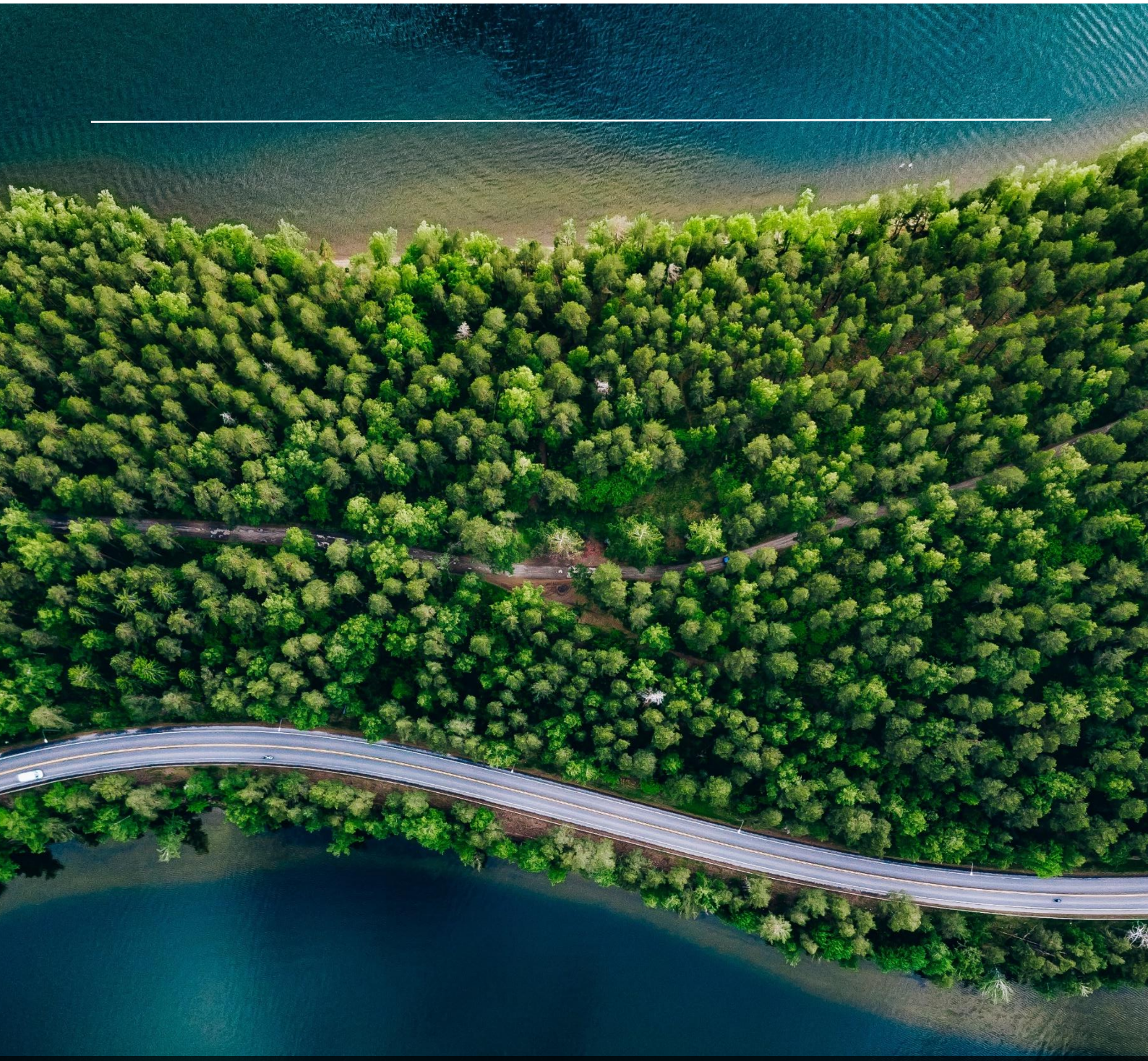

CLIMATE CHANGE MODELLING INFORMATION

Quarterly report – Q1 2022 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 behavioural changes, in addition to the regular sections on Nationally Determined Contributions, Mid-century strategies and the Sustainable Development Goals.

