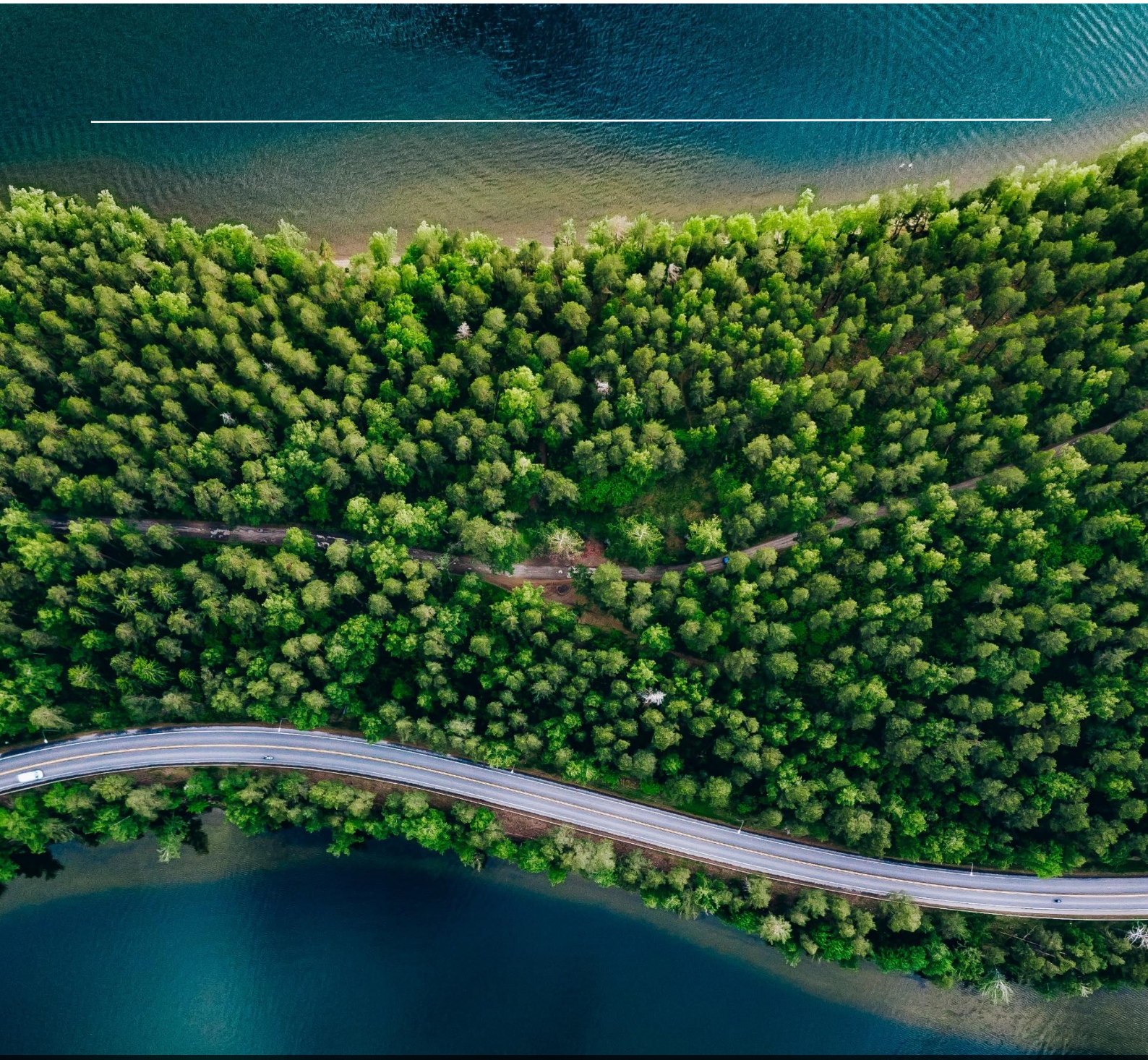

CLIMATE CHANGE MODELLING INFORMATION

Quarterly report – Q1 2023 report

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A report submitted by ICF S.A.
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High-level executive summary

This report under the "Climate change modelling information" series presents recent developments reported by key international climate modelling institutions. This issue sets a particular emphasis on methane emissions and emissions reduction options, hard-to-abate sectors, in addition to the regular sections on implementation of NDCs and mid-century strategies.

