PARIS REINFORCE

31/05/2021

D6.3 First round of nationally modelled low-carbon pathways outputs

WP6 – Promoting sustainable transitions across the globe

Version: 1.00R

www.paris-reinforce.eu

Disclaimer

Copyright Message

Grant Agreement Number	820846	Acronym	Paris Reinforce
Full Title	Delivering on the Paris Agreement: A demand-driven, integrated assessment modelling approach		
Topic	LC-CLA-01-2018		
Funding scheme	Horizon 2020, RIA – Research and Innovation Action		
Start Date	June 2019	Duration	42 Months
Project URL	https://www.paris-reinforce.eu/		
EU Project Officer	Frederik Accoe		
Project Coordinator	National Technical University of Athens – NTUA		
Deliverable	D6.1 Non-EU model documentation		
Work Package	WP6 Promoting sustainable transitions across the globe		
Date of Delivery	Contractual: 31/05/2021	Actual: 31/05/2021	
Nature	Report	Dissemination Level	Public
Lead Beneficiary	Grantham Institute, Imperial College London		
Responsible Author	Ajay Gambhir	Email	a.gambhir@imperial.ac.uk
		Phone	+44 20 7594 6363
Contributors	Jorge Moreno, Dirk-Jan van de Ven (BC3); Kathleen Vaillancourt, Marie Pied (IEECP); Maurizio Gargiulo, Rocco de Miglio, Alessandro Chiodi, Gabriele Cassetti (E4SMA); Andrey Kolpakov, Alexander Shirov (IEF-RAS); Xi Yang (CUP); Sara Giarola (Grantham Imperial); Alexandre Koberle (Grantham Imperial); Shivika Mittal (Grantham Imperial); Alexandros Nikas (NTUA), Ben McWilliams, Georg Zachmann (Bruegel)		
Reviewer(s):	Marc Vielle (EPFL); Baptiste Boitier (SEURECO); Alexandros Nikas (NTUA)		
Keywords	Energy models; IAMs; mitigation; major emitters; non-European countries		

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

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, in May 2021, and then updated in February 2022 to include the stakeholder-informed modelling analysis for all relevant regions (which was delayed due to COVID-19).

2. Dissemination and uptake

This deliverable will serve as a document to report the first round of mitigation modelling undertaken across a range of non-European regions in the PARIS REINFORCE project.

3. Short summary of results (<250 words)

The "Promoting sustainable transitions across the globe" Work Package (WP6) of PARIS REINFORCE is designed to produce analysis of low-carbon pathways in a range of major emitting and additional regions outside of Europe, using national level models. The pathways will be developed over two iterations. The outputs of the first iteration are reported in this deliverable.

This report sets out how each of the regions examined (USA, China, India, Brazil, Russia, Central Asian Caspian, Canada, Mexico) has the potential to make deep emissions reductions, in many cases to net-zero by 2050, but in all cases on a pathway towards net-zero by 2070 at the latest. In most regions this is achieved by a rapid penetration of renewables (and in some cases nuclear) into the electricity system, increasing electrification of end-use sectors (industry, transport, and buildings) and the use of other low-carbon energy vectors such as biomass and hydrogen.

The stakeholder results which have fed into the creation of scenarios in five of the eight regions covered has proven an important component of scenario co-creation, as well as education to stakeholders around the different attributes and capabilities of energy system models used to formulate low-carbon pathways. The next iteration of scenarios will allow a first stakeholder engagement with the remaining three regions, as well as an opportunity to re-engage with stakeholders from the first round of scenario co-creation.

4. Evidence of accomplishment

This report.

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

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	

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

Executive Summary

A series of non-European country mitigation modelling exercises was undertaken during the first modelling period of the PARIS REINFORCE project. The countries covered are USA, Canada, Mexico, China, India, Brazil, Russia, and countries of the Central Asian Caspian region (Azerbaijan, Kazakhstan, Turkmenistan, and Uzbekistan). In most cases, these modelling exercises were developed and co-created in close cooperation with stakeholders from within the different countries covered. For the exceptions (Mexico, Canada, and Brazil), stakeholder consultation and interaction will be undertaken in the second modelling iteration round, to be reported on in Deliverable D6.6: Second round of more ambitious low-carbon pathways outputs.

This document reports the key steps undertaken to engage stakeholders, the major insights gleaned from those stakeholders, and the resulting scenarios co-created from these interactions. It specifically focuses on a series of "reference" and "deep mitigation" scenarios. In the former case, the reference scenarios reflect where current emissions are heading on the basis of current policies and/or Nationally Determined Contribution pledges to 2030, with extrapolations of effort after 2030. In the latter case, the deep mitigation scenarios reflect an interpretation of the maximum plausible mitigation effort at the time of interactions with stakeholders, considering these stakeholders' views.

Engaging stakeholders in scenario co-creation has highlighted a number of important attributes of deep mitigation pathways analysis. For example, in most cases the majority of stakeholders in the three regions for which specific polling was undertaken (Russia, China, India) feel that the NDC targets for 2030, around emissions, emissions intensity, and/or specific targets such as nuclear, renewables, and electric vehicles are achievable. A significant share of polled stakeholders also indicated that there is potential to go beyond these NDC commitments. This paves the way for ratcheted climate action through the 2030s and beyond. The majority of country and region scenarios reported on in this deliverable thus achieve deep decarbonisation across the energy system, with decarbonisation of electricity (through wind, solar, carbon capture, and nuclear, depending on the region), significant electrification of buildings, industry and transport, and a considerable role for other low-carbon energy vectors such as bioenergy and hydrogen, as well as fossil fuels with carbon capture and storage. Energy efficiency is a pervasive and essential element of the scenarios.

Another key aspect of scenario co-creation has come from the identification of important barriers and opportunities stemming from low-carbon pathways. In the USA, for example, early consultation with on-the-ground collaborating organisations highlighted the importance of both jobs and equity in low-carbon pathways development. In Russia, key issues discussed in the workshop stemmed from a consideration of the forestry sector, as well as the cost reduction and scale-up prospects of both renewables and nuclear energy sources. In China, a strong focus on policy design, for example through emissions trading system development, was brought to light. In India, integration of renewables in the grid, managing decarbonisation in the context of rapid urbanisation, and the air quality issues stemming from continued fossil fuel use were all discussed. In the Central Asian Caspian regions, a strong focus on energy tariffs, water resources, and energy trade dominated discussions. Each of these aspects can be further investigated in ongoing research in PARIS REINFORCE, notably through the following WP6 deliverable, D6.4: Ancillary impacts, including SDGs, of national low-carbon pathways outputs.

The stakeholder views, as well as resultant low-carbon pathways, will feed into a second round of global mitigation modelling (WP7), so as to make the representation of global low-carbon pathways in integrated assessment models more realistic, and more reflective of stakeholder views.

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

Contents

Table of Figures

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

Table of Tables

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

1 Introduction

PARIS REINFORCE has undertaken in-depth analysis of national-level decarbonisation pathways for the world's major economies as well as for selected less emitting countries. This includes national-level analysis for major economies and less developed/emitting countries *outside* Europe (the focus of Work Package 6). This analysis uses a range of national-level energy system models, as follows:

- **CONTO**: A model detailing the inputs into and outputs from different sectors of the Russian economy, including energy details.
- **GCAM-China**: A region-specific variant of the global, multi-region GCAM integrated assessment model, which details 31 different provinces in China, including flows of energy and goods between them.
- **GCAM-USA:** A region- specific variant of the global, multi-sector GCAM integrated assessment model, which details the energy and goods interaction between all (fifty plus the District of Columbia) USA states.
- **India AIM/CGE:** A model for India based on the Asia Integrated Model / Computable General Equilibrium Model, representing India as a single region.
- **MAPLE:** A China-specific model based on the TIMES energy modelling framework, which includes a large range of energy technologies.
- **NATEM:** A 23-region TIMES model for North America, including Canada, Mexico, and the USA, detailing trade flows and other regional interactions.
- **MUSE-Brazil:** An energy system model for Brazil.
- **TIMES-CAC:** A TIMES model with country-level detail for the Central Asia Caspian region countries Kazakhstan, Uzbekistan, Turkmenistan, and Azerbaijan

Table 1 details the main features of these models.

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

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

Model	Country / Region	Country Partner	Time horizon	Time step intervals (years)	Sectoral level of representation							
					Upstream	Electricity	Heat	Transport	Buildings	Industry	Agriculture	Land use
CONTO	Russia	IEF-RAS	2050	10	Detailed	Detailed	Detailed	Detailed (road)	Detailed	Detailed	Detailed (energy)	N/A
GCAM-China	China	BC3	2100	5	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed (energy)	Detailed
GCAM-USA	USA	BC3	2100	5	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Basic	Detailed
India Aim/CGE	India	Grantham	2100	5*	Detailed	Detailed	N/A	Detailed	Detailed	Detailed	Detailed (energy)	N/A
MAPLE	China	CUP	2050	5	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	N/A
NATEM	USA, Canada, Mexico	IEECP	2050	5	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	N/A
MUSE-Brazil	Brazil	Grantham	2100	5	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed (energy)	Basic
TIMES-CAC	Central Asian Caspian	E4SMA	2050	10*	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed (energy)	Basic

*Notes: *Flexible to run with shorter time periods. "Detailed" means that the key low-carbon technologies are represented, as set out in the comprehensive model descriptions given in deliverable D 6.1: Documentation of national / regional models for countries outside Europe.*

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

Each of the models to be used in Work Package 6 is intended to allow the development of detailed decarbonisation pathways for major and less emitting economies of the world, encompassed by the relevant model(s). Figure 1 shows the different country and regional coverage encompassed by all of the models used in this work package.

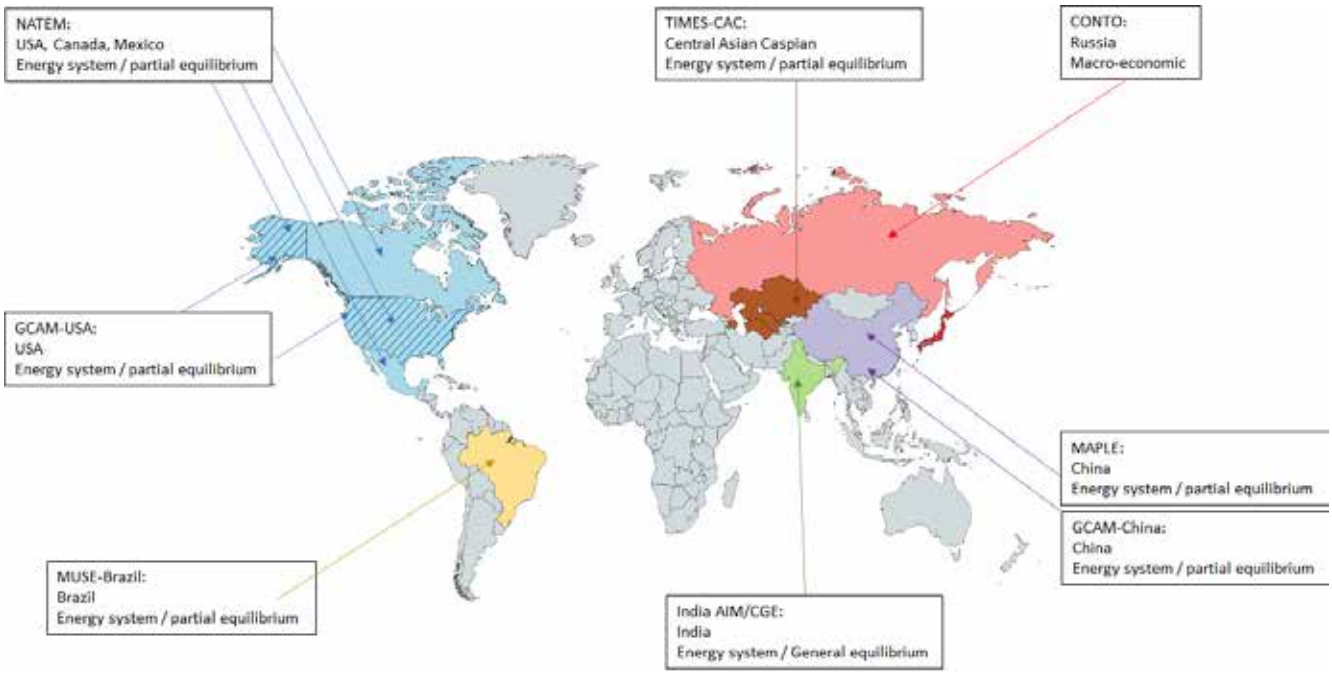


Figure 1: Country coverage for the different models

WP6 has been organised such that different stakeholders provide an informed contribution into the co-design of future scenarios to develop these low-carbon pathways in each region shown, as well as engage with the detailed outputs that accompany each modelled pathway. The scenarios and choice of mitigation pathways that result encompass the following attributes:

- Projections for future economic and population growth that drive energy demand as well as demand for other goods and services that result in greenhouse gas (GHG) emissions (e.g., agriculture and land use)
- The technologies and measures available, by what time and to what extent, to allow mitigation
- The costs and performance characteristics of different technologies
- The emissions targets or constraints consistent with different regions' contributions to different long-term, Paris-compliant temperature goals (i.e., well below 2ºC, 1.5ºC)
- The mix of policies that can be implemented to aim to achieve these emissions targets
- The interactions of different resulting mitigation pathways with other policy goals, in particular the sustainable development goals (SDGs) and adaptation goals.