Behavioural change is important in the context of climate change mitigation as behavioural habits have a direct impact on anthropogenic emissions and are a necessary element, alongside technological and policy solutions, of national and international mitigation strategies. Changing a behaviour such as the transport preference, e.g., switching to cycling instead of using the car, or a consumption pattern, etc. using a different plant protection product for crops, can directly reduce greenhouse gas emissions. Modelling changes in behaviour is complex but crucial to be able to help design comprehensive mitigation policies.

The first section of the report features different studies on modelling **behavioural changes** linked to climate change. Research conducted in **Greece** highlights the advantages of rewarding behavioural change in the context of energy efficiency as a way to actively reduce consumption and help achieve climate targets. Researchers led by the Economics Institute of the University of Hohenheim in **Germany** examined new approaches to model the development of the bioeconomy sector, particularly to capture impact of behavioural changes such as lifestyle and consumption patterns. Study conducted in the **United Kingdom** presents a toolkit that considers farmers' behaviour in response to changes in water availability and agricultural export prices.

A number of modelling developments linked to the implementation of the **Nationally Determined Contributions (NDCs)** are reported in the second section. A study conducted in **China** highlights the positive economic and climate benefits of Electric Vehicles participating in *Vehicle To Grid* for the low-carbon transition of the power system. In **India**, researchers reviewed more than 40 energy system scenarios for India to 2050, considering different implementation of NDCs and arguing for improved modelling for policy insight by giving more attention to the development of the overarching socio-economic development scenarios. Research from the **USA** shows the importance of considering trade-offs in decisions making when looking at different sustainable development options to reach long term climate goals through the implementation of the NDCs.

In the third section, the report features research linked to **mid-century strategies.** A study in **Sweden** explores decarbonisation pathways of carbon and energy-intensive industries, showing that full decarbonisation is possible only under very specific assumptions and likely to fall outside of the 2050 timeline. Another study from the **USA** demonstrates how public perceptions of climate change, the future cost and effectiveness of mitigation technologies, and the responsiveness of political institutions are key constraints on controlling global warming. Researchers from **the Netherlands** showed that the energy use of residential sector can become net-zero by 2100, however, the right policy strategies for it should carefully consider the local climate, socio-economic, and building stock characteristics.

The fourth section of the report is dedicated to emerging research on modelling for the **Sustainable Development Goals (SDGs)**. A study in **India** highlights variation in solar yields across different regions over time, showing for example that in the **EU** there is no real threat to future photovoltaic power planning. Research published in **Pakistan** examines air quality and health co-benefits, demonstrating the effectiveness of an integrated approach to pollution control. A research consortium led by **Italy** modelled the water-energy-food nexus by focussing on one of the largest river basins in Africa. The findings pointed to the importance of connecting global climate change

mitigation policies to local dynamics to better understand possible future scenarios for sustainable mitigation and adaptation solutions.

Introduction

This report is the first quarterly report of 2022 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 as no responses were received from the open survey sent to more than 200 modelling teams worldwide.

The survey asked modellers to report relevant developments with a focus on **behavioural changes**, the implementation of **Nationally Determined Contributions (NDCs), mid-century strategies** and the **Sustainable Development Goals (SDGs)**. Although the objective of this report is to present an extensive list of recent developments, it cannot be considered as exhaustive.