Methane emissions and emissions reduction options are important in the context of climate change mitigation, considering that non-CO2 greenhouse gas, like methane, contribute directly to global warming. Main sources of methane emissions include the production and transport of coal, natural gas and oil, but also livestock, some agricultural activities and landfills.

The first section of the report features different studies on modelling **Methane emissions and emissions reduction options** linked to climate change. Researchers from **New Zealand** represented a methane-reducing technology for livestock, while in **Canada** researchers analysed emissions from manure considering the type of management and the region. The section also features a review from the **USA** on the advancements on emissions from the permafrost and a study focusing on methane emissions from the natural gas industry.

The second section focuses instead on **hard to abate sectors**, featuring emissions reduction option from ship engines in a study led by researchers from **Finland**, as well as on the steel industry in China in the context of achieving carbon neutrality in a research led by **China**. Also clean hydrogen is explored in a study led by the **USA**, as a way to break the Chinese bottleneck to carbon neutrality.

An overview of developments linked to **Mid-century strategies is** reported in the third section, featuring a study from **the Netherlands** which models the North Sea energy system in 2050, another one from **France**, focusing on hydrogen and the energy system in Europe in 2050, and another one which combines the energy system and road freight in **Norway**.

In the last section, the report features research linked to **Nationally Determined Contributions (NDCs),** featuring a study from **Indonesia** on the role of international climate finance towards the achievement of the NDCs, highlighting the importance of strengthening green-bonds and non-public finance also domestically; another study from **China** analyses the ambition of updated NDC, suggesting that developed Parties should take the lead in further ratcheting up the NDCs while increasing financial and technological support to developing countries to close the gap to 1.5 °C. Finally, research led by modellers in **Italy** explores the impact of the Glasgow commitments towards the achievement of the Paris Agreement, finding that major economies with the Glasgow net-zero pledges will need substantial increase investments in electric transport and power generation to meet the Paris goals.

Introduction

This report is the first quarterly report of 2023 under the series "Climate change modelling information" financed by the European Commission. The objective of this series is to inform the European Commission and the wider climate change and energy modelling community about recent and relevant modelling developments. The data presented in this report is the result of desk research and answers received through the survey that was shared with our community of modellers and researchers. The survey received inputs from organisations based in New Zealand, Turkey, and Kenya.

The survey asked modellers to report relevant developments with a focus on **methane emissions and emissions reduction options**, **hard-to-abate sectors**, in addition to the regular sections on **implementation of NDCs** and **mid-century strategies.**

Although the report seeks to provide a comprehensive overview of recent developments, it cannot be considered exhaustive.

The modelling developments discussed in this report are summarised below and further described in the coming chapters.

Modelling developments linked to methane emissions and emissions reduction options

- The Climate PoLicy ANalysis (C-PLAN) Model, Version 1.0 (New Zealand)
- Regional climate influences manure temperature and methane emissions – A pan-Canadian modelling assessment (Canada)
- Permafrost and Climate Change: Carbon Cycle Feedbacks From the Warming Arctic (USA)
- Assessing Methane Emissions From the Natural Gas Industry: Reviewing the Case of China in a Comparative Framework (USA)

Modelling developments linked to hard-to-abate sectors

- Breaking the hard-to-abate bottleneck in China's path to carbon neutrality with clean hydrogen (USA)
- Reduction in greenhouse gas and other emissions from ship engines: Current trends and future options (Finland)
- The CO2 emission reduction path towards carbon neutrality in the Chinese steel industry: A review (China)

Modelling developments linked to mid-century strategies:

- Modelling a highly decarbonised North Sea energy system in 2050: A multinational approach (The Netherlands)
- Hydrogen and the decarbonization of the energy system in Europe in 2050: A detailed model-based analysis (France)
- Modelling the interaction between the energy system and road freight in Norway (Norway)

Modelling developments linked to implementation of NDCs:

- Revisiting the role of international climate finance (ICF) towards achieving the nationally determined contribution (NDC) target: A case study of the Indonesian energy sector (Indonesia)
- Comparison and analysis of mitigation ambitions of Parties' updated Nationally Determined Contributions (China)
- Glasgow to Paris—The impact of the Glasgow commitments for the Paris climate agreement (Italy)

Modelling developments linked to methane emissions and emissions reduction options

- Researchers from New Zealand, led by the Auckland University of Technology, described the representation of a methane-reducing technology for livestock in a Computable General Equilibrium (CGE) model. They used the C-PLAN model, a global, open-source, recursive dynamic CGE model tailored to the economic and emissions characteristics of New Zealand. The model offers a detailed representation of agricultural sectors, methane-reducing technologies for dairy farming and beef and sheep farming, geothermal electricity with CCS, bioheat for industrial sectors, electric vehicles for commercial and household transport, and explicit representation of free, output-based permit allocations. More details can be found here.