The modelling objective and scenario set up of all models – in terms of structure, assumptions, and data sources, is detailed in Deliverables D6.1 and D6.2.

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

2 Workshops and scenario design

In all regions, stakeholders from government, academia, business, and civil society (NGOs) were identified for involvement in the workshops, drawing on the internal stakeholder database developed and maintained in the project. Key questions for discussion in the workshop were identified on the basis of review of existing government targets and policy documents, as well as national pathways analysis documents for the countries of focus. In many cases, and as elaborated later in this section, bespoke surveys and polls were designed before the workshops, to relate to key issues and to test the extent of ambition envisaged as realistic by the stakeholders. Figure 2 outlines the process for engaging stakeholders in the workshops.

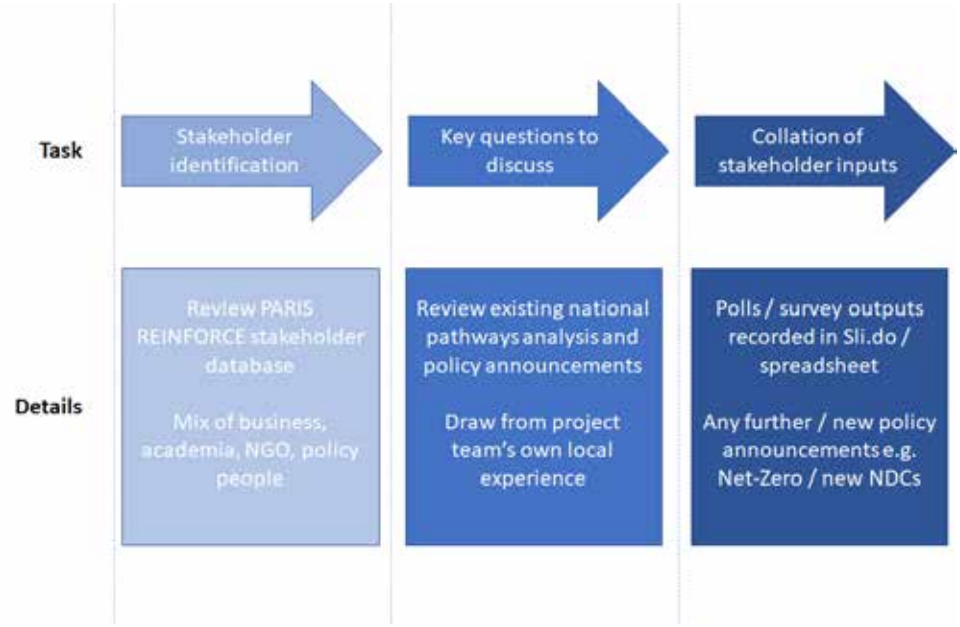


Figure 2: Process for organising and interpreting stakeholder workshops

The workshops also presented an opportunity to understand stakeholders' familiarity with low-carbon pathways modelling analysis, and to explain to them what models can and cannot be useful for in the context of decision-making around low-carbon futures analysis, so as to allow them to be better informed about mitigation options (Pizarro-Irizar et al., 2020). In some regions, the discussion focused on specific technologies' readiness and deployment levels in the coming years and decades, whilst in others more cross-cutting issues around equity and jobs were the focus. Table 2 summarises the timing, discussion points, and implications of the workshops. The following sub-sections then provide further details of each of the workshops.

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

Table 2: Summary of workshops held and implications for national scenario design

Workshop details	Details discussed	Scenario design plans
India (Nov 2020)	Role of power sector, transport sector, and urbanisation in achieving mitigation pathways.	Specific polling data on power, transport, NDCs, buildings to build into mitigation scenarios.
Central Asian Caspian (Dec 2020, Mar 2021, May 2021)	Discussion on policy measures and regional climate ambitions, regional integration and cooperation, implications of water consumption in power sector, commodity tariff phase-outs, hydrogen market development.	Multiple scenarios to explore different aspects discussed in the workshops.
Russia (Mar 2021)	Overall discussion of Russia's potential pathways, and deep-dives into the role of forests, industrial manufacturing, and electricity in Russia's low-carbon pathways.	Specific polling data on NDCs, 2050 target, role of renewables (wind, solar, hydro) and nuclear, energy efficiency in manufacturing, to be fed into scenario design.
US (May 2021)	Targeted discussion on the importance of considering equity and jobs in the US long-term strategy towards net-zero in 2050.	Analysis of jobs and where possible equity-related metrics in net-zero modelled pathways.
China (Jun 2021)	Discussion on China's net-zero 2060 target, role of multiple sectors including power, industry, role of coal, provinces. Discussion of Belt and Road initiative and opportunity and challenge for it to become Low Carbon.	Polling data on China's 2030 target, role of nuclear, renewables, coal, EVs, to be fed into new scenarios.

2.1 India

The online India workshop, held in November 2020, involved structured discussions on the Indian energy transition with experts from NGOs, academia, the private sector, and government. This was with the purpose of allowing modelling teams to develop stakeholder-driven modelling scenarios, as well as to co-create some of the core assumptions being fed into models.

The project team first gave an overview on what modelling studies have so far revealed about low-carbon transitions in India. Participants were then split into three breakout groups to allow for more detailed discussions. The themes of the three breakout groups were the Indian power sector, the Indian transport sector, and the theme of urbanisation in India. Each session was structured around gathering participants' understanding of the key themes driving modelling results—i.e., are assumptions too ambitious, too pessimistic, or unrealistic/infeasible in other ways?

The power sector session investigated the political feasibility of early retirement of coal plants in India, particularly focussed on the chances of retirement during the period 2020-2030, as well as the target of 450GW renewable electricity capacity in India by 2030. Discussion centred around whether this target is realistic and the key support mechanisms that must be put in place to support such rapid renewable electricity deployment.

The urbanisation session investigated the evolution of building cooling demand (e.g., demand for air conditioning), including the implications of increased urbanisation and incomes for this demand. Participants also discussed smart cities and the potential benefits of better public transport infrastructure and more energy efficient buildings that could result from them. Finally, the discussion covered key innovations or disruptive technologies that could influence the development of sustainable urban living in India.

The transport sector session investigated the feasibility of the government's 30% electric vehicle share by 2030 target, implications for the electricity grid of a surge in electric vehicles, and the role for hydrogen in decarbonising India's transport sector.

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

Following the breakout groups, representatives from each session informed the larger group on the issues they had discussed in their respective groups. An interactive sli.do voting session then allowed participants to give their feedback on all topics before closing remarks.

2.2 China

The China workshop was held online on June 8, 2021. The workshop discussed China's carbon neutrality goal, how to achieve it from policy to practice, and topics related to the energy system in the context of the Belt and Road Initiative. Stakeholders from the Chinese government, academia, and Chinese companies participated in the event.

A representative from China's National Centre for Climate Change Strategy and International Cooperation (NCSC) discussed how to promote carbon neutrality from the perspective of the energy transition, and how to make China's policies promote realistic actions. Following this, representatives from the PARIS REINFORCE consortium introduced China's energy status and carbon neutral policy background, as well as some initial mitigation scenarios to show how China could achieve net-zero carbon emissions by 2060.

Following these initial presentations, workshop participants entered into an open discussion session around China's net-zero target, focusing on the energy-intensive industries of provinces, the synergistic effects of pollution reduction and carbon reduction and the challenges of reducing carbon emissions in the power system, including integrating renewable energy power, operation control technology, market mechanisms and policy incentives. The discussion also encompassed how China's carbon market has a relatively significant development effect, but there are still many problems, such as high regulatory costs, quota allocation and other issues.

A second open discussion session on the Belt and Road Initiative included opinions and comments from industries and enterprises in China, including Guangdong Energy Group, Datang Group, China Power Finance and the Climate Change and Sustainability Division of Ernst & Young LLP. Key topics included the critical role of finance, and specifically how companies can participate in the green construction of the Belt and Road Initiative through using green bonds or green credits as financial support.

Finally, participants were invited to vote online on the sli.do platform, to collect stakeholders' views on China's carbon neutrality and the Belt and Road Initiative, carbon emissions reductions, and energy transition and development prospects.

2.3 Russia

The Russia national workshop was held online on March 16, 2021, to receive insights from local stakeholders into the public policy context as well as a better understanding of some of the key assumptions modelling groups must make to build relevant mitigation pathways for the country. To this end, a range of stakeholders were invited from NGOs, academia, business, and government, constituting over 100 participants in total.

The workshop began with the PARIS REINFORCE project team presenting preliminary insights from the global modelling activities of the project and elaborating on the low-carbon development of Russia by delving into the current status of the country, its NDC pledges, as well as an estimation of where Russia is headed based on the "where we are headed" scenario logic of PARIS REINFORCE. The Russian partners of the PARIS REINFORCE consortium (IEF RAS) then introduced the model system dedicated to modelling the low-carbon development of Russia, with a focus on the potential for mitigating GHG emissions in the country, as well as the long-term national mitigation scenarios currently being explored alongside their impact on emissions reduction, economic dynamics, energy efficiency, and investments. Emphasis was placed on the importance of the carbon sink potential from the Russian forests, which is currently underexplored in the established scenarios.

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

Participants were then split into three breakout groups, to discuss three specific topics: first, the structure of electricity generation; second, pathways to decarbonise the manufacturing sector of the Russian economy, including businesses exporting goods to the EU; third, carbon sequestration potential of Russian forests and ways to maximise it.

The power sector discussion revolved around the electricity mix and emission intensity, with emphasis on the role of nuclear energy, natural gas-based generation and renewable energy considering different policy scenarios like carbon regulation measures, direct limits on CO_2 emissions and carbon prices. Discussions focused on the economic and financial evaluation of each technology, with cost-effectiveness being expected to influence the diffusion levels of each technology in decarbonisation plans.

The manufacturing sector discussion included the activities Russian businesses have implemented in the past to reduce emissions, as well as future plans and how these plans are expected to affect the competitiveness of Russian companies. A key part of the discussion involved opportunities and threats of the manufacturing sector brought from the climate agenda including the possible expenses from the introduction of a carbon border adjustment mechanism.

The forests discussion focused on how to assess and maximise the carbon sequestration potential of Russian forests. Different estimations of the Russian forest carbon budget and ways to improve them were discussed, as well as strategies to maximise the carbon sequestration potential by improving the control for forest disturbances, forest management techniques, and by promoting forest conservation projects.

Following these discussions and a following open discussion, an interactive sli.do voting session allowed participants to give their feedback on the level of emission targets they consider to be realistic and ambitious, their estimations on the rate of GDP energy and carbon intensity improvement, the shares of key low-carbon technologies in the future, the level of carbon sinks, as well as their evaluation of key restrictions that could slow down the low-carbon transition of the country.

2.4 USA

The US workshop took place over two half-day sessions, on 24th and 25th May 2021. It was organised in collaboration with key US partners with a view to maximising stakeholder engagement at a time of renewed climate action in the country, under the leadership of the recently elected President, Joe Biden. The other partners were: ClimateWorks Foundation, University of Maryland Center for Global Sustainability, Rocky Mountain Institute, World Resources Institute, and the University of Michigan's School for Environment and Sustainability. They convened US and international experts from a broad range of communities concerned with the US low-carbon transition, to discuss strategic, analytical, and implementation needs to achieve a successful US long-term strategy (LTS) to Net Zero.

These stakeholders included: climate change and energy analysts and strategists from academia, NGOs, think tanks, and businesses; policy and regulatory officials from the federal government; experts with on-the-ground experience of implementing low-carbon transitions, including amongst workers and communities. Together, they discussed a number of themes including strategic and analytical needs towards a successful LTS, challenges and opportunities to decarbonising whilst ensuring the transition is equitable, and implications of the transition on the economy, including jobs and opportunities

The first day of the workshop involved a number of presentations from a range of national and international experts, primarily from academia, government and NGOs, setting out the context for US long-term decarbonisation action, in light of the US's recently updated NDC. Many presentations highlighted the critical need to consider equity, jobs, and a range of non-climate concerns into account to achieve a workable long-term

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

strategy. Comments highlighted that there must be greater analysis of local, community-level implications. In addition, to achieve Net Zero, all sectors and gases must be analysed in detail.

The second day of the workshop opened with a series of presentations on current analysis and future requirements to consider aspects of equity and jobs. This paved the way for two breakout discussions on jobs and equity respectively. The equity discussion highlighted that there is a need for better data to build appropriate metrics to highlight equity implications of the transition, and that without equity concerns at the core of a long-term strategy, it would not succeed. The jobs discussion highlighted how there needs to be better analysis that goes beyond jobs numbers, including on jobs quality, wages, contract length, and inclusivity.

A constant theme throughout the workshop was that stakeholder participation and inclusion is a central element of equity and is essential in the design of the LTS and its sub-national elements.

2.5 Central Asian Caspian (CAC) countries

The consortium took a different approach with the Central Asian Caspian countries, as compared with the other regions for which workshops were undertaken. Here, the stakeholder engagement sessions were organised across a series of three separate workshops, the first held online on 9th December 2020, the second on 2nd March 2021, and the third on 18th May 2021.