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

Modelling developments linked to behavioural changes:

- Monetising behavioural change as a policy measure to support energy management in the residential sector: A case study in Greece (Greece)
- Modelling the bioeconomy: Emerging approaches to address policy needs (Germany)
- A novel modelling toolkit for unpacking the Water-Energy-Food-Environment (WEFE) nexus of agricultural development (United Kingdom)

Modelling developments linked to nationally determined contributions (NDCs):

- Economic and climate benefits of vehicle-to-grid for low-carbon transitions of power systems: A case study of China's 2030 renewable energy target (China)
- Scenarios for different 'Future Indias': sharpening energy and climate modelling tools (India)
- The sustainability of decarbonizing the grid: A multi-model decision analysis applied to Mexico (USA)

Modelling developments linked to mid-century strategies:

- A race to zero - Assessing the position of heavy industry in a global net-zero CO_2 emissions context (Sweden)
- Determinants of emissions pathways in the coupled climate-social system (USA)
- Efficiency improvement and technology choice for energy and emission reductions of the residential sector (The Netherlands)

Modelling developments linked to Sustainable Development Goals (SDGs):

- Future of solar energy potential in a changing climate across the world: A CMIP6 multi-model ensemble analysis (India)

- Co-benefits of air pollution control and climate change mitigation strategies in Pakistan (Republic of Korea)
- Unintended consequences of climate change mitigation for African river basins (Italy)

Modelling developments linked to behavioural changes

- A study published on the *Energy Policy* journal, led by the National Technical University of Athens, examines how behavioural energy efficiency is included in current models and evaluates the monetisation of behavioural change as a viable policy measure to support energy management in the residential sector. The research is carried out by linking an energy efficiency reward mechanism based on a digital energy currency, ATOM, with the Dynamic high-Resolution dEmand-sidE Management (DREEM) model, a bottom-up agent-based model designed to simulate buildings' energy consumption. A case study is provided by a pilot implemented in the Greek residential sector.

  The study finds that monetisation is an effective incentive for households to actively reduce their consumption. Moreover, monetisation allows to quantify behavioural change in monetary units which could help to better integrate social aspects in models. The case study in Greece shows the potential of reducing energy levels by 5.3%, nation-wide, and by 10% at household level, just by rewarding simple energy saving actions such as manually adjusting the thermostat.

  Policy implications: Energy efficiency from behavioural changes is expected to play a key role in meeting future climate targets. The study highlights that monetisation of behavioural change should be considered as a promising policy option, since the monetary reward provides an adequate incentive for end-users to actively reduce consumption and contribute to achieving climate targets.

- An article published on the *Journal of Cleaner Production*, and led by the Economics Institute of the University of Hohenheim in Germany reviews emerging approaches to model the development of the bioeconomy. Modelling developments related to bioeconomy can support in designing transitional pathways for a sustainable and climate-neutral future. Researchers focused the review on how bioeconomy modelling addresses key enabling factors related to, among others, consumer behaviour related to biomass and bioproducts use. In particular, the study examines examples of how to model the impact of preference and lifestyle changes i.e. changes in consumption patterns which are usually complex to capture, such as new modes of diets, leisure activities and mobility.

  The article shows that existing modelling frameworks offer large possibilities analysing short-run impacts related to climate change and circularity, however, for the analysis of long-term development, characterised by fundamental structural changes driven by, for example changing lifestyles, most of the existing modelling approaches are insufficient. Emerging modelling techniques, such as the Agent-Based Modelling, could improve and complement existing bioeconomy modelling efforts, allowing to better capture a complex reality which includes, most importantly, the endogenous capacity of changing structures and qualitative developments.

  Policy implications: Emerging bioeconomy models are valuable instruments to inform policy makers about potential interventions and their impact, as these new models allow for a better understanding of the complex context in which policy intervenes, particularly when capturing impacts from behaviour changes.

- A research published on the journal of *Renewable and Sustainable Energy Reviews* and conducted by the Environment and Sustainability Institute of the University of Exeter as part of the project *NEXT-AG: Nexus Thinking for sustainable agricultural development in*

Andean countries, developed an integrated Water-Energy-Food-Environment (WEFE) Nexus modelling toolkit to cover the biophysical and socioeconomic aspects of agricultural expansion. The toolkit combines different modelling approaches, including a socio-economic analysis module that simulates market dynamics and the behaviours of key actors (i.e. farmers). The purpose is to model farmers' behaviour in allocating land to specific crops in response to external factors such as water resources and market prices.