  The research argues that the development and deployment of new technologies are important determinants of the costs of reducing biogenic methane emissions, in the context of an Emission Trading Scheme (ETS) with emissions caps decreasing over time. If alternative production techniques are not available, a sector can reduce emissions by reducing its output, which can impact GDP. As the carbon price increases between 2030-2035 with the tightening of the cap, the study finds that methane-reducing technology for dairy farming and beef and sheep farming (with improved effectiveness over time) will result in lower costs for meeting New Zealand reduction target for biogenic methane emissions.

  Policy implications: the model was built for the New Zealand Climate Change Commission (CCC) to provide policy advice to the government. The model could support decision-makers in ensuring transparency in policy developments and build capacity and strong evidence for future analyses.

- Researchers from Canada, led by Agriculture and Agri-Food Canada, published a study on the *Science of the Total Environment Journal* that explores the variation of methane emissions from liquid manure in six different climate zones, representing different regions across Canada, over 30 years. The model, Manure-DNDC, was used to model daily methane emissions, considering two manure storage emptying scenarios, 1) early spring and autumn, or 2) late spring and autumn.

  Results show that the regional climate influenced methane emissions with difference of up to 80% between regions; for example, emissions were greater in the pacific maritime and great lakes regions than the prairie region. Also, inter-annual weather variability led to substantial variation in inter-annual methane emissions. The analysis of the two scenarios shows that early manure storage emptying (vs late removal) reduced methane emissions in some regions but had a small effect or the opposite effect in other regions.

  Policy implications: mitigation practices will require region-specific measurements and consider local weather patterns (relative to climate normal) to determine the impact of emission-reducing interventions in each region.

- A review published on the *Annual Review of Environment and Resources*, conducted by researchers from the USA, Canada, Sweden and Germany, provides an update on the latest knowledge related to Arctic environmental change and particularly on understanding how much permafrost carbon will be released, over what time frame, and what the relative emissions of carbon dioxide and methane will be.

The review finds that abrupt thaw[1] represents a threshold change that degrades permafrost significantly faster than gradual top-down warming alone. In the Artic landscape, a sizeable fraction (20%) that has high ground ice content, is susceptible to abrupt thaw with warming. Abrupt thaw degrades permafrost and also changes the distribution of upland and lowland ecosystem types, alternating carbon dioxide and methane emissions. Studies show that the greenhouse gas equivalent of additional CO2 and CH4 emissions from abrupt thaw can add 40% to projections of carbon release by top-down gradual thaw.

Policy implications: quantifying and understanding the impact of emissions released from permafrost is important in order to assess their influence on the global society and to the people living in the arctic region. It also supports better understanding of its landscape-level responses to a changing climate.

- A paper published by a group of researchers from the USA, China and Belgium, and led by the School of Engineering and Applied Sciences of Harvard University, focuses on natural gas industry emissions in three countries: the United States, Canada, and China. Researchers focused on 210 key studies, finding that China has much less research on methane emissions from the natural gas industry.

  The study concludes that methane emissions from the natural gas production phase are the largest in the whole natural gas supply chain and that there is large mitigation potential for methane emissions from the natural gas industry. Researchers argue that more effective waste reduction technologies, like green well completion, should be used in the production phase, especially in China. Also, all countries compared in the study should draw more attention on the need for leakage detection technologies of pipelines.

  Policy implications: to achieve climate targets it is important to enhance methane emissions mitigation measures and leakage detection technologies. The joint development of multi-disciplinary methane quantification technology will become an area where major gas-producing and consuming countries can work together.

Modelling developments linked to hard-to-abate sectors

- An article published on *Nature Energy* led by Harvard University carried out an integrated dynamic least-cost modelling analysis to explore the role for clean hydrogen in reducing emissions from heavy industries and heavy-duty transport for China. Researchers defined four modelling scenarios, 1) business as usual (BAU), 2) China's Nationally Determined Contributions under the Paris Agreement (NDC), 3) net-zero emissions with no-hydrogen applications and 4) net-zero emissions with clean hydrogen. The hard to abate (HTA) sectors included in this study are the industrial production of cement, iron and steel and key chemicals (including ammonia, soda and caustic soda) and heavy-duty transport, which includes trucking and domestic shipping.