The first workshop aimed to receive insights from regional stakeholders into the public policy context as well as a better understanding of some of the key assumptions modelling groups must make regarding the region. To this end, a range of stakeholders were invited from national governments, NGOs, the private sector, international institutions, and academia, with attendees from Kazakhstan, Uzbekistan, and Turkmenistan.

The workshop began with the PARIS REINFORCE project team introducing the TIMES-CAC model, the structure of the initial exploratory scenarios used for analysis (designed to facilitate the first round of engagement), as well as the diverging pathways of key assumptions (e.g., the price of natural gas) under each scenario. Here, an emphasis was placed on the help that stakeholders can provide by allowing for more politically and contextually relevant policies and assumptions to define scenarios.

Additionally, an interactive dashboard was shared and demonstrated. This dashboard allows for a user-friendly visualisation of the key performance indicators relevant to the TIMES-CAC model.

Participants were then split into two breakout groups, in order to allow for more intimate discussion around key policies and key data assumptions.

The session on key policies discussed water supply within the region (with respect to its integration with the energy chain), the capability to keep track of regional “strategic agreements”, as well as the deployment of renewable energy capacity with relation to targets set by national governments. Furthermore, additional regional studies and data sources were discussed.

The session on key data assumptions discussed the accuracy and reliability of different data sources were discussed in relation to the regional context. Discussions focused particularly on the effects of the COVID-19 pandemic on relevant economic drivers, oil price long-term projections, and costs of key energy technologies (e.g. PV, carbon capture and storage, etc.).

The second virtual workshop focussed on informing regional stakeholders on the progress of the modelling exercise presented during the 1st regional workshop and on receiving a second round of insights from regional stakeholders. The project team first presented how the first round of stakeholders' insights were elaborated in the storylines and the structure of the new exploratory scenarios developed for analysis, as well as the diverging pathways of key assumptions under each scenario. Emphasis was placed on the topics investigated in the second

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

phase of the analysis: foreign investments in the region (e.g., Belt and Road Initiative) and hydrogen chain development. The interactive dashboard already used in the first workshop was shared and demonstrated.

Participants were then invited in a discussion session to allow for more focused discussion, including around water consumption within the region along the energy chain, the capability to manage/analyse tariff reforms as well as international topics such as carbon border adjustment. Furthermore, the possibility to open the technology portfolio to additional solutions (e.g., nuclear for Uzbekistan) was discussed.

The goal of the final workshop was to inform regional stakeholders on the further progress of the exercise presented during the previous two regional workshops and receive a final round of their insights. Stakeholders' insights collected during the previous workshops and in bilateral discussions were elaborated in three final storylines, including some variants: Where are We Headed, NDC-like, and Deep Mitigation. The total number of scenarios developed in this last phase of the analysis was eight (all included in the dashboard). The topics investigated were mainly around “Watergy”, the correlation between power production and water consumption, and commodity tariffs phase-outs, in combination with GHG reduction targets.

The project team also introduced the CAC Forum (https://cac.tribe.so), a tool built to continue the dialogue with stakeholders after the series of workshops. The main features of the forum were presented and described.

Participants were then invited in the final discussion session to allow for more focused discussion. Some of the main topics discussed were around the possibility to simulate net-zero emissions in the region by 2050 (in particular in Uzbekistan), the capability to manage public funded/private investments (with different risks/discount rates), and define service-related, or consumption-related, tariffs for the energy commodities.

The dashboard used for the visualisation of the key performance indicators relevant to the TIMES-CAC model was illustrated, enriched with the new indicator of water consumption in the power sector for each scenario, and used to demonstrate the response of the underlying energy system model to the various scenario elements.

2.6 Summary of stakeholder mix

The workshops engaged a variety of stakeholders from different institutional types, with the majority in most cases coming from academia, though in many cases with at least some representation of business, policy, and NGO/international institutional interests. Figure 3 sets out the total number of participants in each workshop.

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

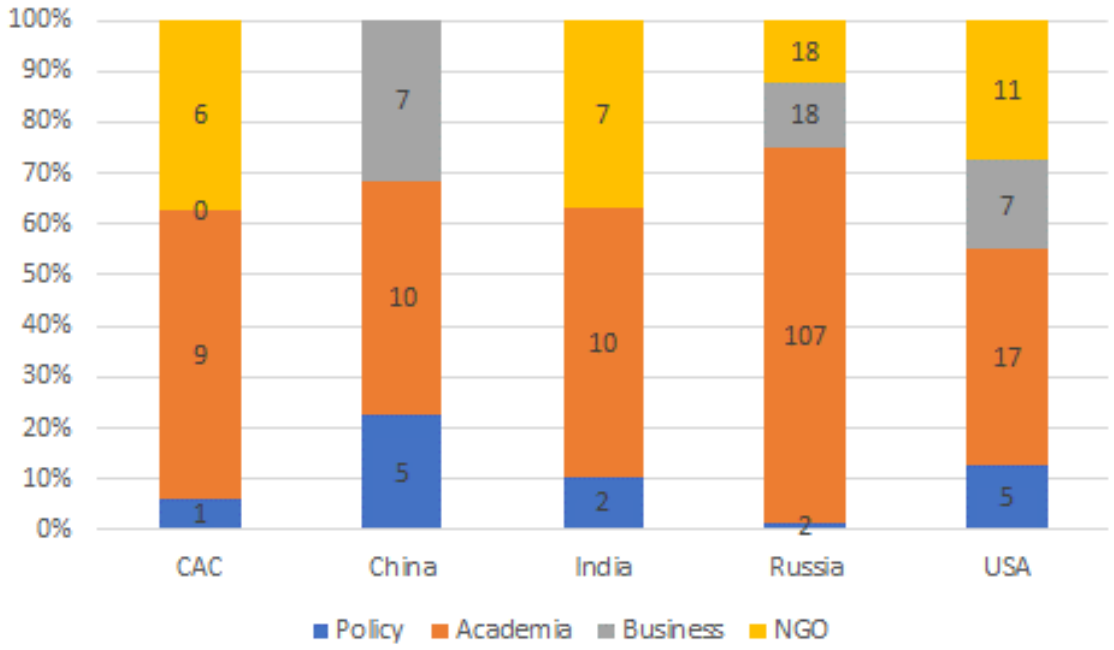


Figure 3: Stakeholder numbers and split by organisation type, for each workshop

Note: CAC stakeholder mix is for the first workshop. The second and third workshop mixes were near-identical.

2.7 Co-creation of scenario design

The workshops have produced a range of interactions with—and outputs from—stakeholders. In some cases (for example, the Central Asian Caspian region) it was deemed appropriate to have more open, exploratory discussions, with a strong focus on educating stakeholders about model types, purpose of models, and typical outputs.

In other cases, stakeholders were deemed sufficiently knowledgeable about the low-carbon transition, key government policies and targets, and the technological and behavioural choices, that it was deemed appropriate to undertake polling around specific policy-relevant questions. This was the case in the India, China, and Russia workshops, with results shown in Figures 4-6.

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

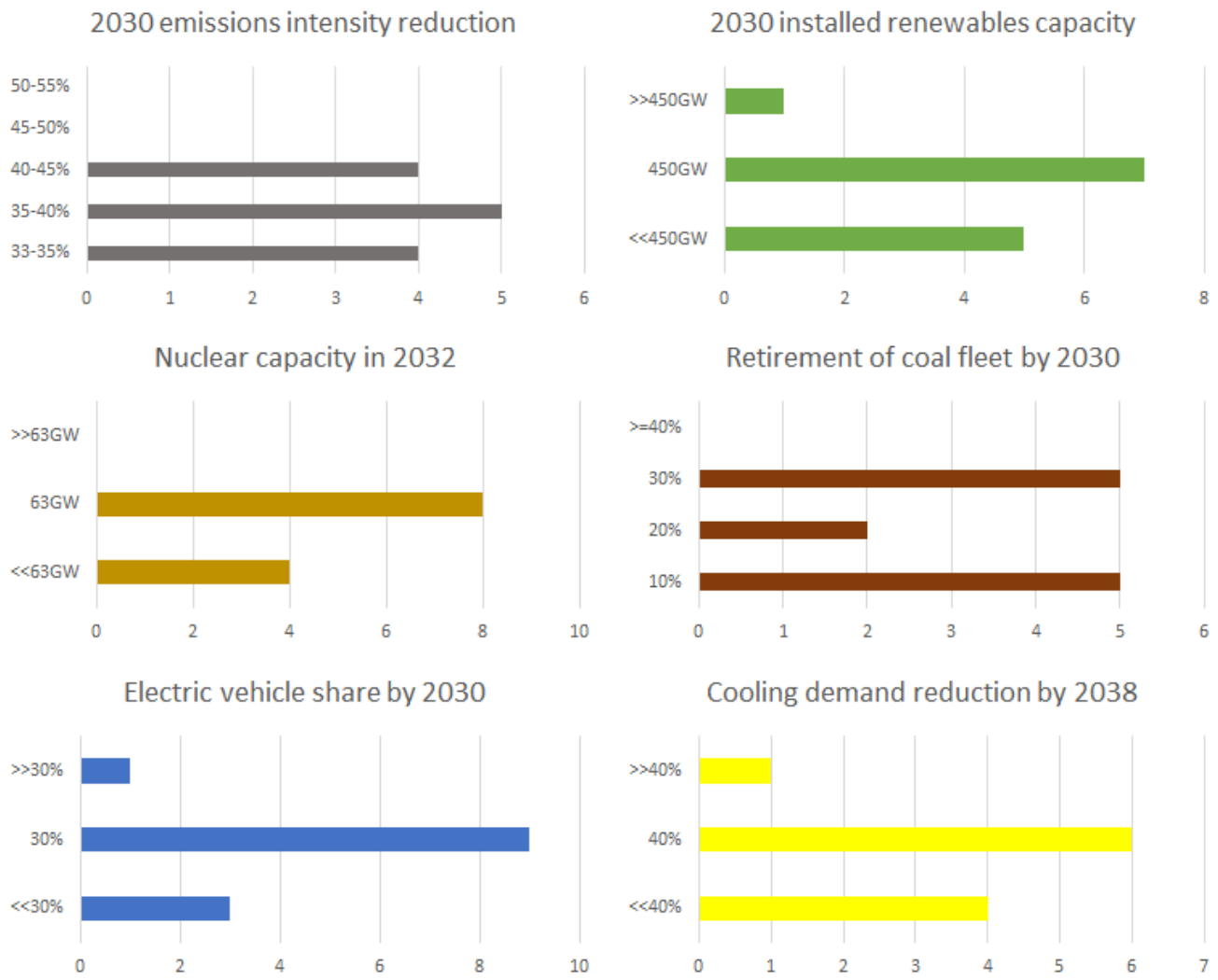


Figure 4: India workshop polling results

Notes: Emissions intensity reduction is measured relative to 2005, as per the India NDC. Cooling demand reduction is measured relative to the reference case in 2038. Specific figures for emissions intensity reduction (33-35%), 2030 renewables installed capacity (450GW), nuclear capacity (63GW), cooling demand reduction (40% on reference levels), and electric vehicle share (30%) are based on India NDC and subsequent announced technology-specific targets.

