCE and now PARIS REINFORCE, as well as its sister projects NAVIGATE, ENGAGE and LOCOMOTION.

However, as explained in Section 2, the level of depth and systematicity with which the models in PARIS REINFORCE are inter-compared, and more importantly scenario and input assumptions harmonised, is highly novel, going well beyond the state-of-the-art. Specifically, a number of modelling "storylines" and input parameters have been compared and where possible harmonised across the models, as set out in Figure 2.

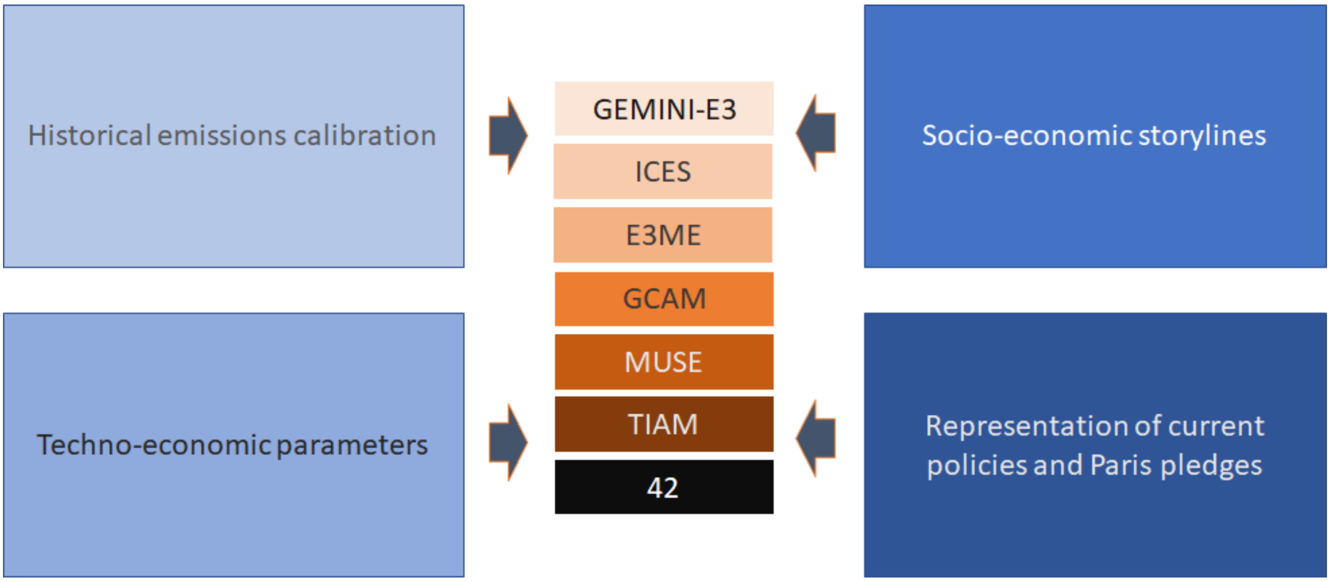

Figure 2: Key assumptions and parameters to harmonise into models for WP7 global IAM emissions pathways analysis

The rest of this report is set out as follows: Section 2 first reviews the literature on inter-comparisons of integrated assessment models, highlighting advances and remaining challenges; Section 3 details the steps taken to harmonise the input assumptions across the models, so as to move beyond the state-of-the-art; Section 4 presents the major results for the different scenarios across the different models; Section 5 discusses the key findings with regard to the differences between model structures; Section 6 concludes by highlighting future analytical research directions to shed further light on the implications of the inter-model similarities and differences.

2 A review of previous model inter-comparison exercises

Inter-comparisons of multiple integrated assessment models are a mainstay of the academic literature on climate change mitigation pathways. Model inter-comparison (MIP) studies are often undertaken—and justified—on the basis that using a wide range of different models can help better explore the future possibility space (Nikas et al., 2021). The large MIP studies used to form the basis of over 1,000 reference and mitigation scenarios that were assessed in the Intergovernmental Panel on Climate Change's fifth assessment report (IPCC, 2014a) include: the Energy Modeling Forum (EMF) 27 (Krey et al., 2013) (Kriegler et al., 2014); ADAM (Adaptation and Mitigation Strategies: Supporting European Climate Policy) (Edenhofer et al., 2010); RECIPE (Report on Energy and Climate Policy in Europe) (Luderer et al., 2012) and AMPERE (Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates) (Riahi et al., 2015). The years since the fifth assessment report have seen the emergence of further MIPs, including ADVANCE (Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies) (Luderer et al., 2016), CD-Links (Climate-Development Links) (Roelfsema et al., 2020), and a new tranche of Horizon 2020-funded projects including PARIS REINFORCE. In addition, numerous individual studies have utilised a range of model inter-comparisons, including to investigate emerging technologies like Direct Air Capture (DAC) (Realmonte et al., 2019), deep mitigation scenarios in line with limiting warming to 1.5°C (Rogelj et al., 2018), as well as the implications of different cost assumptions for a range of low-carbon technologies, as determined from expert elicitations (Bosetti et al., 2015).

Whilst it is undoubtedly true that MIPs such as those detailed above can indeed help explore a broader range of future possibilities by addressing the limitations of individual IAMs (Doukas et al., 2018), as well as increase the robustness of modelled findings, if these findings are similar across different types of models (Realmonte et al., 2019), it can also be argued that they provide too large a range of futures without sufficient explanation of what is driving these results (Gambhir et al., 2019). A notable example stems from the "cost of mitigation" as reported in the IPCC's Fifth Assessment Report, Working Group III, which reports a cost of achieving a below 2°C limit to global warming of between 1 and 4% of global GDP by 2030, between 2 and 6% of global GDP by 2050 and between 3 and 11% of GDP by 2100 (IPCC, 2014b). One high-profile criticism of the above-mentioned AMPERE project stems from the assertion that one key study within the project (Kriegler, Riahi, et al., 2015) does not make clear how different IAM outputs depend on their technology input assumptions and indeed what these assumptions are (Rosen, 2015). Strides have been made to better explain model characteristics (Kriegler, Petermann, et al., 2015), as well as better understand outputs of models and their key drivers (Koomey et al., 2019), including underlying technology costs (Krey et al., 2019).

Nevertheless, if modellers and policy officials are challenged to explain to their Ministers and other decision-makers what drives the huge diversity in model results, it is likely that they will not be able to say so with sufficient confidence. This is a critical limitation in MIPs, since undertaking the potentially considerable expenditure of mitigation of climate change, even to reap vast benefits in terms of avoided climate change damages, as well as co-benefits such as cleaner air and related health improvements, would be easier to justify if it were known why some models state mitigation costs a whole order of magnitude above others (Clarke et al., 2009; Clarke et al., 2014).

A major limitation of MIPs has been the lack of systematic harmonisation and communication of input assumptions across models, as already pointed out by Rosen (2015). Many exercises have harmonised specific sets of assumptions, such as around socio-economic storylines (O'Neill et al., 2014), availability of key technologies and energy resources like biomass (Riahi et al., 2015), costs and techno-economic parameters of specific technologies like DAC (Realmonte et al., 2019), as well as timing of mitigation action (Gambhir et al., 2017). But few, if any, have done so in a holistic manner, with a view to isolating as many inter-model differences as possible to model structures, as opposed to model input assumptions. This is by no means a trivial task, with Krey et al. (2019) noting that structural differences across models make it challenging and in fact infeasible to undertake a complete harmonisation. Nevertheless, as noted by Shiraki and Sugiyama (2020), more transparency and harmonisation of the underlying data behind the IAMs would be a valuable endeavour, as well as helping the modellers to "show their workings" (Pfenninger, 2017).