  The study shows that relying on the improvement of energy efficiency combined with carbon capture, use and/or storage (CCUS) and negative emission technologies (NETs) alone is unlikely to be a cost-effective path for deep decarbonisation of China's HTA sectors, especially heavy industries. Clean hydrogen could be a more

[1]Abrupt thaw is defined by the authors as the "loss of ground ice resulting in subsidence, redistribution of surface water perched on permafrost, and subsequent erosion that exposes deeper permafrost to thaw more rapidly than with changing temperature alone."

cost-effective decarbonisation solution in many hard to abate areas in China, helping the country meet its 2060 carbon neutrality target.

Policy implications: to achieve net-zero targets, the energy system will need to be dominated by renewable sources. In this context hydrogen offers an opportunity to indirectly extend the benefits of renewable power to other sectors. China, as other countries, could evolve from a fossil fuel importer into a green hydrogen exporter. Clean hydrogen presents emerging new opportunities and challenges that relevant for other countries as well, rethinking their relationship to HTA sectors for a net-zero world.

- A research team led by the VTT Technical Research Centre of Finland performed a review to asses the available options to reduce ship emissions. This review examines possibilities to mitigate ship emissions in the atmosphere, focusing on emissions that contribute to global warming and climate change and emissions with negative impacts on human health and the environment. Marine engines and carbon-neutral fuel options and emission control choices are introduced, and emission factors are presented for large engines at engine loads above 40%.

  The review finds that the impact of ship emission reductions can be maximised by considering climate, health, and environmental effects simultaneously and using solutions fitting into existing marine engines and infrastructure. Promising solutions include, for example, dual-fuel marine engines for methane and methanol, which use diesel as a back-up and primarily use their carbon-neutral counterpart, such as bio-, waste- or electro-based fuels.

  Policy implications: the combination of carbon-neutral drop-in fuels and efficient emission control technologies would enable (near-)zero-emission shipping that could be already used in the short- to mid-term. The introduction of policies and investments to support developments in retrofitting or improve solutions compatible with existing ship fleet could help unlock net-zero shipping.

- A group of researchers form China, led by the North-eastern University of Shenyang in China, explored the steel industry's CO2 emission reduction path to carbon neutrality in a review published on the *Environmental Assessment Review* journal. Accounting for 13% of the country's total consumption and 15% of CO2 emissions, decarbonising this industry is key for achieving China's National Determined Contributions target to peak CO2 emissions by 2030 and goal to be carbon neutral by 2060.

  Researchers find that additional efforts in terms of industrial structure, material efficiency, energy efficiency, and low- or zero-carbon technologies are required to achieve a low-carbon transition. The study also suggests that a deep decarbonization could be achieved by combining CCUS and hydrogen metallurgy technologies.

  Policy implications: the steel industry requires collaborative efforts to standardize CO2 emission accounting methodologies and policy-makers should consider the establishment of a carbon trading system to strengthen carbon emission management.

Modelling developments linked to Mid-century strategies

- In a study published on *Advances in Applied Energy,* researchers led by the University of Groningen, analysed different optimal system configurations to achieve net-zero emissions in the North Sea energy system by 2050. The IESA-NS model was developed for the study; this is an optimization integrated energy system model written as a linear problem, that optimises the long-term investment planning and short-term operation of seven region countries in the North Sea (Belgium, Denmark, Germany, the Netherlands, Norway, Sweden and the United Kingdom), accounting for all the national GHG emissions and including a thorough representation of all the sectors of the energy system. Several decarbonisation scenarios for 2050 net-zero targets were run.

  Results from the modelling suggest that a more interconnected offshore infrastructure (e.g. power, hydrogen and CCS offshore grids) can be beneficial for the system. Moreover, researchers find that there is a difference between the Scandinavian countries (Denmark, Sweden and Norway) and the rest of the North Sea Region (Germany, the Netherlands, Belgium and the UK), when it comes to system costs. Across all the scenarios, Scandinavian countries can meet their targets without a high increase of system costs, with relatively low CO2 shadow prices and low energy costs. Whereas, the rest of the North Sea Region, notably Germany, pays a higher price, especially in constrained scenarios.

  Policy implications: the findings from the study highlight the importance of developing multinational energy system models to better understand the impacts of national and regional policies in the context of a highly interconnected energy system.