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

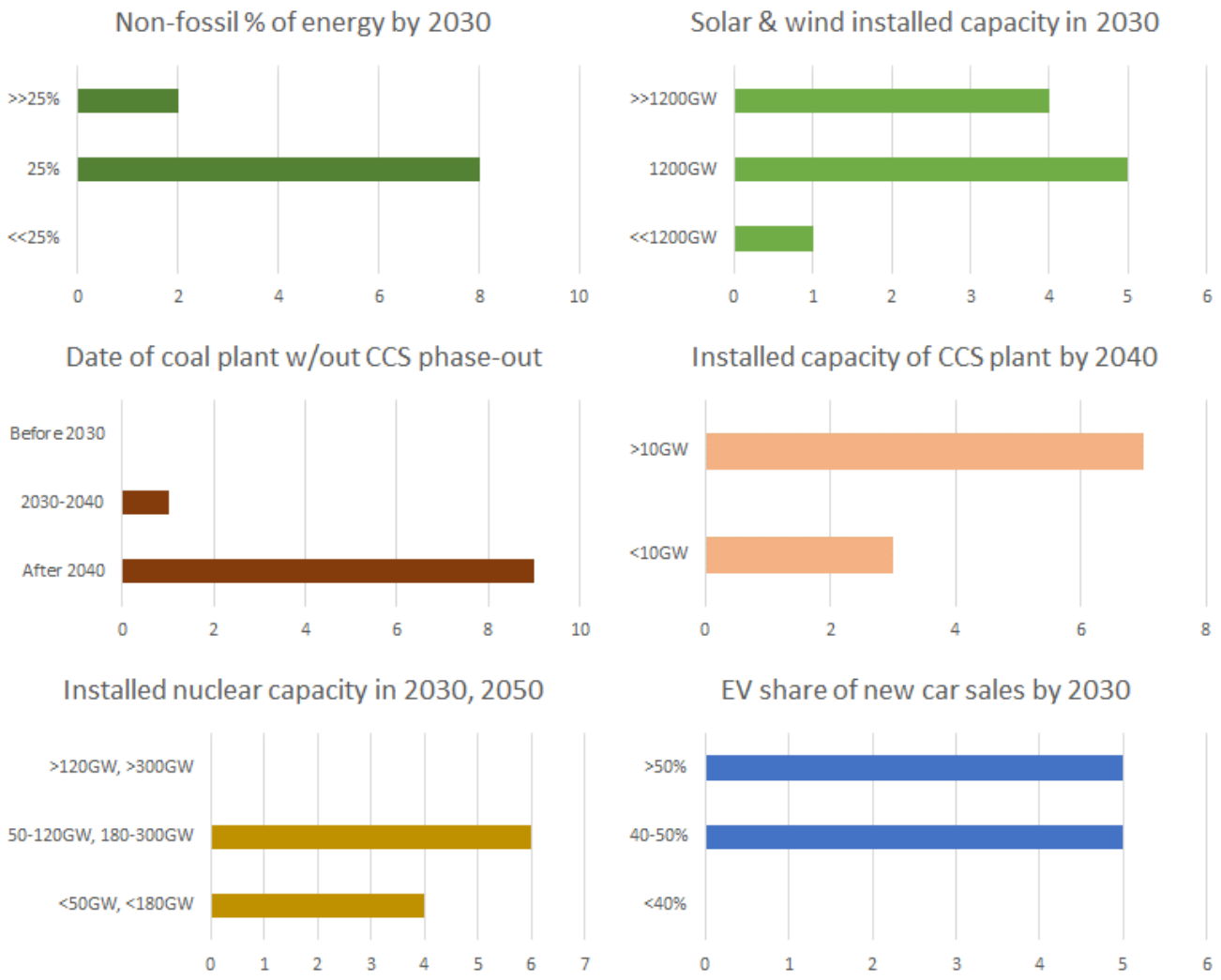
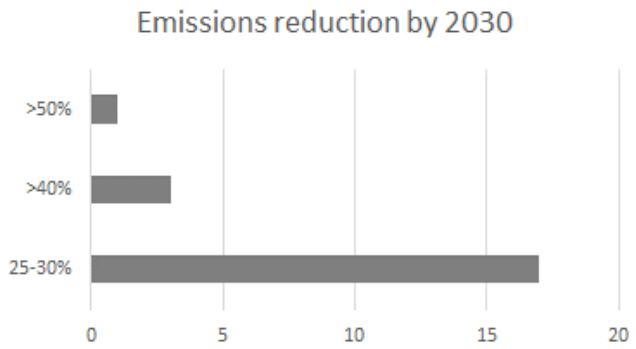
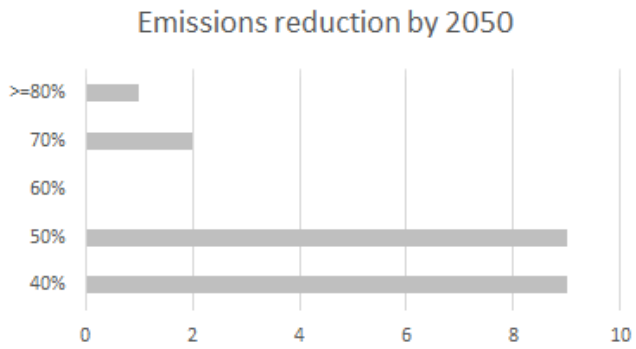


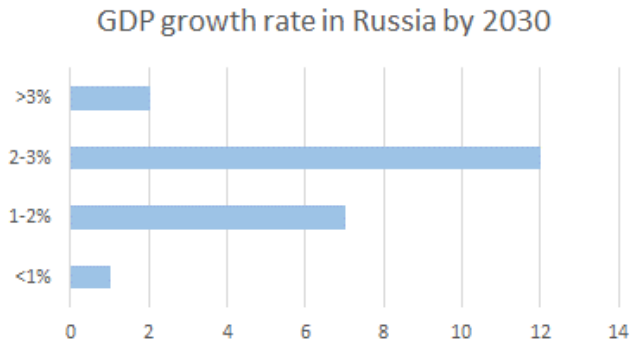
Figure 5: China workshop polling results

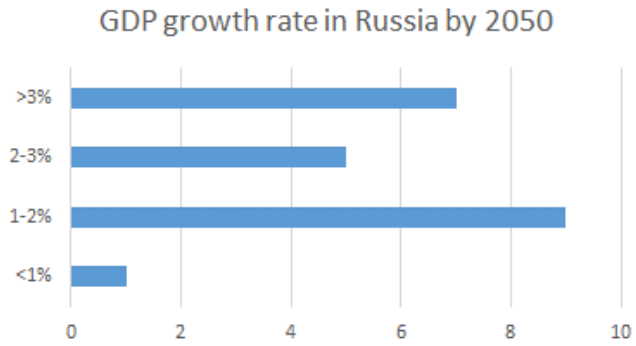
Notes: Specific figures for non-fossil % of energy (25%), 2030 renewables installed capacity (1200GW), EV share of new sales (40%) from latest State action plan announcements. Nuclear capacity, coal plant retirement, and CCS plant installed capacity inferred from various announcements and stakeholder discussions.

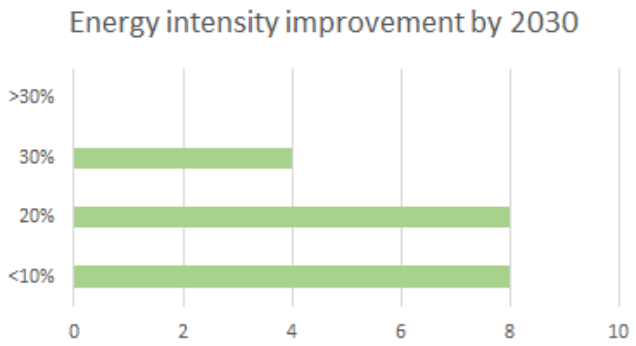
The PARIS REINFORCE project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 820846.

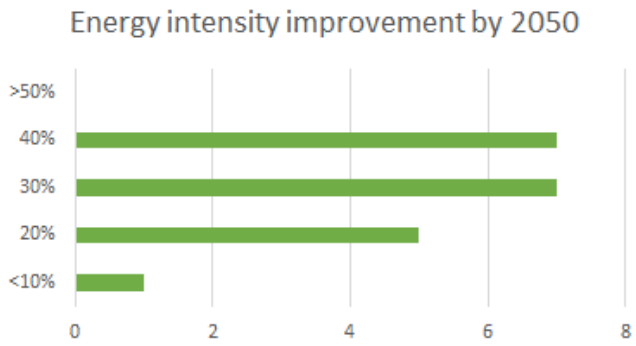


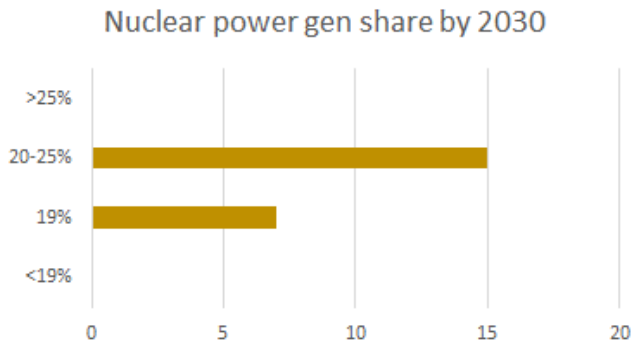


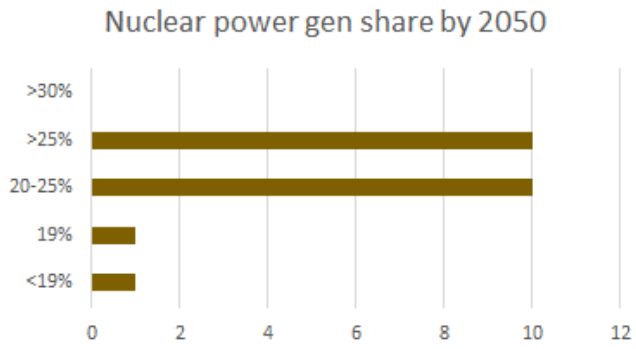












The PARIS REINFORCE project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 820846.

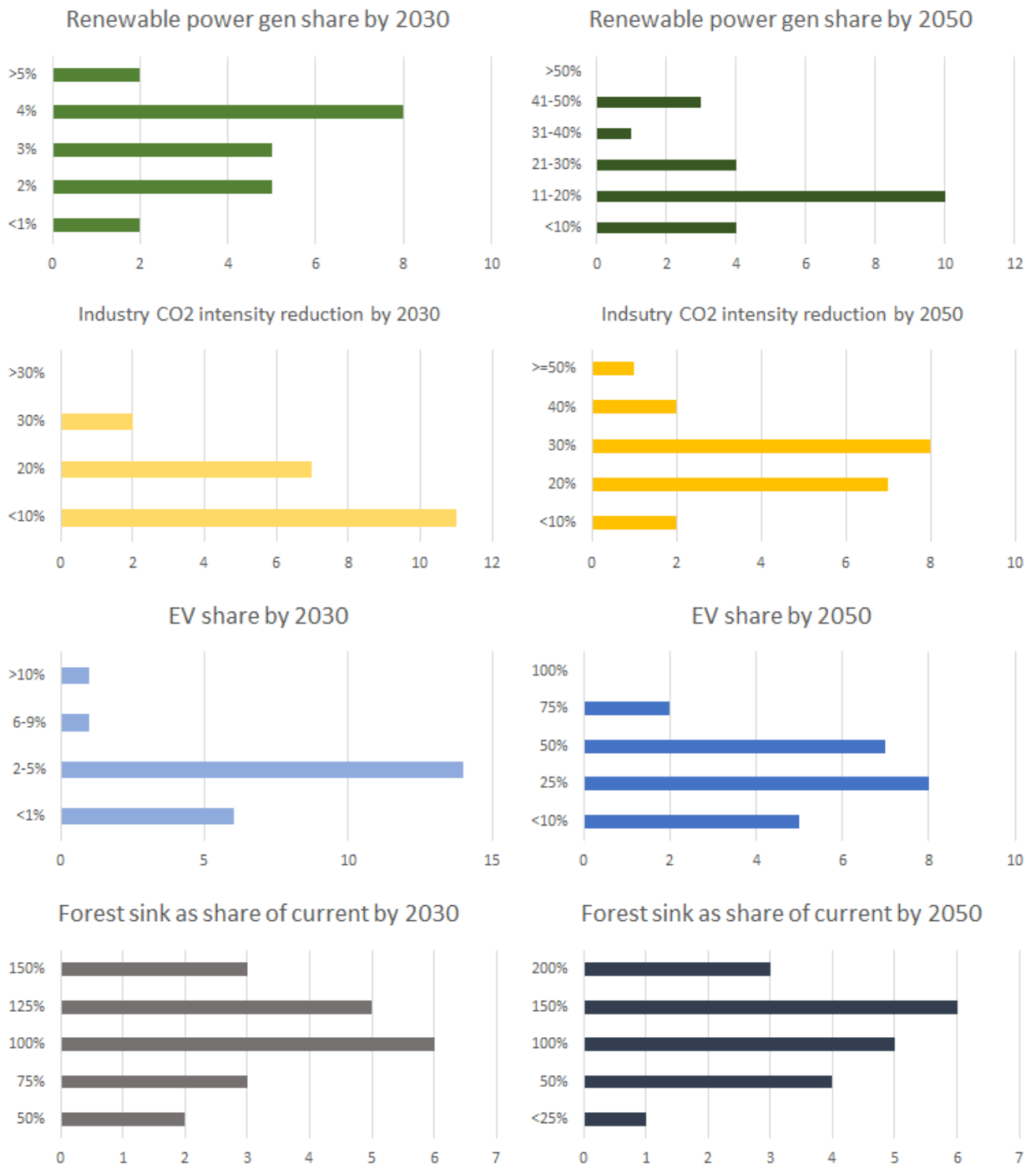


Figure 6: Russia workshop polling results

Notes: All reductions and improvements (emissions, energy intensity, industrial CO_2 intensity) stated relative to 2019. Key ranges arrived at in discussion with IEF-RAS economic experts, deriving from Russia's announced NDC and reported energy intensity, emissions intensity, and economic announcements.

Unlike the India, China and Russia workshops, the CAC and USA workshops undertook more open discussion around critical topics relevant to stakeholder concerns. In the CAC workshops, the earlier discussions elicited information on stakeholder areas of focus, determining that water consumption, hydrogen, energy tariffs, and the

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

role of oil and gas and regional trade were all critical. In the case of the USA, PARIS REINFORCE partnered with a range of organisations in the USA to capitalise on the attention being given to the long-term strategy development following the election of President Joe Biden in late 2020. In discussion with these organisations (University of Maryland, World Resources Institute, Rocky Mountain Institute, ClimateWorks Foundation, and University of Michigan), an agenda firmly focused on jobs and equity was arrived at. This was considered a valuable addition to the already numerous analytical studies on long-term decarbonisation pathways in the country.

Tables 3-5 show the way, in which polled stakeholder results were translated into scenario design choices in China, India, and Russia, respectively.