A further limitation of many MIPs is a perceived lack of credibility of results stemming from a lack of uniform calibration to base-year or recent historical out-turn data. This can lead to significant divergences between model results in the near-term, calling into question which, if any, of the modelled pathways present a realistic and feasible—or at least useful and actionable—picture of how emissions and related underlying changes to energy, agricultural and land systems might play out in the coming years. For example, in a landmark 2018 MIP study on 1.5°C-consistent emissions pathways under the full range of shared socio-economic pathway (SSP) storylines, there is already a divergence of emissions of the order of 10 $GtCO_2$ across scenarios by as early as 2020 (Rogelj et al., 2018). This can understandably be explained by the fact that the SSPs run from a base year of 2010 in many models, as well as genuine uncertainties in historical emissions. However, the lack of calibration to emissions data near the time of publication can potentially call into question the utility of the analysis, particularly with regard to the near-term emissions dynamics (including those in the coming decade, which—from the perspective of the Global Stocktake and Paris ratcheting mechanisms—will be increasingly critical in achieving a Paris-compliant emissions reduction pathway).

Section 3 describes the protocol for harmonising assumptions across a range of socio-economic, techno-economic and policy input variables, as well as around calibration to recent out-turn data, to help separate parameter variation from model variation.

3 Specific assumptions used in global modelling

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 bespoke data set constructed primarily from the second SSP (the "middle of the road") pathway (Fricko et al., 2017), 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 out-turn data.

Full details of the socio-economic parameters are taken from Deliverable D7.2 ("Interlinkages of global IAMs with the I^{2}AM PARIS platform") and reproduced in Table 2 below.

3.2 Base year emissions

The PARIS REINFORCE consortium compares against 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 (often 2015) will be compared to this emissions dataset to ensure they are closely aligned to the latest available CEDS data. Since each of the models requires different sector breakdowns of emissions, the CEDS data was only used to ensure models were consistent with CEDS without necessarily modifying the model-calibrated emissions data. At the time of assessment, we used an updated version of CEDS (Feng et al., 2019). At the time of writing, a version was released to 2019 (O'Rourke et al., 2020). For N_2O we used PRIMAP (Gütschow et al., 2019) and HFC, SF6, C2F6, and CF4 were based on WMO Ozone Assessment 2018 (WMO, 2018), as these were not included in CEDS.

3.3 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. Likewise, some technologies have not been deployed as fast as anticipated, such as Carbon Capture and Storage (CCS).

Table 2 summarises the key data sources for technoeconomic parameter harmonisation. Not all harmonisation parameters are applied in each model since some model structures do not allow the harmonisation of certain inputs. Also, for some models, the required effort for harmonising variables was deemed 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 either updated or checked their outputs for which harmonised variables. This list shows that socioeconomic input data is harmonised across all models, as well as CO_2 emissions that are output by the models. 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.

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	

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

3.4 Current policies and NDCs

As well as the socioeconomic, techno-economic and other parameters described above, all models in the PARIS REINFORCE consortium are set up in such a way that their reference scenarios reflect current levels of climate policy ambition in different world regions. This includes 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 is 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 (see Section 3.5).

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). Critically, we update the CD-Links database with assumptions on policies from more up-to-date sources, notably the IEA policies database (IEA, 2020) – see Appendix for the full list of updated and extended policies over and above the CD-Links database.

3.5 Scenario protocol to extrapolate current ambitions beyond 2030

As well as setting the scene for the scenario development with harmonised socio-economic and techno-economic input parameters as detailed in Sections 3.1-3.4 above, the modelling protocol for developing global reference scenarios includes an explicit, and harmonised, process for interpreting current ambition beyond 2030.

This is done in two principal ways, for both scenarios that reflect current policies implemented to 2030, and scenarios that reflect NDC Paris pledges to 2030:

1. The change in CO_2 emissions intensity of GDP in each region represented by the global models, over the period 2020-2030, is extended forward until either 2050 or 2100, depending on each model's time-horizon (following Fawcett et al., 2015). Combined with the projections for regional GDP as obtained from the data highlighted in Section 3.1, this allows a specification of the long-term trend in CO_2 emissions over the period 2030-2050/2100.
2. A 2030 carbon price is calculated, such that this price achieves (in each region of each model) the level of emissions reduction effort achieved by the implementation of either NDCs or current policies by 2030. This carbon price is then extended beyond 2030, growing at the rate of GDP per capita growth in region, so as to simulate a "constant" economic burden from carbon pricing, as proxied by the ratio of carbon price to per capita income over time. This extended carbon price is then applied to each region in each model to determine the emissions trajectory beyond 2030. The development of energy/agricultural and land systems is then simulated under both current policies and (in the case of the NDC scenarios) also NDCs to 2030, with current policies assumed to extend beyond 2030 at a "constant" level[1], as well as being constrained by the emissions trajectory under the post-2030 carbon price extrapolation. Carbon

[1] The interpretation of what constitutes such a "constant" level of current policy effort differs across models. For example, in energy technology-rich models (e.g. TIAM, MUSE, GCAM) current policies are applied according to minimum levels of energy efficiency in vehicles, as well as minimum shares of renewables, according to how the current policy is specified. In more financial models (e.g. ICES, GEMINI-E3) the current policies are extended as constant subsidy levels for particular technologies.

price extrapolation in this way follows previous studies, which also extend carbon prices outwards, such as by the discount rate (for example, Napp et al., 2019). Figure 3 shows diagrammatically the protocol for extending current ambitions, in 2030, post-2030 using carbon prices.

The methodology behind each extrapolation method is described in further detail in each of the following two sub-sections.

3.5.1 Extending post-2030 effort on the basis of emissions intensity trends

The first method by which post-2030 emissions changes that are consistent with pre-2030 efforts can be interpreted is simply through extrapolating rates of change of emissions into the future. Within this basic principle, there are at least two different ways of doing so:

1. By maintaining the pre-2030 rate of change of absolute emissions in each country and region
2. By maintaining the pre-2030 rate of change of emissions intensity (i.e. emissions per unit GDP) in each country and region.

Whilst both methods have merit, here we focus on the second method. This is to capture the fact that several major regions, such as China and India, have expressed their Nationally Determined Contributions (NDCs) precisely in these emissions intensity reduction terms, and could well continue to do so following any update or extension of these targets into the future (noting that China's recent net-zero announcement serves as both an absolute and intensity target—i.e. net zero emissions and net zero emissions intensity by 2060). More importantly, we assert that the essential challenge of mitigation, which is implicitly agreed across all countries in current climate change actions, is one of *decoupling* emissions from economic growth. At its heart this involves reducing to an eventual net zero level (and potentially a net negative level) the emissions intensity of economic activities. It is through tracking emissions intensity that we can most readily judge the extent to which countries are on track to achieve this long-term goal.