- Researchers led by the *IFP Energies Nouvelles* studied the potential of low-carbon and renewable hydrogen in decarbonizing the European energy system, in the context of reducing emissions by 55% in 2030 compared to 1990, and reaching net-zero emissions by 2050 (the study can be found here). Researchers used there different models complementarily following a cost-optimization modelling approach: a European TIMES-type model (MIRET-EU); an aggregated model for the European energy system, allowing endogenous cost reductions based on technology deployment in a dynamic programming formulation for investment strategies (Integrate Europe); and a dedicated model for assessing hydrogen import options for Europe (HyPE). Researchers also developed two policy-relevant scenarios: a Technology Diversification (TD) and Renewable Push (RP).

  Results show that hydrogen production could increase sharply over the next decades, exceeding 30 million tons by 2030 and more than 100 million tons by 2050 in both scenarios. Around 1800 GW of solar and wind power will be needed for the production of renewable hydrogen. Nonetheless hydrogen production will be complemented also with imports from neighbouring regions, corresponding to between 10 and 15% of total demand in 2050.

  Policy implications: the access to existing cross-border pipelines represents a critical advantage for hydrogen use compared to maritime transport, which policymakers should consider if they are to accelerate the development of the hydrogen industry. Furthermore, as the study indicates, there could be considerable cost reductions associated with the combined technology deployment of solar power and hydrogen production with electrolysers.

- An article published on *the Transportation Research Part D: Transport and Environment* journal presents the results from a research conducted by the Institute for Energy Technology in Norway which links models for transport demand, vehicle turnover, and energy generation and use, focusing on light commercial vehicles and heavy-duty trucks and tractor-trailers. Researchers used an energy system model (IFE-TIMES-Norway) to track the relationships between energy prices, fiscal incentives, and optimal vehicle technologies, and a stock-flow vehicle fleet model to calculate the time lag between innovation affecting new vehicles and the penetration of novel technology into the fleet. The models help to estimate the flow of new vehicles with more or less decarbonized powertrains, depending on energy prices and fiscal incentives, thus allowing to give a more realistic assessment of the time needed for radical CO2 mitigation in Norway.

  The study suggests that combining different models can provide more reliable and relevant results to support policy developments. Using this approach, the study suggests that electrification of road freight has limited impact on the energy system, including low peak demand, at the aggregate level; therefore, it points to the feasibility – from a system perspective – of fully decarbonising road freight.

  Policy implications: ambitious climate policy can support significant emissions reduction in the Norwegian road freight sector by 2030. To accelerate the decarbonisation within this transport segment, a sector specific stick and carrot policy might be required to increase the adoption rate of zero emission technologies.

Modelling developments linked to NDCs

- A paper led by the Climate Change Center of Bandung Institute of Technology studies the impact of International Climate Finance (ICF) flows to support the achievement of Indonesia's Nationally Determined Contributions (NDCs). Indonesia has pledged to reduce greenhouse gases emission by 29% using domestic resources (unconditional) and 41% with international support (conditional) from the business as usual (BAU) scenario by 2030. This paper explores to what extent ICF supports the achievement of Indonesia's Nationally Determined Contribution (NDC) target, using qualitative analysis to provide an overview on its climate finance strategies and focusing on the energy sector as a case study.

  The paper finds that several ICF financing channels, such as, loans and grant instruments, could be utilised more optimally by disseminating more information on the requirements for each financing option. Nonetheless, it acknowledges the important role that ICF has in supporting the energy transition from coal-based to renewable energy sources and increasing energy efficiency.

  Policy implications: to meet climate finance needs, developing countries cannot solely rely on international support, and it is necessary to develop innovative financing through various instruments In Indonesia, for example, innovative climate finance instruments could include private sector investments and securities instruments to attract domestic and international funding.

- Researchers from China, led by Tsinghua University, published a study on the *Advances in Climate Change Research* journal, presenting a new framework that integrates equity and economic costs to compare and analyse mitigation ambitions

of Parties' updated NDCs. Researchers used multiple equity-principled allocations to derive the alignment of the updated NDCs with the Paris Agreement goals. Then they further apply a computable general equilibrium model to assess the economic costs of implementing the updated NDCs. The modelling is performed considering a 2 °C and 1.5 °C pathway.

Results show that global 2030 emissions may meet global 2 °C pathway if all Parties achieve their most ambitious mitigation efforts. However, there is still an emissions gap of 10–15 GtCO2 to achieve the 1.5 °C pathway. The study also argues that China's GDP loss will be at 0.43%–0.55% in 2030, which is higher than that of the USA (0.30%–0.38%) and the EU (0.25%–0.28%).