Table 3: China scenario design in light of stakeholder feedback

Main opinions from stakeholders	Reflections in scenario design
Majority view of 25% non-fossil energy by 2030, with some showing >25% possible	Ambitious scenario aiming for 30% by 2030.
Majority view of solar and wind combined capacity of 1,200 GW by 2030	Rather than "forcing on" this capacity, analysis of scenarios to see what level deployed, and post-hoc adjustment if much less/more than 1,200 GW.
Equal share of stakeholders said 40-50% EV share of new car sales by 2030, and >50% EV sales	60% EV sales target implemented.
Majority view of coal plant phase-out after 2040, but with >10GW CCS by 2040	Decision to examine scenario results without forcing these constraints, to judge comparability with them.
Majority view of 50-120GW of installed nuclear by 2030	Analysis of 2030 scenario results to examine how they fall with respect to this target.

Table 4: India scenario design in light of stakeholder feedback

Main opinions from stakeholders	Reflections in scenario design
Majority view of renewable capacity of 450 GW by 2030	Ambitious scenario of 450 GW capacity is specified for 2030, along with 500 GW non-fossil fuel capacity announced at COP26.
Majority view of 63GW of installed nuclear by 2030	Analysis of 2030 scenario results to examine how they fall with respect to this target.
Majority view of 35-40% emission intensity reduction target in 2030	Emissions intensity in the year 2030 is compared with scenario results in the ambitious net-zero by 2070 scenario; emissions trajectory is adjusted if more than 45% emission intensity reduction in 2030.
Majority view of 30% electric vehicle share by 2030	Decision to examine scenario results without forcing these constraints, post adjustment is done if it's coming less than 30%.

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

Table 5: Russia scenario design in light of stakeholder feedback

Main opinions from stakeholders	Reflections in scenario design
<30% emissions reduction by 2030	Scenarios have a range of 2-14% emissions reduction based on capital stock and other inertia.
A wide range of possible emissions reductions to 2050, from <40% in reference scenarios, to 70% or more in mitigation scenarios	Scenarios have a range of 14-77% emissions reduction by 2050, depending on whether reference or mitigation scenarios.
Majority view of 2-3% GDP growth to 2030. Range of views on GDP growth to 2050, with majority at 1-2% but sizeable share at >3%	Scenarios assume 2-3% growth rate, covering the most likely range.
Majority view of 10-20% improvement in energy intensity by 2030, and 40%+ improvement in 2050	Scenarios assume 20% improvement by 2030 and 45% improvement by 2050, targeting the upper (ambitious) range.
Majority view of 20-25% share of nuclear by 2030 and 25%+ by 2050	Scenarios assume 18-21% share in 2030 and 25-29% share in 2050, targeting the upper (ambitious) range. Rosatom (owes nuclear power plants) has a strategy goal to reach 25%.
Majority view of 4% renewable electricity by 2030, growing to over 10% by 2050	Scenarios assume 2% share in 2030 which is determined by policies implemented and 10-21% share in 2050, targeting the most likely range
Majority view of <10% or greater energy intensity reduction in industry in 2030, 30% by 2050	Scenarios assume 30% reduction in 2030 and 60% in 2050, targeting the most ambitious levels. This corresponds to other benchmarks we applied (GDP growth rate, energy intensity).
Majority view of 2-5% EV share in 2030 and 25% share in 2050	Scenarios assume 5% in 2030 and 30-50% in 2050, targeting the most likely and at the same time ambitious levels.
Majority view of 100-125% forest sink in 2030, and 150% in 2050	Scenarios assume 100-125% in 2030, targeting the most likely range; 175% in 2050 targeting possible ambitious level.

2.7.1 USA scenario design

As already discussed, the focus of the discussion in the USA workshops was on equity and jobs, since the 2030 updated NDC had already been put in place following President Biden's inauguration, so it seemed sensible to design scenarios around this pathway. Specifically, the scenarios included a reference scenario whereby all current climate and energy measures on the federal, state, city, and business level were simulated until 2030. Post-2030, the assumption was to ensure policy measures stay constant, and the equivalent carbon price of all measures was linearly extrapolated until 2050, separately for each US state (reflecting strong difference in climate ambitions between states, in the absence of federal policy). Details of the policies were taken from Hultman et al. (2020).

The deep mitigation scenario, building upon the current measures scenario, reflects a reasonable representation of energy and climate policies in line with the updated U.S. NDC target of 50-52% emission reductions in 2030 relative to 2005. Similarly, post-2030 measures stay constant, and state-specific equivalent carbon prices of all measures in 2030 are extrapolated until 2050. It should be noted that in the analysis presented in Section 3, the jobs and equity implications are not included. These will be included in Deliverable D6.4: Ancillary impacts, including SDGs, of national low-carbon pathways outputs.

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

2.7.2 Central Asian Caspian region scenario design

The scenarios for this region were designed in a more qualitative manner, following feedback from stakeholders in the first and second workshops. Specifically, the reference scenario was designed around a principle of "where emissions are heading" according to current policies (following Giarola et al., 2021, and Sognnaes et al., 2021). The emissions trend to 2030 is subsequently in line with GDP growth, but then begins to decouple from this post-2030, as the continuation of current policies sees low-carbon sources deployed, thereby reducing the emissions intensity of GDP. For the deep mitigation scenario, emissions reduction targets for each country were applied such that each had net-zero emissions by 2060-2070.

2.8 Scenario design in other regions

For three of the eight regions included in this report (Canada, Mexico, Brazil), workshops were not undertaken in the first round of mitigation modelling. As such, assumptions were implemented by the national modelling teams. The resulting scenarios will be presented to stakeholders in future PARIS REINFORCE workshops.

2.8.1 Canada scenario design

The reference scenario presents results using no constraining GHG reduction targets. Macroeconomic assumptions (GDP, population, oil and gas export prices) are aligned with the reference scenario used in Canada Energy Regulator's Energy Future 2020 outlook (Canada Energy Regulator, 2020), imposing no additional constraints in terms of GHG emissions reductions, but including policies already in place as well as the COVID-19 impacts. The deep mitigation scenario based on a net-zero emissions target on total CO_2-eq by 2050, and a 40% reduction target by 2030 (with respect to 2005). It corresponds most closely to the government's current target.

2.8.2 Mexico scenario design

The reference scenario for Mexico includes current policies. Deep decarbonisation scenarios are based on the conditional commitment of the Mexico NDC for the 2030 target, and 2050 is then extrapolated from it, using the trend of 2020-2030 emissions.

2.8.3 Brazil scenario design

The scenario design extends the WP7 protocol to Brazil, in terms of harmonisation of socio-economic drivers (population, gross domestic product), techno-economics, and policies in place up until 2030 (Giarola et al., 2021). Tow central scenarios are developed:

Reference: Following the WP7 protocol (Sognnaes et al., 2021), this scenario answers the question about where "Brazilian emissions are heading". It embeds the current policies in force up until 2030 and considers a plausible continuation beyond 2030 based on emissions improvements between 2020 and 2030 and projected to 2100 according to the per capita GDP variations.

Mitigation: Built upon the reference, the mitigation is set to achieve a net-zero target by 2060, which aligns with the most recent ambitions of the country, in absence of international policies. The cumulative budget is deemed compatible with a 1.5°C achievable with 66% likelihood. The cumulative budget estimated between 2010 and 2100 equals 1.3 $GtCO_2$, lower than the Brazilian budget estimated in a global MUSE simulation compatible with a 1.5°C scenario achievable with 66% likelihood, according to the protocol designed within the WP7 mitigation protocol.

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

3 Results from low-carbon pathways modelling

3.1 CO_2 emissions pathways

In all cases, the national modelled pathways can achieve deep decarbonisation by 2050. The reference scenarios, which are in most cases commensurate with continuations of current mitigation efforts, see emissions either rising (India, Mexico, USA – NATEM, China - MAPLE), falling (China – GCAM-China, Russia, Brazil, USA – GCAM-USA) or remaining approximately flat (CAC, Canada).

Only Canada and USA achieve net-zero energy-related CO_2 emissions by 2050. The other countries' emissions reduction trajectories take them to net zero by 2070 at the latest. In Brazil, although the energy-related emissions become negative in 2050, the total system emissions become net-zero only from 2055. In Russia, net zero CO_2 emissions (with LULUCF) are achieved by 2055 in the deep mitigation scenario. If LULUCF is excluded, zero CO_2 emissions will be achieved by 2070 according to the pathway followed. Mexico's deep decarbonisation pathway set an 80% emissions reduction target by 2050 (compared to 2000 levels); the country has not yet announced a net-zero target. For the CAC region, a range of net-zero targets are assumed, between 2060 and 2070. For India, the pathway is consistent with the COP26 announcement of a net-zero target by 2070, whilst for China, the pathway is consistent with the 2060 net-zero target announced in 2021.

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

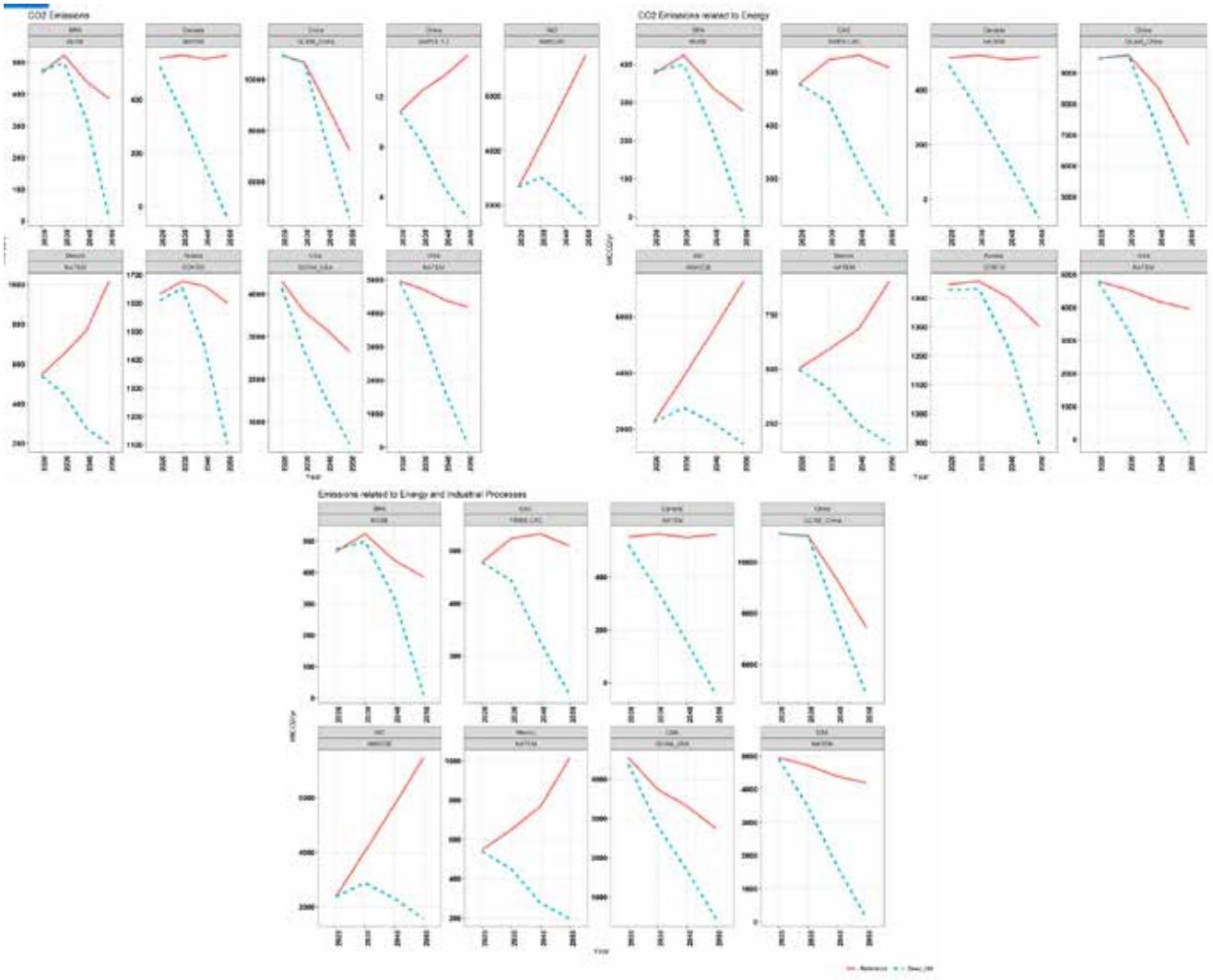


Figure 7: CO_2 emissions in reference and deep mitigation scenarios

Notes: Not all models report all three of Total CO_2, Energy CO_2 and Fossil Fuel and Industrial CO_2. Results for relevant models shown.

All regions see considerable deployment of carbon capture and storage (CCS) in the deep mitigation scenario, with the GCAM models showing CCS deployed in the reference scenario too, reflecting the tendency of the GCAM models to deploy CCS more readily than others (Sognnaes et al., 2021).