Figure 3 shows the specific protocol for extending effort beyond 2030 using the emissions intensity extrapolation method for both current policy and NDC scenarios. First, a full representation of current policies is applied in each major region represented by each model, to 2030, using data on current policies as detailed in Section 3.4 above. Next, these current policies are simulated as "constant" from 2030 onwards. This simulation depends on the models in question:

- For models that have detailed representations of energy systems (MUSE, TIAM, GCAM), current policies are simulated as constraints. For example, where current policies represent the achievement of a minimum share of renewables in power generation, or minimum vehicle efficiency standards, then these policies are kept constant (i.e. a constant minimum share of renewables, or constant minimum vehicle efficiency) beyond 2030. Note that the renewables shares are not kept constant, but rather at a constant minimum bound—this allows the models to simulate over-achievement against these policy targets, if for example the cost-competitiveness of renewables drives them to do so.
- For models that are more representative of financial/monetary metrics, such as the computable general equilibrium (CGE) models ICES and GEMINI-E3, policies are more commonly applied as minimum subsidy levels to specific low-carbon technologies, so as to encourage their take-up. In such cases, these subsidies are held constant in the period beyond 2030, to simulate a continuation of policy support for these technologies.

After the implementation of current policies to 2030 and beyond, the emissions intensity between the years 2020 and 2030 is calculated for each region represented by each model, and the compound average annual rate of change in intensity over this period is then calculated. The resulting annual rate of change of emissions intensity is then applied for all periods after 2030 for each model. We note that this precludes any model reaching a net zero level of emissions, since emissions can only decline by a fixed percentage on previous years' emissions post-2030. Some models (GEMINI-E3, ICES, E3ME and 42) only simulate until mid-century, whereas others (TIAM, GCAM, MUSE) run until 2100. In each case, the emissions intensity extrapolation is undertaken until the end of the simulation period. The emissions resulting from this emissions intensity extrapolation is then applied as an upper bound of emissions levels within each region in each model. Models can in theory produce emissions pathways *below* this emissions level, if the underlying system dynamics see rapid substitution of low-carbon for high-carbon technologies, for example. It should be noted that this method does not allow any reversal in emissions intensity of economic activity over time, for example in response to economic shocks, which could reverse decarbonisation efforts.

The basic methodology of emissions intensity extrapolation is the same for both the current policies and NDC scenarios. In the case of the NDC scenarios, as shown in the bottom panel of Figure 3, after implementing current policies to 2030 and then extending them beyond 2030 as described above, the NDC targets for each region represented by each model are then applied for the year 2030. Where NDC targets are more ambitious than the current policies (in terms of the level of 2030 emissions achieved), this results in a lower level of emissions in 2030, and a different rate of emissions intensity change over the period 2020-2030, compared to the current policies scenarios. Where NDCs are *less* ambitious than current policies, the current policy level is taken to be entirely coincident with the NDC level. As such, for these regions, the NDC and current policies scenarios are essentially the same.

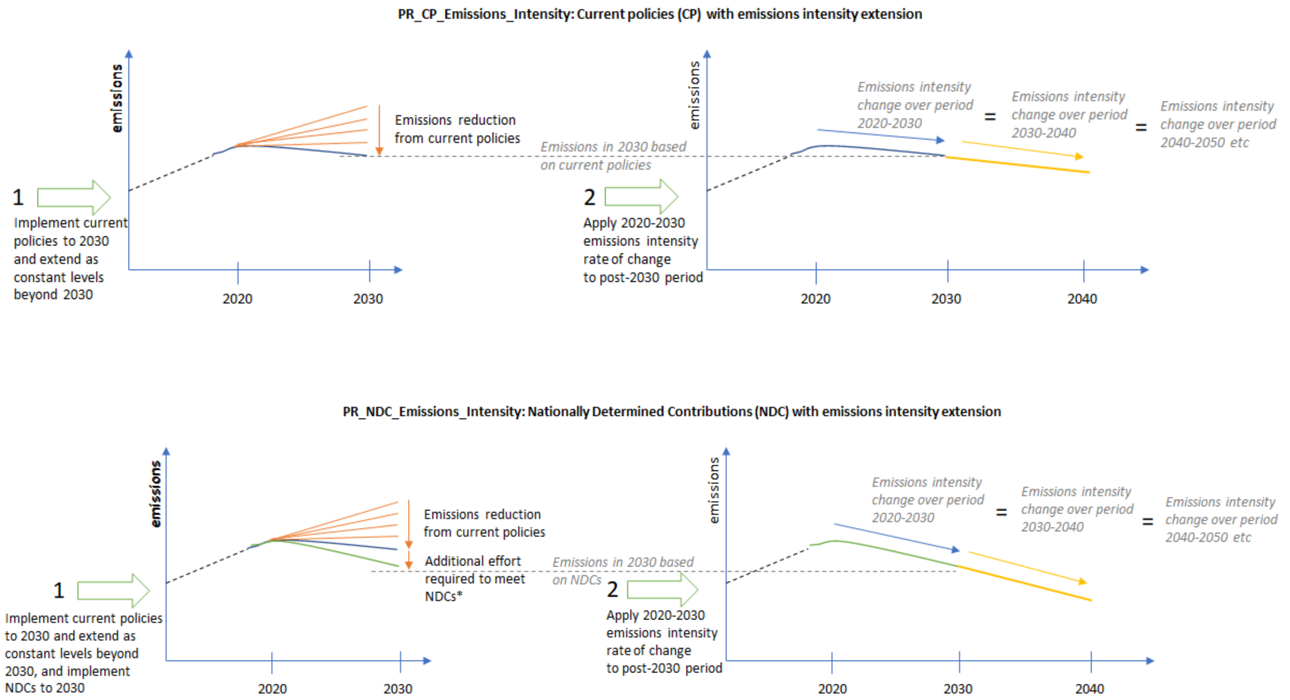

Figure 3: Graphical representation of emissions intensity extrapolation method, for Current Policies (top panel) and Nationally Determined Contributions (bottom panel) scenarios.

**For most regions additional effort will be represented by the carbon price required (on top of current policies) to meet NDC targets. If for any region, current policies outperform NDCs (i.e. current policies lead to larger emissions reductions than those set out by NDCs), emissions are defined by current policies, not the NDC targets. Note that emissions intensity caps in Step 2 are set as an upper bound, NOT a fixed level that every model must meet.*

3.5.2 Extending post-2030 effort on the basis of carbon prices

A common proxy for policy "effort" is the carbon price, which in energy systems and integrated assessment models represents (at its most basic) the carbon "tax" that would need to be placed on carbon-intensive fuels in order to incentivise a shift away from carbon-intensive to low-carbon technologies, such that a given emissions pathway is achieved. This is commonly also known as the "shadow" price of carbon, which reflects the intrinsic or true cost of carbon emissions in a cost-optimising model achieving a particular emissions-constrained pathway.

Here we use the principle that any carbon tax that achieves either current policy or NDC levels of emissions in 2030 is representative of the degree of policy effort at that point in time. Extending this carbon price out beyond 2030 is therefore one way of representing the extension of policy effort beyond 2030, as an alternative to extending emissions intensity trends in the way described in Section 3.5.1 above.

There are many potential choices of how to extend carbon prices:

1. They could be kept constant (in real i.e. non-inflated) terms, to represent a constant level of real cost on carbon-intensive fuels in each economic region represented by each model;
2. They could instead be inflated, in line with economic growth, to represent a constant incidence relative to the total growth in income in each region.
3. They could be inflated in line with per-capita economic growth, to reflect that in some regions (particularly sub-Saharan Africa) growth will be significantly driven by population increases, rather than purely per-capita income increases.
4. They could be inflated by a discount rate over time, to reflect the constant present value of carbon prices over time.