Policy implications: to close the gap to 1.5 °C, this study suggests that developed Parties should take the lead in further ratcheting up the NDCs and increase financial and technological support to developing countries.

- Researchers from the Euro-Mediterranean Center on Climate Change used a detailed-process integrated assessment model (WITCH) to explore the impact of the Glasgow net-zero commitments and compare it to scenarios consistent with the Paris' agreement. The study is available here.

  The study finds that if Glasgow's commitments were fully implemented, it would be possible to close the gap to 2°C, covering more than 80% of the world's needed emission reductions by 2070. The pledges would lead to exceeding 1.5°C, with a temperature increase (50% likelihood) of 1.6C- 1.8C by the end of the century.

  Policy implications: major economies with the Glasgow net-zero pledges will need substantial increase investments in electric transport and power generation. Compared to scenarios with uniform carbon taxation, Glasgow differentiated pledges' are fairer, and deliver better health co-benefits by promoting cleaner air. However, the study acknowledges that they may delay coal phase-out, thus increasing the need for negative emission technologies.

Insights from the 2022 IAMC Annual Meeting

The 15th annual meeting of the Integrated Assessment Modelling Consortium was held in person in College Park, Maryland in the USA, and online between 29 November and 1 December 2022. There were five keynote plenary session, 109 papers presented in the oral parallel sessions, and 144 poster presentations (98 online and 46 in person). The conference was attended by 368 participants, 191 attended in person and 177 online. Participants came from 29 countries.

The first plenary session discussed the data that integrated assessment modelling provides to inform policymakers and to enhance climate ambition at all levels. The second plenary session focused on the scenario analysis in an insecure and fragment world - economically and socio-politically - which is of high relevance for energy and climate change modelling and policy. The third plenary session provided an update on the status of development of community scenarios and the so-called shared socioeconomic pathways (SSP), and discussed remaining issues to be addressed. While the fourth plenary session focused on reflections and evaluation of the outcomes of COP27, the last plenary session centred the discussion around the topics of climate justice and just transition, which brought in different dimensions of the implications of climate policy and climate impacts.

The papers presented in the oral and poster sessions were divided into 18 research topics, including the assessment of national mitigation strategies and the 2023 Global Stocktake; the analysis of deep mitigation strategies; pathways to carbon neutrality in individual sectors; modelling energy demand, lifestyle change and radical energy efficiency improvements; the analysis of circular economy concepts and their consequences for greenhouse gas mitigation; the analysis of distributional aspects of mitigation strategies and just transition strategies; as well as the role of electricity and hydrogen as part of mitigation strategies, adaptation, and land use. Sessions also covered methodological issues, citizen science and novel ways of communicating IAMC results. All posters presented at the meeting are available online on the Conference platform for all registered participants. Information about the speakers and edited recordings of the plenary sessions can be found on the website.

Events

Event	Date and location	Objectives	Topics covered / relevance to climate change modelling	Deadlines
EGU General Assembly 2023	23–28 April 2023 Vienna, Austria	The EGU General Assembly 2023 brings together geoscientists from all over the world to one meeting covering all disciplines of the Earth, planetary and space sciences. It aims to provide a forum where scientists, especially early career researchers, can present their work and discuss their ideas with experts in all fields of geoscience.	The assembly covers all aspects related to geoscience.	Submission of abstracts is now closed.
The International Society for Ecological Modelling Global Conference	2-6 May 2023, Scarborough, Canada	ISEM 2023 aims to provide insights into the current state of the field of ecological modelling, and also highlight the major challenges in supporting adaptive management implementation.	The conference welcomes contributions that present novel strategies to improve the contribution of models to environmental management, including the development of ecological model ensembles, novel uncertainty analysis techniques, Bayesian inference methods, emerging techniques of data assimilation and model optimization.	Registrations are open.
41st edition of the International Energy Workshop	13-15 June, 2023, Golden, Colorado, USA	The International Energy Workshop (IEW) is one of the leading conferences for the international energy modelling research community. In a world of environmental and economic constraints, energy modelling is an increasingly important tool for addressing the complexity of energy planning and policy making.	The conference covers the latest developments on international energy modelling.	Registrations will open soon.
International Conference on Urban Energy System Modelling and Climate Change	17-18 July 2023 Berlin, Germany	The International Conference on Urban Energy System Modelling and Climate Change aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results on all aspects of Urban Energy System Modelling and Climate Change.	The conference covers all aspects of Urban Energy System Modelling and Climate Change.	Submissions of papers is open.