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

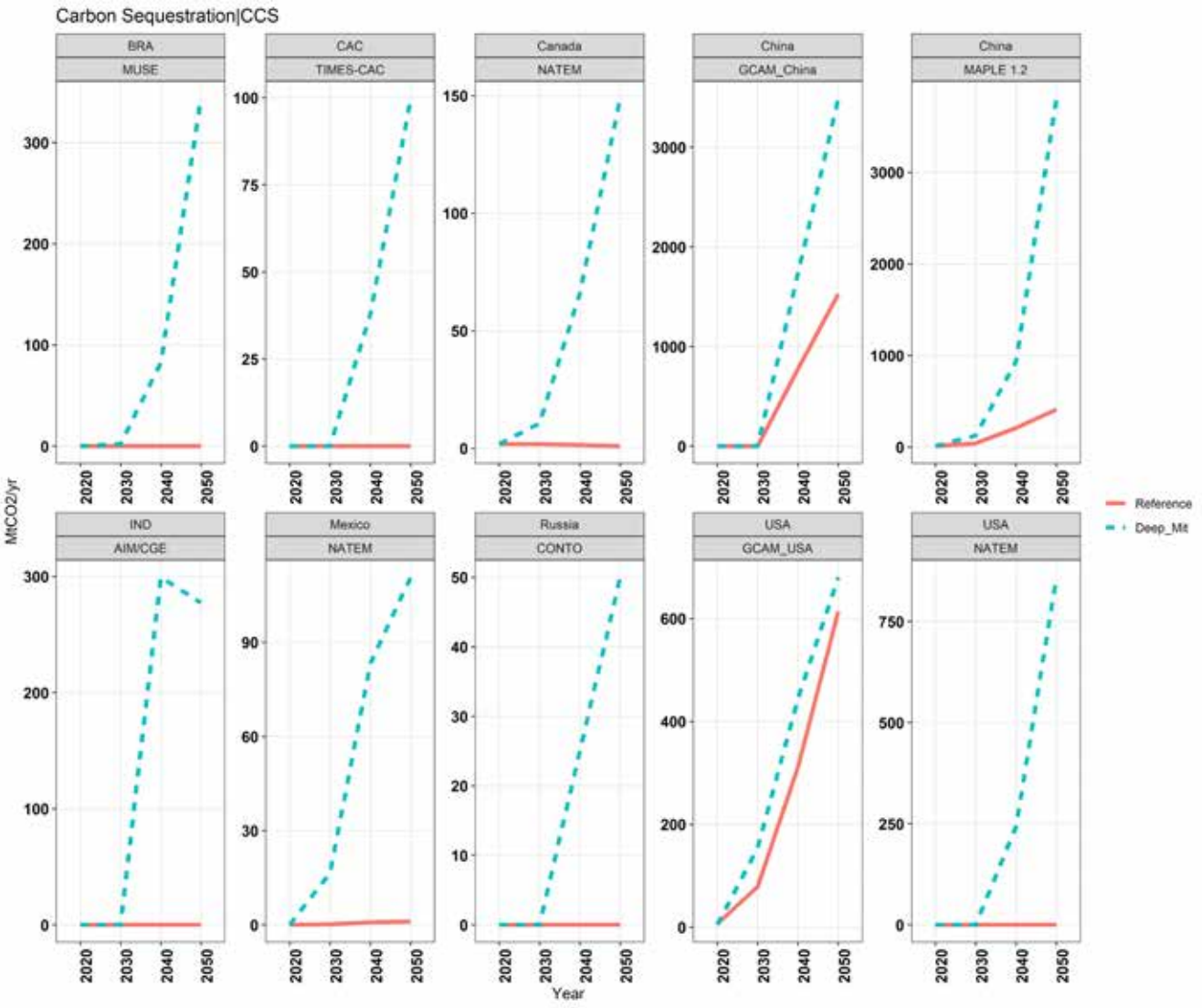


Figure 8: CO_2 capture in reference and deep mitigation scenarios

3.2 Carbon prices

The deep emissions reductions are driven by a rapid increase in carbon pricing in all regions, though to different extents: by 2050, the highest carbon prices are seen in the three North American regions (USA: \$300-1000tCO_2; Mexico: \$900/tCO_2; Canada: \$650/tCO_2). This is a level of pricing broadly consistent with the (admittedly very large) range of prices at a global level (by 2050 in 1.5ºC-consistent scenarios this range has a median of \$460/tCO_2, with a 10th-90th centile range of \$160-1,190/tCO_2 (Huppmann et al., 2018)). In some regions there is carbon pricing in the reference scenarios, representing an extension of mitigation efforts not represented by direct implementation of policies to 2030 and beyond. This is the case in China and the USA, where there is some representation of carbon markets in the countries to 2030. It should be noted that carbon prices, as presented here, are the prices associated with the decarbonisation trajectories, rather than specific imposed policy instruments.

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

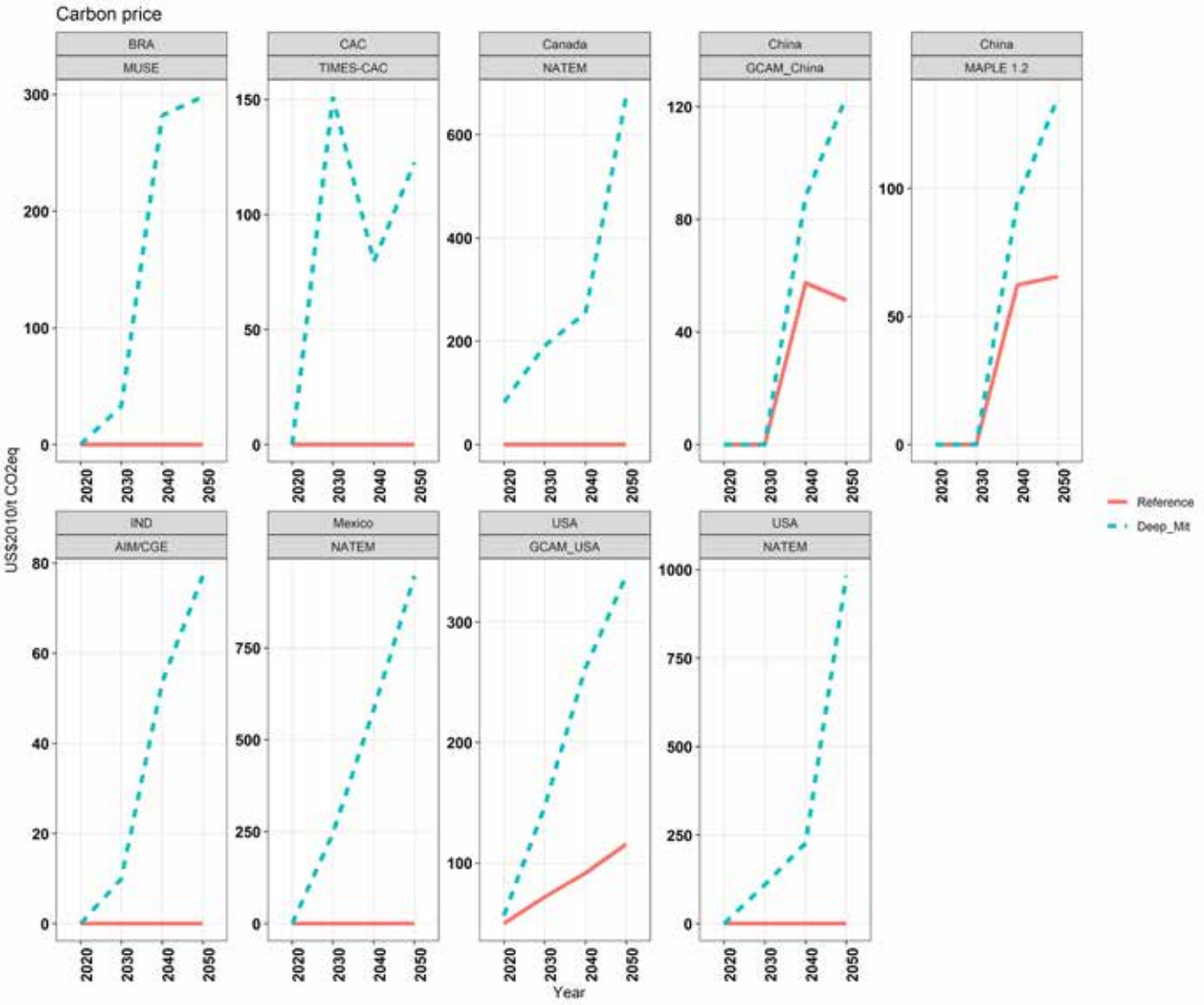


Figure 9: Carbon price evolution in each scenario

Note: Russia — the CONTO model does not calculate carbon pricing.

3.3 Primary energy demand

The primary energy evolution in each region's reference versus mitigation scenario shows a considerable degree of inter-regional variation, reflecting the starting energy mixes and national resource and energy reliance contexts of each region. However, in almost all cases, the mitigation scenarios have less primary energy demand by 2050, compared to the reference scenarios. The exception is Mexico, which sees considerable direct air capture deployment in the 2040s, leading to a large increase in primary energy demand. For each region in turn, the following key primary energy system transformations occur:

- In Brazil, a significant shift by 2050 is the replacement of gas and coal with biomass, driven by the expansion of the biofuel industry to serve the road transport sector, and by the uptake of biomass in the industry and power generation sectors, where the integration with CCS leads to negative emissions. The system increases the demand for electricity, driven primarily by transport, where light duty vehicles become fully electrified by 2070.

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

- In the CAC region, the dominance of gas in primary energy is considerably reduced by the increase in solar and wind. Oil and coal demand are also reduced, within the context of smaller primary energy demand, reflecting a more energy-efficient economy over time.
- In Canada, there is a marked shift away from oil and gas, with nuclear becoming the dominant primary energy source, whilst biomass, wind, and solar also grow.
- The two models running China scenarios (GCAM-China and MAPLE) show two contrasting storylines of shifts away from China's coal-dependent economy. The overall primary energy mix is relatively unchanged from the reference to the deep mitigation scenario in GCAM-China, although coal use is down about one-third by 2050, and with considerable CCS as indicated in Figure 8. In MAPLE, fossil fuels are nearly completely phased out by 2050, with nuclear, solar, and wind dominating primary energy by 2050.
- India shows a marked shift away from coal reliance all the way through to 2050 in the reference scenario, shifting to (less carbon-intensive) gas and oil, as well as solar, wind (to a lesser extent), and greater reliance on biomass.
- Mexico sees a near-complete shift away from oil, towards wind and solar, as well as other renewables, which dominate in 2050.
- Russia sees a shift from gas reliance in the reference scenario, towards greater renewables, hydro, and nuclear in the deep mitigation scenario. Although the share of oil and gas in primary energy consumption remains high, a significant part of this is used for non-energy needs (petrochemicals). The share of non-energy use of liquid and gaseous energy resources increases from the current 15% to 45% by 2050 in the deep mitigation scenario.
- The two USA models show a similar storyline for reference scenario primary energy usage: GCAM-USA shows a shrinking of oil and gas, as solar as well as—to a lesser extent—wind and nuclear emerge. NATEM shows a similar transition but with wind emerging in favour of solar. Both models see a fairly similar mix of primary energy sources by 2050 in their deep mitigation scenarios, dominated by renewables (solar, wind, biomass), again with GCAM-USA favouring solar and NATEM wind.

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

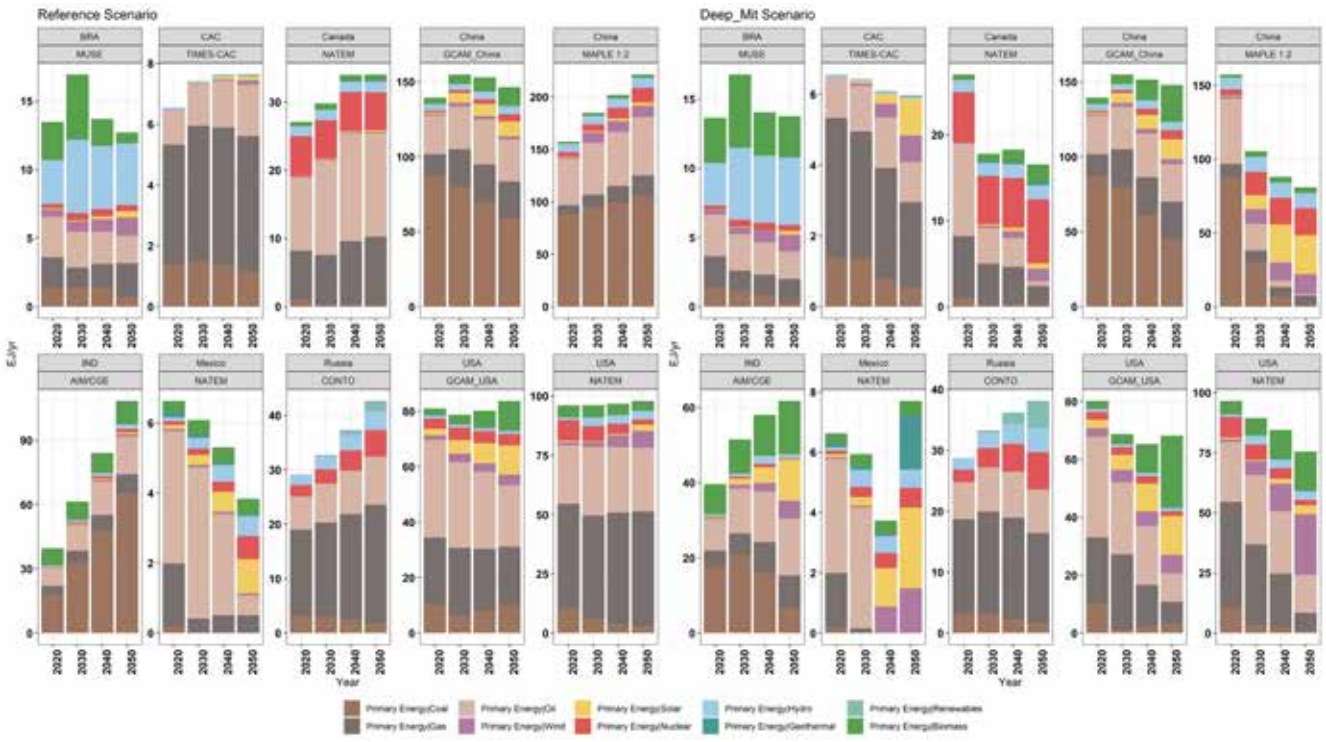


Figure 10: Primary energy demand by source, in reference and deep mitigation scenarios

Note: GCAM-USA and GCAM-China report primary energy consumption, whereas NATEM (USA) and MAPLE (China) report primary energy production, including that exported but excluding imports.