Whilst the latter method has been employed in recent IAM model inter-comparison studies (see for example Napp et al., 2019), here we use the third method (i.e. to increase the carbon price at the rate of per-capita GDP growth in each region), to reflect constant relative to income effort post 2030.

This carbon price extrapolation method is applied to both the current policies and NDC scenarios, as detailed in Figures 4 and 5 respectively. For current policies scenarios (see Figure 4), the carbon price in each region in each model is calculated for 2030 such that it achieves the same level of 2030 emissions as the current policies alone. The emissions beyond 2030 are then calculated by applying the increasing carbon price in the post-2030 period. This emissions level then forms an upper bound for each region in each model, such that when current policies are applied, and extended beyond 2030, the models' emissions are also bounded by the emissions trajectory consistent with the extrapolation of the carbon price beyond 2030.

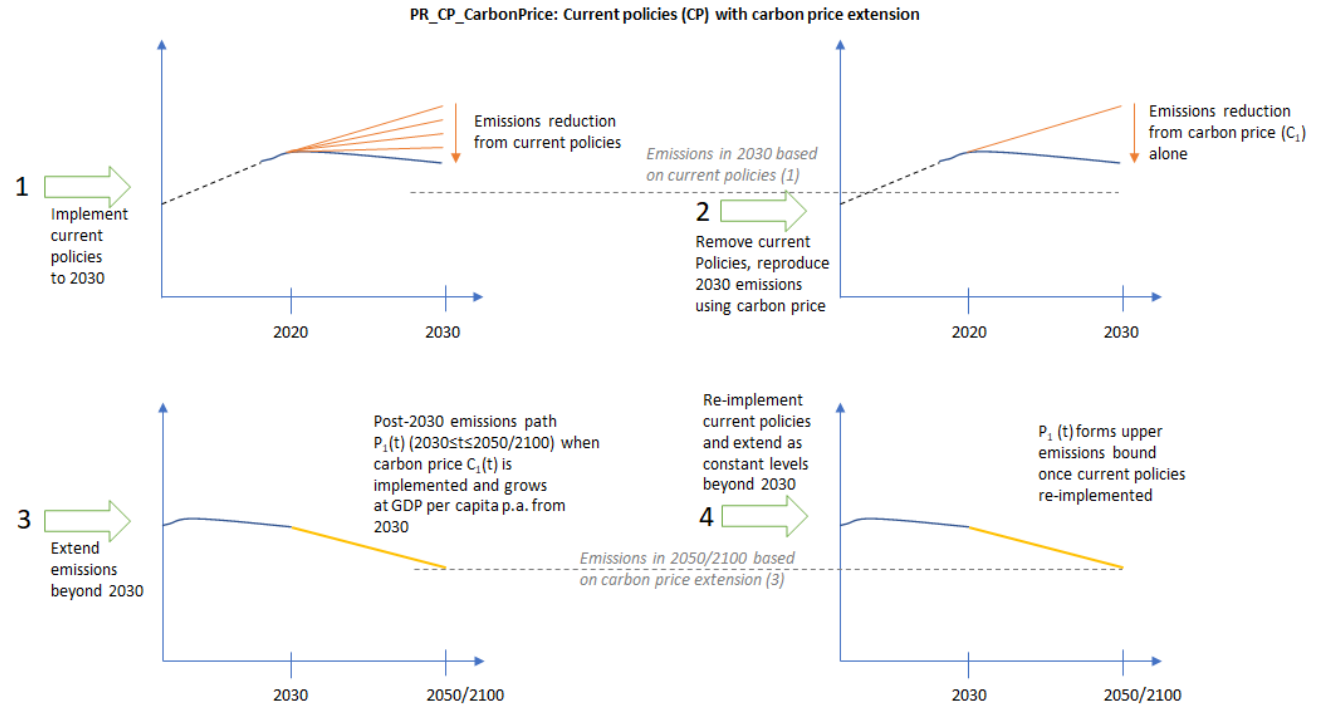

Figure 4: Graphical representation of carbon price extrapolation method, for Current Policies scenarios.

For NDC scenarios (see Figure 5), the carbon price in each region in each model is again calculated for 2030 such that it achieves the same level of 2030 emissions as the NDCs, in those regions where the NDC targets are more ambitious than current policies (i.e. result in a lower level of emissions in 2030). The emissions beyond 2030 are again calculated by applying this increasing carbon price in the post-2030 period, and this emissions level again forms an upper bound for each region in each model. For those regions where the NDC target is less ambitious than the current policies, the carbon price to achieve the current policies alone is calculated, and extended beyond 2030, essentially resulting in the same scenario as per the current policies scenario for that region.

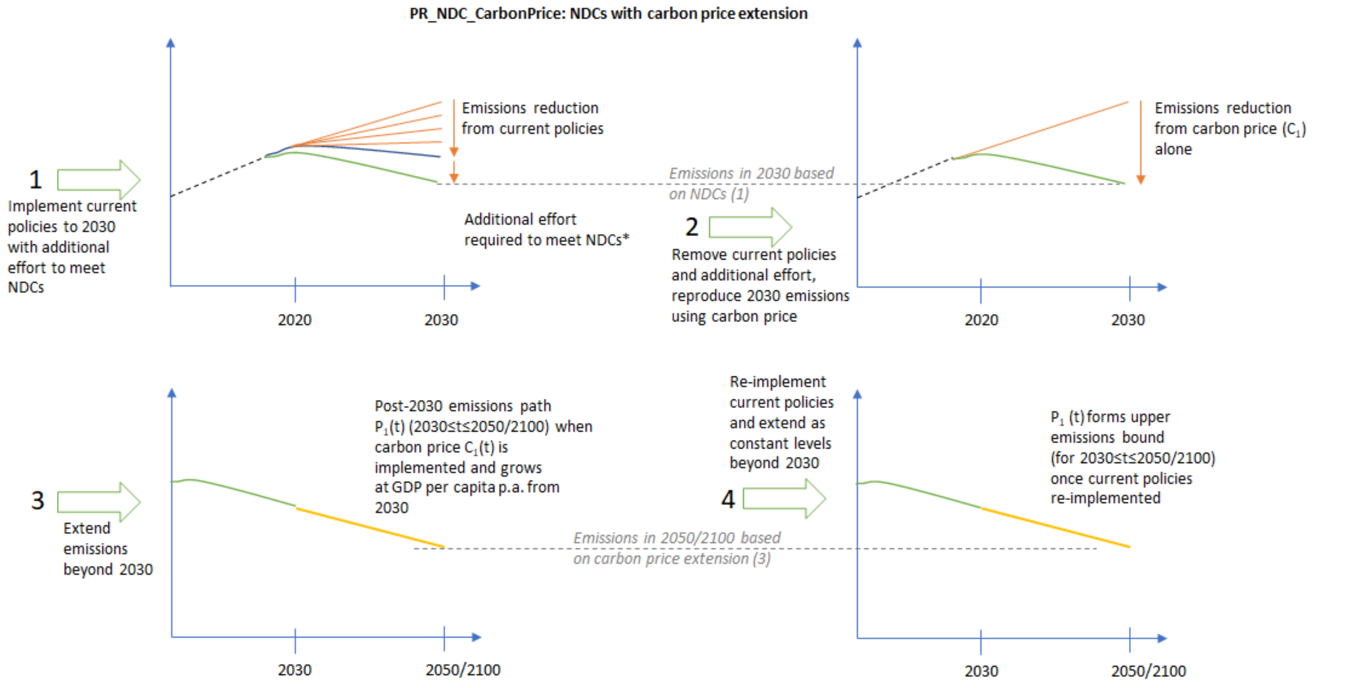

Figure 5: Graphical representation of carbon price extrapolation method, for NDC scenarios.

**For most regions additional effort will be represented by the carbon price required (on top of current policies) to meet NDC targets. This carbon price is independent of the carbon price (C_1) in 2. If for any region, current policies outperform NDCs (i.e. current policies lead to larger emissions reductions than those set out by NDCs), emissions are defined by current policies, not the NDC targets.*

4 Model inter-comparison results

Figure 6 shows the global energy-related CO_2 emissions from each model participating in this exercise, for each scenario described in Section 3. In contrast to recent model inter-comparison exercises, which have used a wider range of sources for historical emissions data than is employed here (Roelfsema et al., 2020), there is a relatively narrow range of emissions for 2020 (~2 GtCO2, compared to over 10 $GtCO_2e$ in Roelfsema et al.'s "no new policies" and "national policies" scenarios, though noting the latter covers all GHGs, rather than just energy-related CO_2 as in this study, with land use emissions in particular adding a considerable degree of uncertainty).

As is immediately clear, there is a wide potential range of future energy CO_2 pathways that derive from the different models and assumptions. By 2030, the range across the models is approximately 31-35 $GtCO_2$, compared to 31.5-32.5 in 2015 and 32-33 $GtCO_2$ in 2020, which implies that—broadly speaking—emissions are expected to remain flat over the coming decade, assuming the implementation of current levels of ambition as embodied in current policies and current NDC pledges. This does not consider any COVID19-related changes to emissions. By mid-century, emissions are in a much larger range of approximately 20-40$GtCO_2$, in many cases (particularly where effort is extrapolated post-2030 using carbon prices) with emissions steadily rising, and in other cases (particularly emission intensity extrapolation scenarios) with emissions falling. Emissions projected by the models that run until the end of the century are in an even larger range of 17-43 $GtCO_2$.

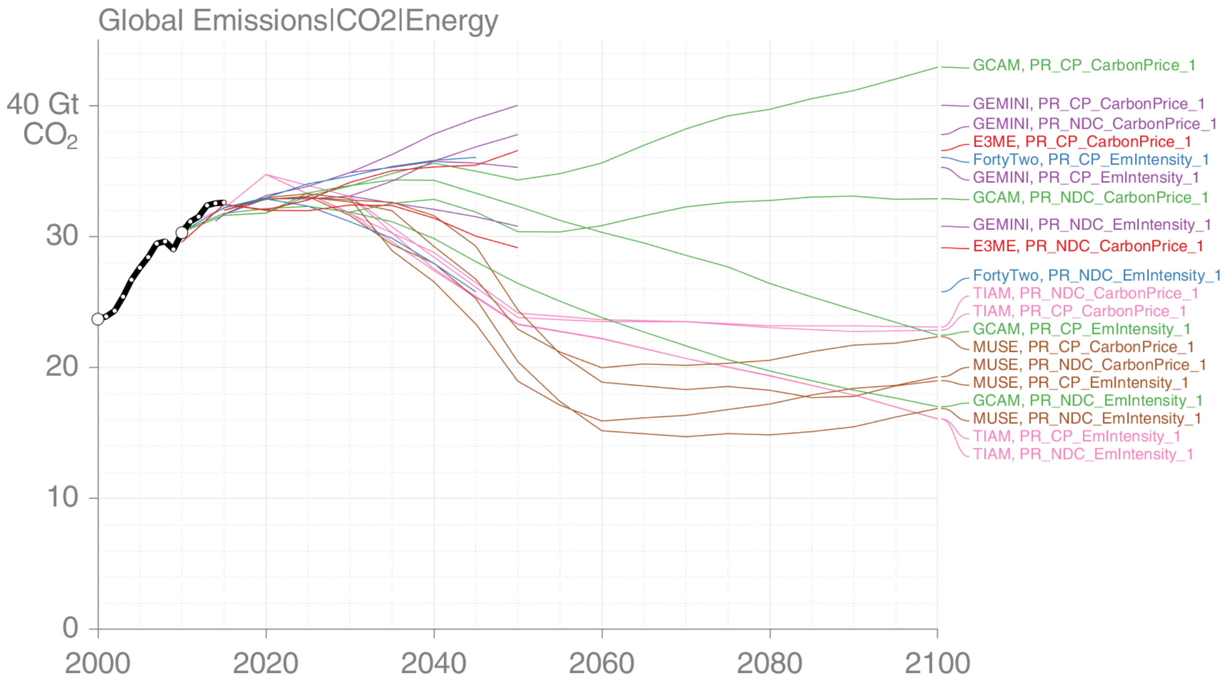

Figure 6: Global energy-related CO_2 emissions projections across all models in all scenarios

It can be seen from Figure 6 that the method used to extrapolate emissions (i.e. the interpretation of how effort is continued post-2030) is more influential to overall emissions in the post-2030 period, compared to whether current policies or NDCs are used to set the 2030 emissions level. This is demonstrated by the fact that the majority of the higher post-2030 emissions pathways use the carbon price method for post-2030 extrapolation, whereas the majority of the lower emission pathways use the emissions intensity extrapolation method, regardless of whether they are NDC or current policy scenarios.

Figure 7 shows this phenomenon more clearly, by separating out the models to show how each model responds for each scenario. This more clearly shows how the carbon price extrapolation scenarios result in higher post-2030 emissions, compared to the emissions intensity extrapolation scenarios. Figure 7 also highlights that emissions in NDC scenarios are lower than emissions in current policies scenarios in 2030 in all models, which is a consequence of the way NDC scenarios have been defined: when countries' current policies exceed (in terms of ambition) their NDC pledges, the NDC scenarios are equal to the current policy scenarios.