3.4 Final energy demand

In terms of final energy, the principal shifts across all countries comes from a shift away from solid and liquid (mainly coal and oil) towards electrification in the deep mitigation scenarios.

- In Brazil, there is also an increasing reliance on biomass in the industrial manufacturing sector (see Figure 15 below) as well as—to a lesser extent—in the buildings sector (Figure 13 below).
- The CAC region sees a rapid substitution of electricity for coal and gas, driven by renewables growth, particularly in the post-2030 period.
- Canada's rapid post-2030 electrification encroaches on both gas and oil, and there is in addition a notable increase in hydrogen in this period.
- In China, GCAM-China sees a relatively small growth in electricity as a share of final energy by 2050. MAPLE shows a high share of electrification up to 2050, especially in the final end-use sectors. However, the electricity generated in the reference scenario is still dominated by fossil fuels, with a significant shift to non-fossil in mitigation scenarios.
- In India, there is a shift away from coal, and an expansion of biomass and other renewables (wind and solar).
- In Mexico, there is a strong trend towards electricity, though oil (liquids) retains its significant share of final energy.

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

- In Russia, final energy remains dominated by liquids and gases, but the overall size of the energy system is smaller in the deep mitigation than in the reference scenario.
- In the USA, final energy becomes increasingly electrified in both GCAM-USA and NATEM, but in the latter (NATEM) the final energy system also sees an increase in hydrogen in the deep mitigation scenario.

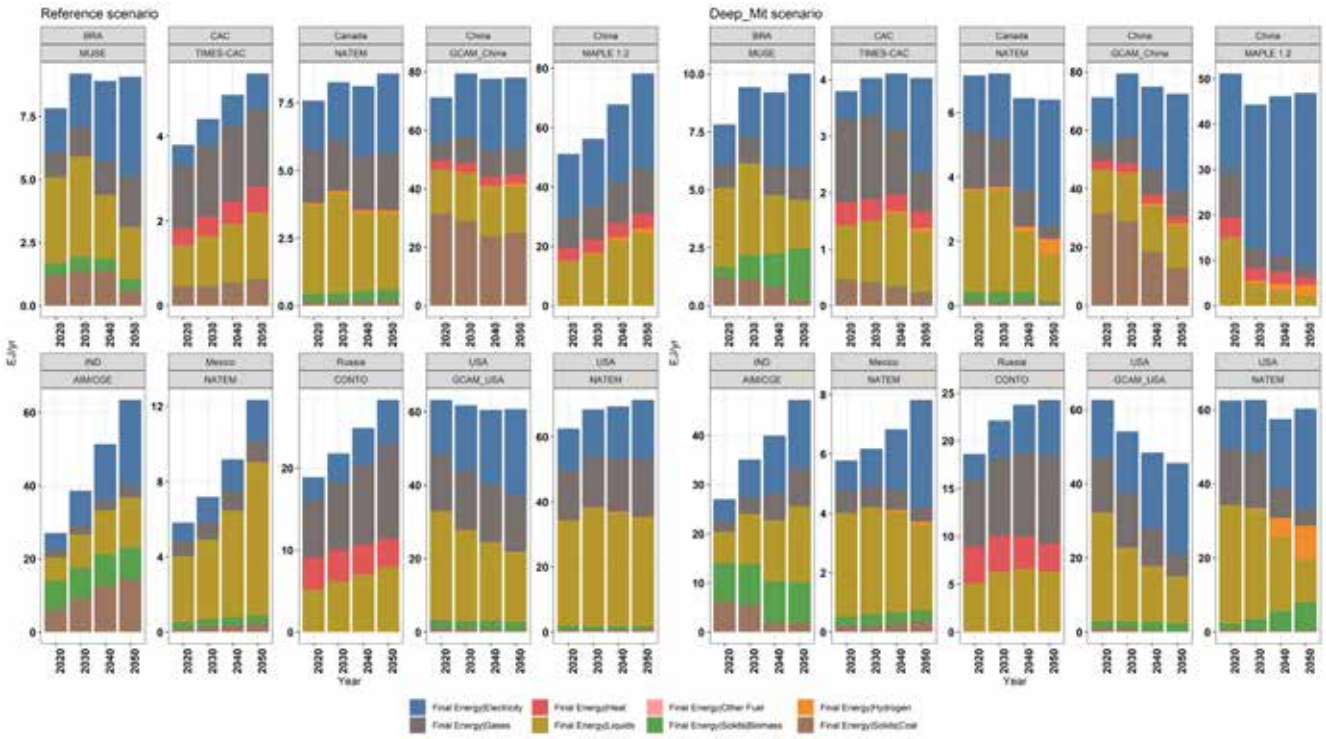


Figure 11: Final energy by source, in reference and deep mitigation scenarios

3.5 Electricity generation

Considering the electricity generation mix in each country, there are a number of different trends towards decarbonisation:

- Brazil shows virtually no change between the reference and deep mitigation scenarios, with hydro power dominating, and a steady growth of wind power in both scenarios.
- The CAC region sees a very different electricity generation mix evolution when comparing its reference and mitigation scenarios, with the reference however seeing rapid growth of unabated gas generation, and the mitigation scenario dominated by wind and solar growth.
- For Canada, in both the reference and mitigation scenarios, hydro-electricity retains its dominance, but although in the reference scenario this is joined by an increase in gas generation over time, in the deep mitigation scenario it is joined by solar and wind, with greater nuclear growth than in the reference scenario.
- In China, both models show the reference scenario with a continuing reliance on coal generation, though in GCAM-China it is joined by solar and in MAPLE by wind. In the China deep mitigation scenarios, solar and nuclear dominate new generation growth in MAPLE, whereas in GCAM-China there is a much more

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

balanced mix of electricity generation sources, though with a large role for solar. Coal remains an important source of generation by 2050, though it is by this time all fitted with CCS.

- India's reference scenario sees continuing reliance on coal, whereas by contrast its deep mitigation scenario sees a complete shift towards solar and wind.
- Mexico's gas reliance in the reference scenario is replaced by solar, wind, and geothermal electricity generation in the deep mitigation scenario.
- Russia's fossil fuel reliance in the reference scenario gives way to increasing shares of nuclear, hydro, and other renewables (wind and solar) in the deep mitigation scenario.
- For the USA, GCAM-USA sees strong renewables (principally solar) growth even in the reference scenarios, whereas NATEM shows strong wind growth. In the deep mitigation scenarios, renewables come to dominate electricity generation by 2050, in both models, with GCAM-USA showing strong solar and wind growth, and NATEM strong wind growth in particular.

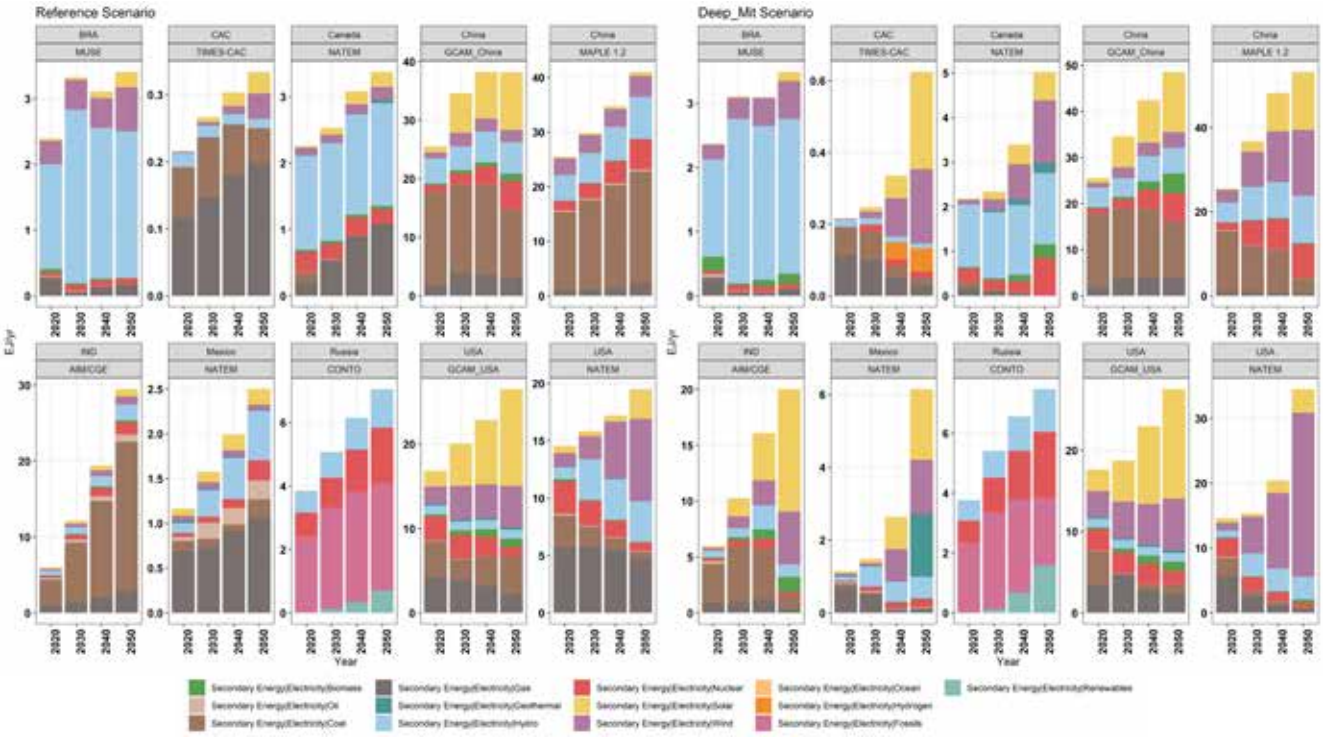


Figure 12: Mix of electricity generation in reference and deep mitigation scenarios

3.6 Buildings final energy

All regions see strong electrification of buildings final energy towards 2050, most marked in Canada, where there is near-complete electrification by mid-century. Brazil is heavily reliant on biomass solids by 2050. India and Mexico also remain heavily dependent on coal and biomass solids to 2050 even in the deep mitigation scenarios, whilst other regions—notably USA, Russia, and China—see a continuing role for gas in building final energy in these mitigation scenarios. Furthermore, it should be noted that all regions see energy efficiency improvements across their buildings sectors, when comparing the mitigation to reference scenarios.

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

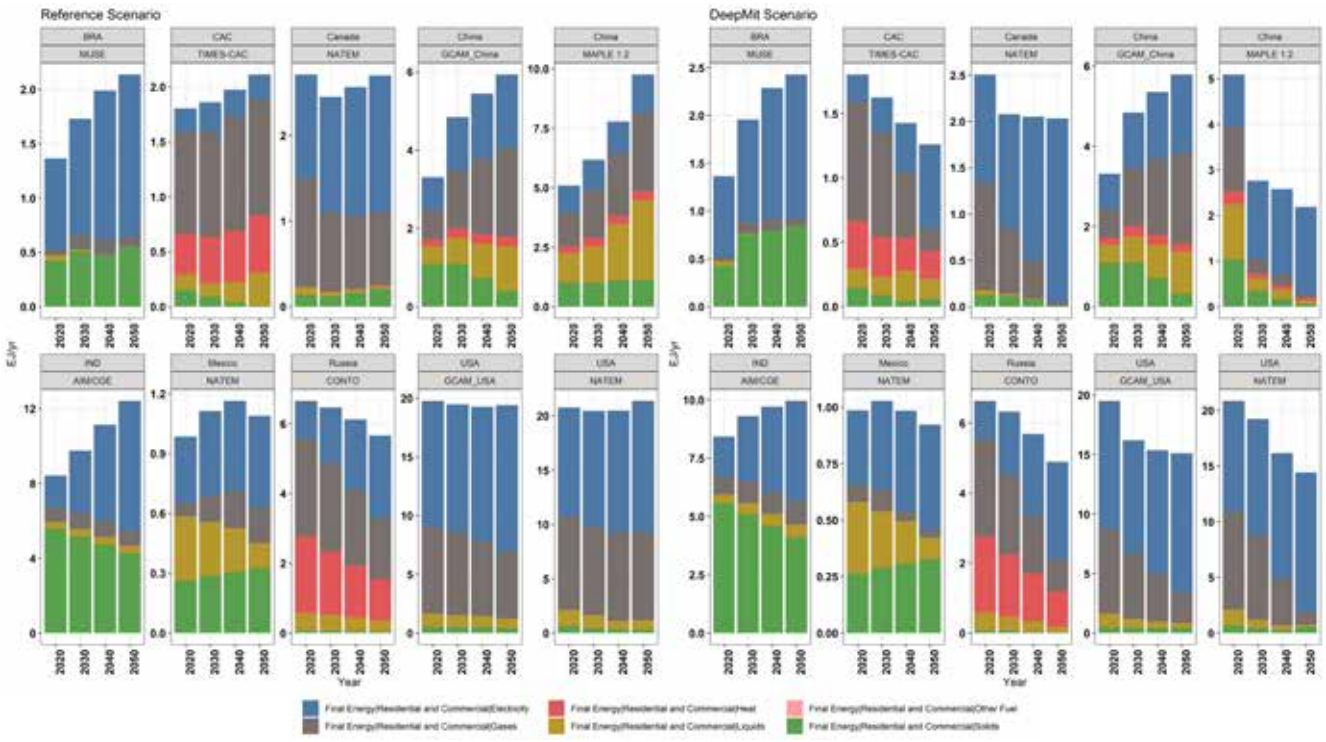


Figure 13: Buildings final energy mix in reference and deep mitigation scenarios

3.7 Transport final energy

The transport sectors of each region remain highly reliant on liquids (primarily oil, though in some regions—Canada, USA, China—a ~5-10% role for biofuels), with the exception of China, where electrification of transport is notable (particularly in the MAPLE model) by 2050. Otherwise, gas replaces oil in many countries, thereby reducing the carbon intensity of transport. In almost all regions (with the exception of Brazil) there is a fall (of the order 10-20% in most cases) in final energy of transport by 2050, when comparing the reference and deep mitigation scenarios.