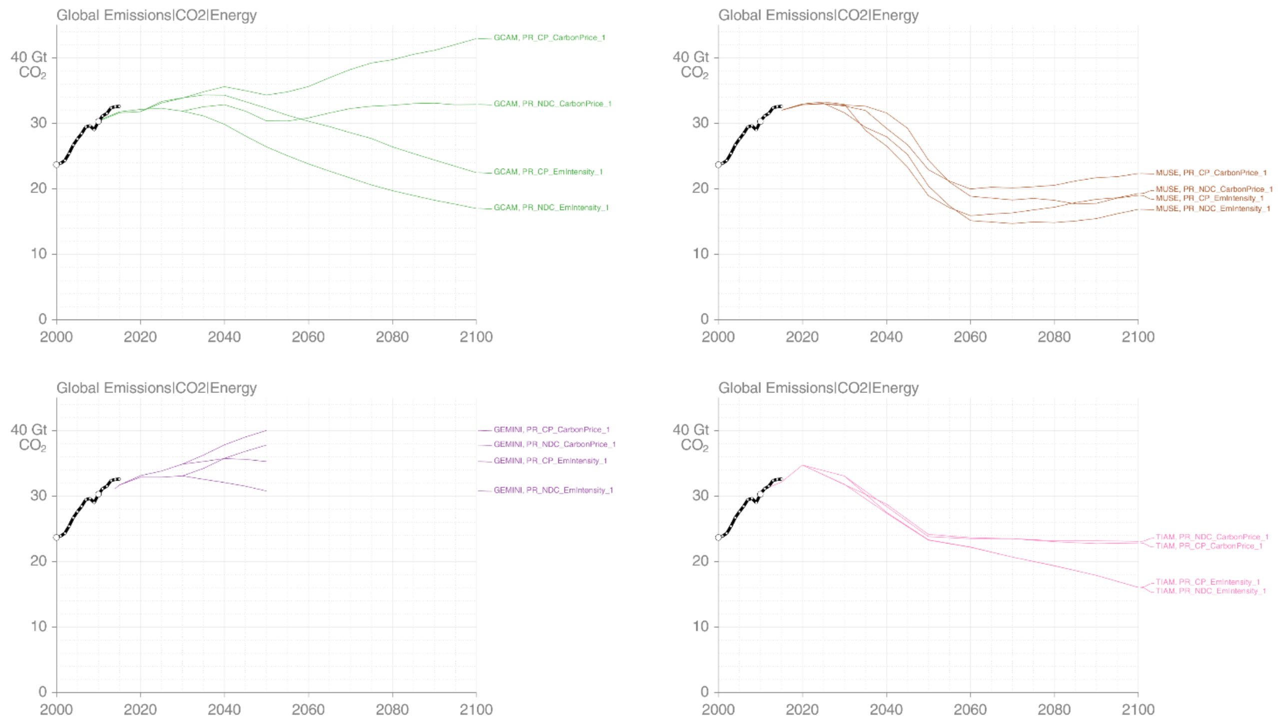

Figure 7: Global energy-related CO_2 emissions for four models in all scenarios

The implication of the carbon price extrapolation resulting in weaker emissions reductions than emissions intensity is that at a global level, in order to maintain the 2020-2030 emissions intensity rate of reduction experienced under either the current policies or NDC scenarios over this period, a rate of carbon price increase in excess of that assumed in this analysis (i.e. in line with GDP per capita growth) would be necessary. As such, continuing emissions intensity reductions are likely to require increasing levels of policy support and overall mitigation effort going forward.

Figure 7 additionally demonstrates that, in spite of broad harmonisation of model inputs, for both socio-socioeconomic and techno-economic inputs, as well as policy and NDC target simulation and uniformly-applied methodologies to extrapolate post-2030 effort, there remain significant differences between models. Some models (e.g. GCAM) generate a much larger range than others (e.g. MUSE or TIAM). This is true both for 2050 and 2100. In fact, GCAM covers the entire range of emissions generated by all other models in 2100. The spread in emissions is determined by (i) the difference in emissions between NDCs and current policies, and (ii) the difference in emissions between different extrapolation methods.

Differences between current policies between different models result from the non-uniform response of models to the different policies, as well as the way in which some policies are implemented. As discussed in Section 3.5, different models' underlying structure, as well as level of technological granularity, means that current policies must be implemented in different ways in some circumstances. For example, technology-rich models such as TIAM and GCAM see policies implemented in terms of minimum shares of technologies in specific sectors (e.g.

renewables in power generation) or minimum efficiency levels in sectors such as road transport. These are direct interpretations of the policies as written in national policy documents. More financial-based models (primarily computable general equilibrium models such as ICES and GEMINI-E3) are better at representing such "forced-on" policies as minimum subsidy levels, which result in the desired shares of technologies in the sectoral energy mix. These differences in model structure mean that strict harmonisation is not necessarily possible.

Table 3 shows the change in 2030 emissions that result from successive harmonisation steps between three example models in this exercise. An initial range of 5.5 GtCO_2 in the no-policy baselines is reduced to less than 2 GtCO_2 as a result of socio-economic, technology cost and policy (including 2019 emissions) harmonisation.

Table 3: Global CO_2 emissions in three models as a result of different harmonisation steps

Energy-related CO_2 emissions (MtCO_2)	MUSE	GEMINI-E3	GCAM
Baseline	41,871	46,417	47,256
Socio-economic	42,039	44,443	46,911
Cost	41,799	44,433	42,573
Policies	37,278	38,818	39,110

Regarding differences between models according to the extrapolation method used, it is clear that the emissions intensity trend differences will derive from 2030 emissions differences, since the 2020-2030 period's emissions intensity trend is what drives the trend in the post-2030 period. For carbon prices, however, this comes down to models' differing mitigation responses to carbon prices given underlying technology and fuel costs in the models. A key difference between models is that of technology "substitutability", with some bottom-up engineering models like TIAM showing a more elastic response to carbon pricing, compared to computable general equilibrium models like GEMINI-E3 (see Figure 7), which characterise technologies within a more rigid macro-economic structure. The EU FP7 AMPERE project's diagnostics of different models did not support such a simplistic dichotomy, however, with a focus on technological options being also a critical factor (Kriegler et al., 2014).

Mid-century intra-model emissions that result from both the 2030 scenario (i.e. current policies or NDCs) and the post-2030 extrapolation method vary from a relatively small range (e.g. TIAM – less than 3 GtCO_2) to a relatively large range (42 – greater than 10 GtCO_2), as shown in Figure 8.

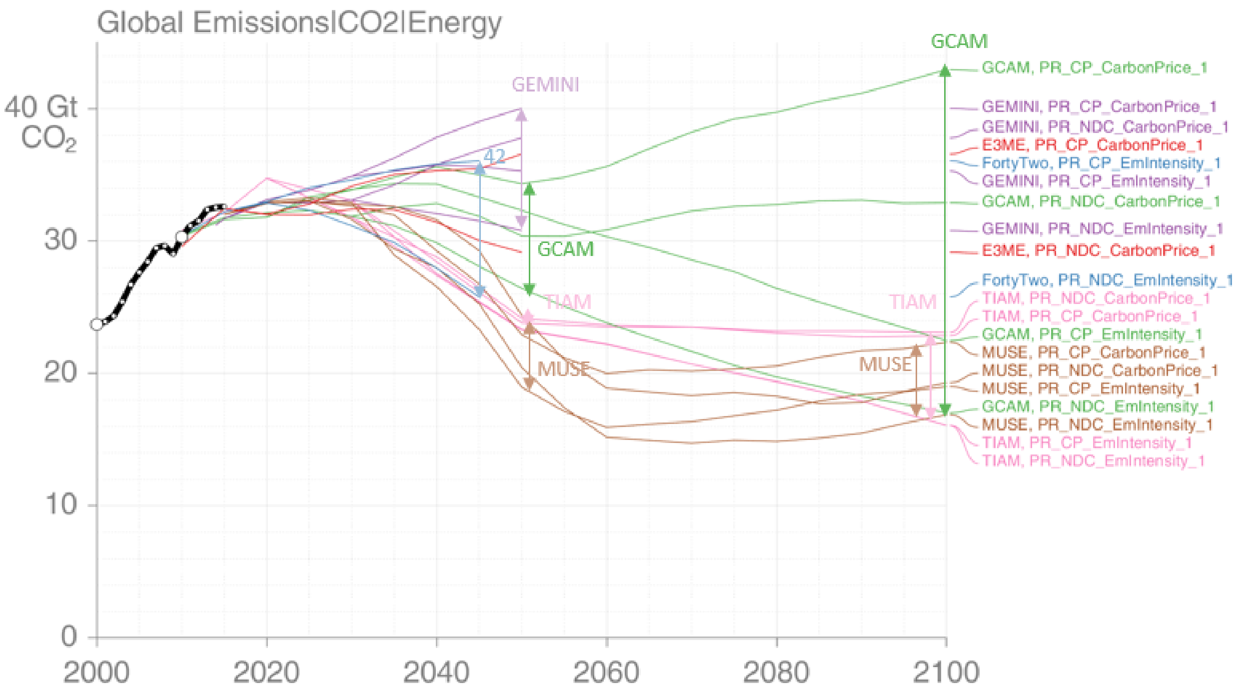

Figure 8: Intra-model ranges in global energy-related CO_2 emissions

Nevertheless, the range of emissions, both within models across the different scenarios that each model covers, as well as across all models and scenarios, still provides a usefully narrowed-down picture of where emissions are heading compared to pure "what if" scenario approaches (i.e. those that project emissions under different end-point assumptions or normative trends, such as "business as usual" or "sustainability" trends). To illustrate this point, Figure 9 compares this exercise's modelled range of energy-related CO_2 emissions with that from the IEA's 2019 World Energy Outlook (IEA, 2019).

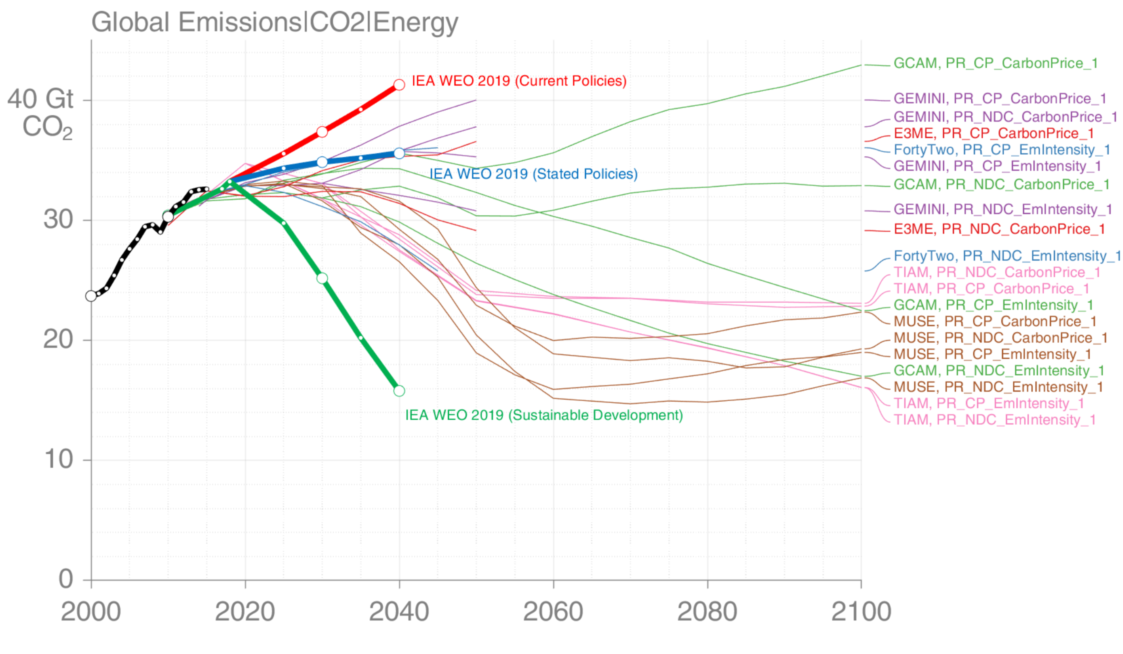

Figure 9: PARIS REINFORCE global energy-related CO_2 emissions compared to IEA World Energy Outlook

Of particular note is that the 2030 energy-related CO_2 emissions in our study's scenarios are significantly below the IEA's Current Policies scenario, as well as (in most cases) below the IEA's Stated Policies scenario. The latter differs from the former in that it includes policies that have been stated, but not yet implemented, in each country. Importantly, our scenarios show some degree of filling of the approximately 10 $GtCO_2$ "ambition" gap (Roelfsema et al., 2020) between the current or stated policies and the IEA's Sustainable Development scenario, which is in line with keeping warming below 2°C.

The IEA's analysis is not sufficiently transparent to assess why such a difference exists between its Current and Stated Policies scenario and our analysis. However, the IEA has historically shown chronically conservative estimates (Mohn, 2020) for both renewables costs (Gambhir, 2017) and renewables deployment levels (Hoekstra, 2017) and this is likely to be an important differentiator between its current policies projections and ours.

Turning to regional emissions variations, our results show significant differences across the models and scenarios for different regions, as demonstrated by Figure 10. Of note is the influence of the different emissions pathways through the 2020s in GCAM and GEMINI-E3, compared to TIAM and MUSE in India. Extrapolating the implied levels of effort to 2100 gives rise to a range of almost 6 $GtCO_2$ (2-8 $GtCO_2$) in India by 2100. Clearly, the way in which emissions pathways develop in the models through the 2020s leads to significant differences in emissions beyond 2030, depending on the extrapolation method used. The ranges of emissions in the four largest emitting regions (USA, EU, China and India), are responsible for a significant portion of the global range of emissions by the end of the century of 28 $GtCO_2$. Of note is that the EU's emissions projection range is narrower than for the other three major emitting regions, falling to around 2 $GtCO_2$ by 2100, with only one model (MUSE) showing a significantly different value to this, at 0.5 $GtCO_2$ by 2100. MUSE's agent-based nature implies inertia in the system as the agents do not react so rapidly to low prices, resulting in the need for relatively high carbon prices in the near-term (i.e. to meet 2030 ambitions) and further leading to higher extrapolated carbon prices in the longer-term, which leads to rapid decarbonisation as technology stocks are renewed.