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

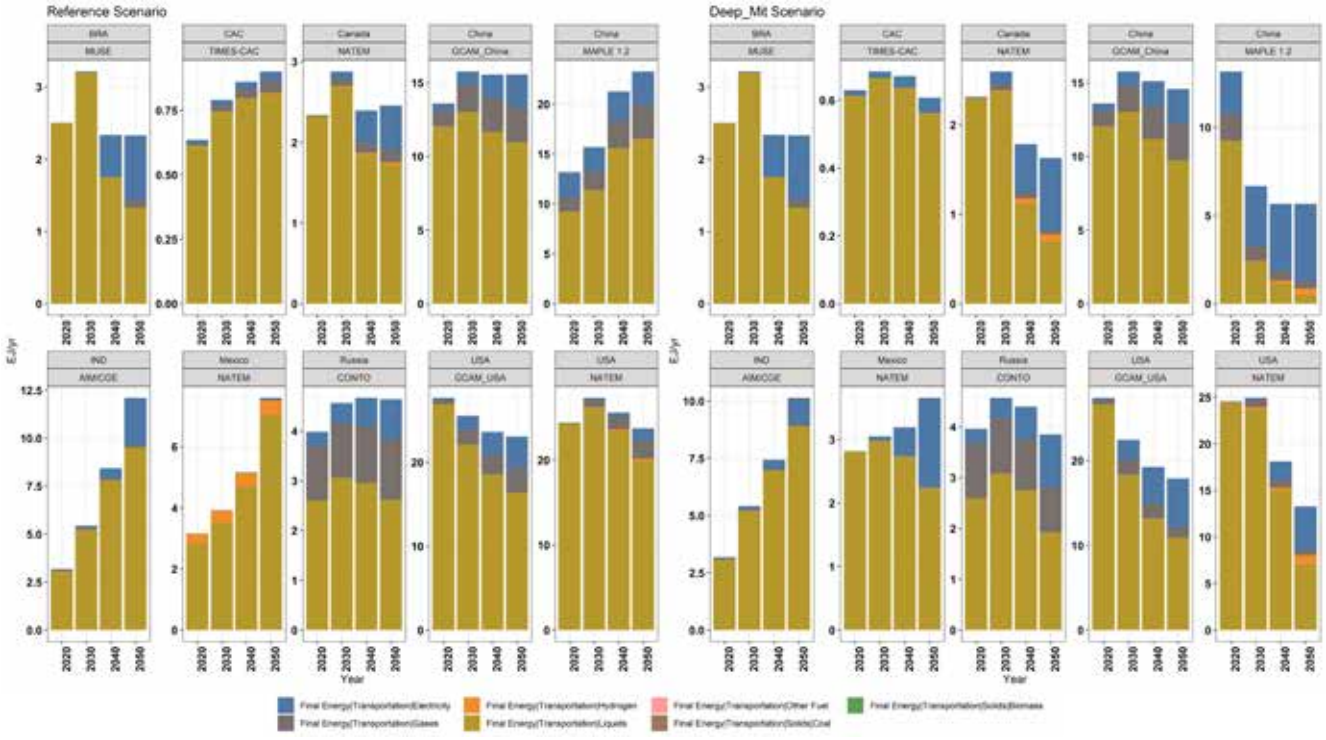


Figure 14: Transport final energy mix in reference and deep mitigation scenarios

3.8 Industry final energy

In each country, there is steadily increasing electrification of the industrial manufacturing sectors to 2050 in the deep mitigation scenarios. One exception is Brazil, which sees biomass replacing gas when comparing the reference with the deep mitigation scenario. In addition, in Brazil, CCS is present in the chemical and the iron & steel subsectors, whereas the cement industries display CCS with bioenergy. In Russia, industrial manufacturing decarbonisation concerns mainly energy efficiency and electrification, some hydrogen. It should be noted that the industrial manufacturing sector sees the least drastic energy system change overall, in line with the realisation that this is likely to be a sector of relatively high “residual” emissions (Luderer et al., 2018).

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

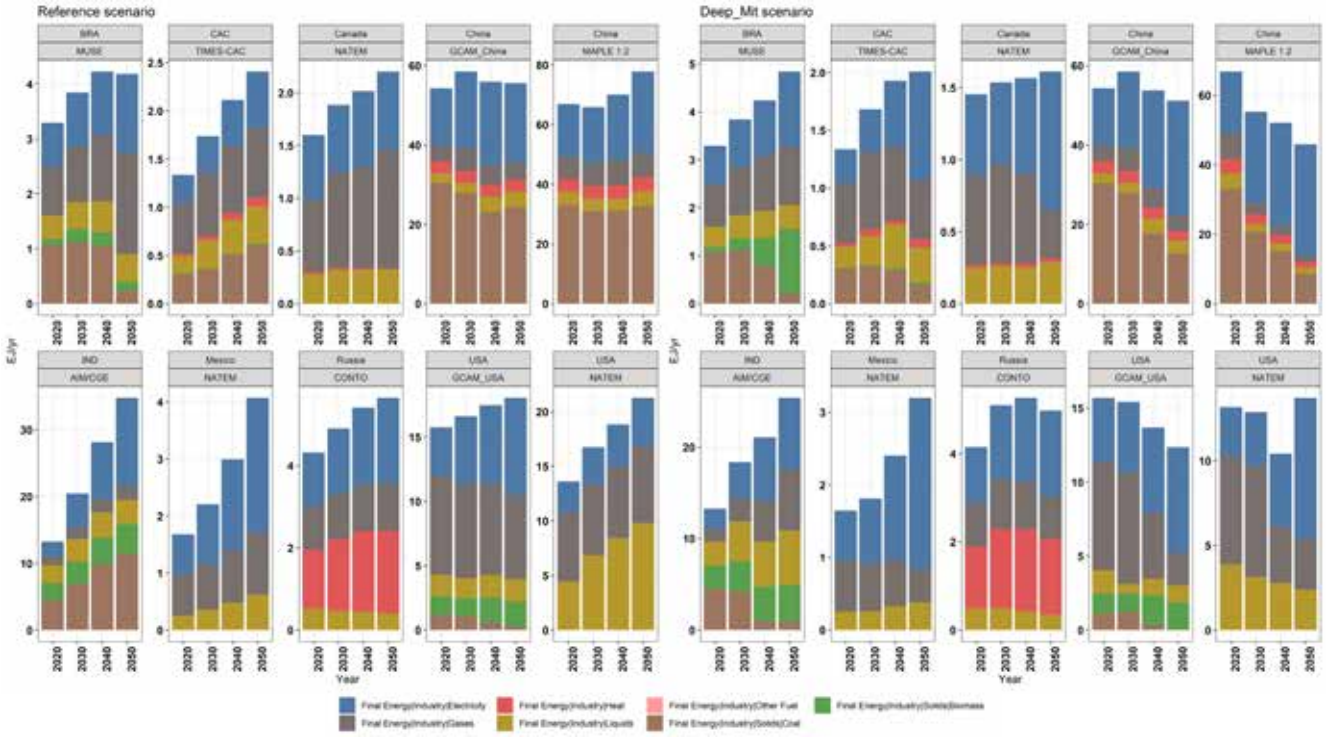


Figure 15: Industry final energy mix in reference and deep mitigation scenarios

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

4 Conclusions

Engaging stakeholders in scenario co-creation has highlighted a number of important attributes of deep mitigation pathways analysis. For example, in most cases the majority of stakeholders in the three regions for which specific polling was undertaken (Russia, China, India) feel that the NDC targets for 2030, around emissions, emissions intensity, and/or specific targets such as nuclear, renewables, and electric vehicles are achievable. A significant share of polled stakeholders have also indicated that there is potential to go beyond these NDC commitments. This paves the way for ratcheted climate action through the 2030s and beyond.

Another key aspect of scenario co-creation has come from the identification of important barriers and opportunities stemming from low-carbon pathways. In the USA, for example, early consultation with on-the-ground collaborating organisations highlighted the importance of both jobs and equity in low-carbon pathways development. In Russia, key issues discussed in the workshop stemmed from a consideration of the forestry sector, as well as the cost reduction and scale-up prospects of both nuclear and renewable energy sources. In China, a strong focus on policy design, for example through emissions trading system development, was brought to light. In India, integration of renewables in the grid, managing decarbonisation in the context of rapid urbanisation, and the air quality issues stemming from continued fossil fuel use were all discussed. In the Central Asian Caspian region, a strong focus on energy tariffs, water resources, and energy trade dominated discussions. Each of these aspects can be further investigated in ongoing research in PARIS REINFORCE, notably through the next WP6 deliverable, D6.4: Ancillary impacts, including SDGs, of national low-carbon pathways outputs.

Key insights from the scenarios modelled in this study are that, in many cases in line with stakeholder views, it is possible to decarbonise national energy systems across the world, through replacing unabated fossil fuels with a combination of renewables, nuclear, and carbon capture and storage, with energy efficiency playing a critical role throughout the economy. The scenario design specificities require high penetrations of electric vehicles in some regions by 2030, but even with these the share of electricity in overall transport sectors is not dominant in the first half of the century. Some countries (notably Russia and China) remain dependent on fossil fuels in some of the modelled scenarios, which means that net-zero will come from carbon capture and (in the case of Russia) considerable forestry sinks. The analysis also suggests that China and Russia, as well as Canada, could have relatively high shares of nuclear by mid-century, with a notable role for nuclear in electricity generation in the US and India as well. The rapid electrification across many sectors, with new low-carbon sources being deployed, will not happen without considerable investment, and carbon prices in these scenarios are broadly in line with other literature showing rapid 1.5°C-consistent transitions over the coming decades.

Next steps for the analysis documented in this deliverable include using the stakeholder views, as well as resultant low-carbon pathways, to feed into a second round of global mitigation modelling, so as to make the representation of global low-carbon pathways in integrated assessment models more realistic, and more reflective of stakeholder views.

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

References

Canada Energy Regulator (2020). Canada's Energy Future 2020, available at: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html

Giarola, S., Mittal, S., Vielle, M., Perdana, S., Campagnolo, L., Delpiazzo, E., ... van de Ven, D. J. (2021). Challenges in the harmonisation of global integrated assessment models: A comprehensive methodology to reduce model response heterogeneity. Science of The Total Environment, 783, 146861. https://doi.org/10.1016/J.SCITOTENV.2021.146861

Hultman, N.E., Clarke, L., Frisch, C. et al. Fusing subnational with national climate action is central to decarbonization: the case of the United States. Nat Commun 11, 5255 (2020). https://doi.org/10.1038/s41467-020-18903-w

Huppmann et al. (2018) Scenario analysis notebooks for the IPCC Special Report on Global Warming of 1.5°C. 2018. doi: 10.22022/SR15/08-2018.15428

Luderer, G., Vrontisi, Z., Bertram, C. et al. Residual fossil CO2 emissions in 1.5–2 °C pathways. Nature Clim Change 8, 626–633 (2018). https://doi.org/10.1038/s41558-018-0198-6

Pizarro-Irizar, C., Gonzalez-Eguino, M., van der Gaast, W., Arto, I., Sampedro, J., & van de Ven., D-J (2020) Assessing stakeholder preferences on low-carbon energy transitions, Energy Sources, Part B: Economics, Planning, and Policy, 15:10-12, 455-491, https://doi.org/10.1080/15567249.2020.1812767

Sognnaes, I., Gambhir, A., van de Ven, D.-J., Nikas, A., Anger-Kraavi, A., Bui, H., ... Peters, G. P. (2021). A multi-model analysis of long-term emissions and warming implications of current mitigation efforts. Nature Climate Change, 11(12), 1055–1062. https://doi.org/10.1038/s41558-021-01206-3

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