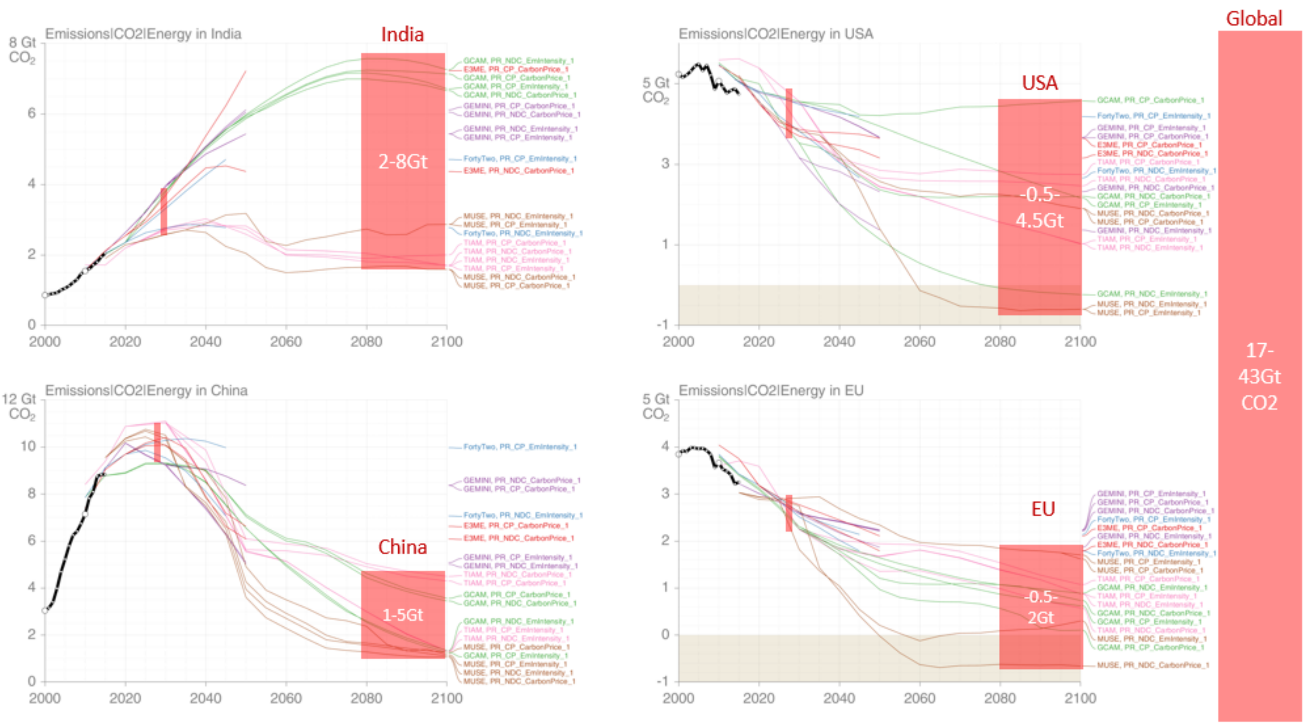

Figure 10: Regional energy-related CO_2 emissions in all models and all scenarios

5 Conclusions

This paper has presented the first global model inter-comparison analysis in the PARIS REINFORCE project, which will form the basis of much of the subsequent scenario design and input database production for both global and regional modelled analyses of mitigation pathways. The focus of this exercise—on reference or, as we have termed them, "where we are heading" scenarios—has been designed so as to fill an important gap in the scientific literature around realistic reference scenarios that reflect current levels of national and regional (and therefore global) ambition.

The high-level results from this analysis are that global energy-related CO_2 emissions, which are currently ~33 $GtCO_2$, are heading to a range of 30-35 $GtCO_2$ in 2030, thereby indicating that emissions are unlikely to either grow or fall significantly in the coming decade, based on current levels of ambition. By 2050, the range indicated by current ambitions, using both NDCs and current policies to represent current ambitions to 2030, and extrapolation of both carbon prices and emissions intensities beyond 2030, indicates a much broader range of potential emissions futures, in the range of 20-40 $GtCO_2$. In other words, it is uncertain whether current ambitions are commensurate with rising, falling or flatlining emissions in the coming three decades. Nevertheless, emissions are unlikely to rise to levels tracking the highest emissions-growth representative concentration pathways, such as RCP8.5 and RCP7.0, which typically see emissions in the range of 50-80 $GtCO_2$ by 2050, and also clearly fall short of any pathway that limits warming to the Paris Agreement 1.5°C temperature level with net-zero CO_2 emissions around mid-century. Hence, whilst to some extent current ambitions represent some good news from a climate change perspective, it also highlights the significant extent of further effort required to pull emissions levels down towards the net-zero levels that many scenarios show them reaching by mid-century in Paris-compliant scenarios.

The inter-model variation demonstrated in this exercise, whilst rather smaller than comparable recent studies, is still notable, and leaves considerable room for uncertainty. Much of this stems from the differing model structures, given a reasonably strong degree of harmonisation of socio-economic and techno-economic assumptions across the models. A significant amount of further analysis is required to understand the precise drivers of this inter-model structural variation. This will be included in the second global modelling round in the PARIS REINFORCE project, which will focus on developing realistic global mitigation pathways closely co-created with, and informed by, both European and a range of non-European stakeholder engagement exercises and subsequent regional modelling analyses.

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Appendix – list of additional and updated policies added to the CD-Links database

Country	Policy interpretation	End Year	Value	Unit
Brazil	Electricity capacity of Solar	2025	3.5	GW
Brazil	Electricity capacity of Wind	2025	27.1	GW
Brazil	Electricity capacity of Small hydro	2025	7	GW
Brazil	Electricity capacity of Hydro	2025	116.7	GW
European Union	Share of renewables in energy use in rail and road transport (biofuels and renewable electricity)	2030	14	%
European Union	Share of advanced renewables (advanced biofuels and biogas) in energy use in rail and road transport	2025	1	%
European Union	Share of advanced renewables (advanced biofuels and biogas) in energy use in rail and road transport	2030	3.5	%
European Union	Fuel efficiency of Light-duty vehicles (passenger vehicles)	2025	80.75	g CO2/km
European Union	Fuel efficiency of Light-duty vehicles (passenger vehicles)	2030	61.75	g CO2/km
European Union	Fuel efficiency of Light-duty vehicles (light commercial vehicles)	2025	124.95	g CO2/km
European Union	Fuel efficiency of Light-duty vehicles (light commercial vehicles)	2030	102.9	g CO2/km
European Union	Economy-wide Emissions from 1990	2030	-40	%
European Union	Share of renewables (final energy consumption)	2030	30	%
European Union	Energy consumption reduction from baseline	2030	-32.5	%
India	Reduce cooling energy requirements	2037	20-40	%
India	Add decentralised solar power capacity	2022	25	GW
India	Fuel consumption standard for 3.5 tonnes weight new vehicles	2018	7	l/100km
India	Fuel consumption standard for 7.5 tonnes weight new vehicles	2018	9	l/100km
India	Fuel consumption standard for 12 tonnes new vehicles	2018	12	l/100km
Russian Federation	Electricity capacity of Solar	2024	2238	MW
Russian Federation	Electricity capacity of Wind	2024	3416	MW
Russian Federation	Economy-wide Electricity intensity from 2018	2024	-8	%
Russian Federation	Economy-wide Electricity intensity from 2024	2035	-17.5	%
Russian Federation	Economy-wide intensity of heat from 2018	2024	-3	%
Russian Federation	Economy-wide intensity of heat from 2024	2035	-6	%

Russian Federation	Electricity capacity of Small hydro	2024	210	MW
Russian Federation	Gas flaring limit	2024	10	%
Russian Federation	Gas flaring limit	2035	5	%
Russian Federation	Economy wide Electricity losses	2024	9.8	%
Russian Federation	Economy wide | Electricity losses	2035	7.3	%
Russian Federation	Electricity generation from CHP	2024	33	%
Russian Federation	Electricity generation from CHP	2035	40	%
Russian Federation	CH4 consumption in Transport	2024	2.7	bcm
Russian Federation	CH4 consumption in Transport	2035	45200	bcm
United States of America	Fuel efficiency of Light-duty vehicles	2020	155.34	g CO2/km
United States of America	Fuel efficiency of Light-duty vehicles	2025	131.73	g CO2/km
United States of America	Fuel efficiency of Light-duty vehicles	2030	131.73	g CO2/km
United States of America	Fuel efficiency of Light-duty vehicles Trucks	2020	220.59	g CO2/km
United States of America	Fuel efficiency of Light-duty vehicles Trucks	2025	178.33	g CO2/km
United States of America	Fuel efficiency of Light-duty vehicles Trucks	2030	178.33	g CO2/km
United States of America	Electric and plug-in vehicles Production	2020	582000	Number/year
United States of America	Electric and plug-in vehicles Production	2025	1334000	Number/year
United States of America	Electric and plug-in vehicles Production	2030	1754000	Number/year
United States of America	Share of clean energy (renewables, nuclear, gas w/ CCS)	2020	36	%
United States of America	Share of clean energy (renewables, nuclear, gas w/ CCS)	2025	38	%
United States of America	Share of clean energy (renewables, nuclear, gas w/ CCS)	2030	42	%