A series of parameters were developed to reflect the sensitivity of farmers' land use decisions in response to two key changing control variables: water availability and prices of export crops. The sensitivity of these variables was estimated based on historical responses to observed changes in water availability and prices.

The overall results suggests that unless a paradigm shift happens, the long-term viability of agriculture in the region is threatened. In fact, higher prices in agricultural exports drive farmers' behaviour towards prioritising export crops which in turn increases pressure on existing environmental resources (water, land). An increased production in the region could bring different trade-offs, both socio-economic benefits, such as an increase in farm income and jobs, and environmental disadvantages, such as reduced water availability, increased energy competition between sectors and increased Global Warming Potential. Water availability and profitability in these regions are key to farmers decisions.

Policy implications: The toolkit can inform decision-makers and policy development, providing insights into the impacts of future changes in agro-economic and socio-economic policy on agricultural transformation. The socio-economic results are useful for policy makers to estimate the effects of agricultural expansion of specific crops in terms of production mix, land use, profitability, rural employment and difference between small and large farmers considering the limited water resources available. It can help exploring synergies and trade-offs among more local, and short to medium term impacts, such as socioeconomics and water availability, and more global or regional and medium to long term impacts, such as climate change.

Modelling developments linked to Nationally Determined Contributions (NDCs)

- A research led by the University of Exeter and published on the Journal of Cleaner Production conducted in China has constructed a multi-regional power dispatch and expansion model to simulate the economic and climate benefits of different proportions of Electric Vehicles (EVs) participating in Vehicle To Grid (V2G) for the low-carbon transition of the power system, considering China's goal of achieving 1.2 billion kW installed capacity of wind power and photovoltaic power generation in 2030. This article quantitatively estimates the potential of V2G to reduce the total cost and carbon emissions of the power system and improve the utilization of renewable energy.

  The results show that by 2030, the implementation of unidirectional V2G and bidirectional V2G in China can reduce the total cost of power system by respectively 2.02% and 2.08%, reduce the annual carbon emissions of the power system by respectively 2.27% and 2.95%, and increase the total proportion of wind and photovoltaic power generation by 1.33% and 1.28% in the power mix.

Policy implications: The study suggests that, on one hand, encouraging EVs to participate in the unidirectional V2G mode is a suitable policy option with low infrastructure costs before 2030; on the other hand, promoting bidirectional V2G is of limited significance in the context of current China's power mix. It also suggests that priority should be given to implementing V2G in areas with high marginal power production costs, such as Guangdong, East China, Sichuan, and North China grids, where the benefits will be higher than in other areas.

- The Energy and Resources Institute in New Delhi (India) has analysed more than forty energy systems scenarios for India to 2050 in an article published on *the Climate Policy* journal. The analysis is based on the results of a multi-model project called CD-LINKS which developed energy and emissions pathways out to 2050 for several large economies, including India, using seven different models. Given India's unusual historical development pattern and economic structure, different assumptions are made when developing models which led to the development of very diverse scenario results.

  Researchers showed that implicit and explicit assumptions on the broader socio-economic pathway are substantially driving the scenario results, no matter the climate policy considered. Existing modelling studies do not adequately detail and contextualise assumptions about India's macro-scale development pathway, and its links to micro-scale patterns of sectoral energy demand and supply. **To improve modelling** to inform effective policy development, the authors propose that more attention should be devoted to creating overarching socio-economic development scenarios linked to sector dynamics, and contextualising these when unpacking and interpreting model results.

  Policy implications: The task of drawing policy insights is hampered by widely divergent, often non-transparent and insufficiently discussed, assumptions in socio-economic scenarios, such as GDP and its structural attributes as implied by sectoral energy consumption, industrial intensity of GDP, and future sectoral demand patterns. Because India is so critical to the future of global energy demand and emissions growth, understanding its potential future development pathways, and their implications for climate mitigation, is also of global importance.

- A study conducted by researchers in the USA, led by the Appalachian State University in North Carolina, evaluates a number of model-derived pathways for the electricity grid in Mexico aimed at meeting the country's climate goals, using a set of sustainability criteria. A key contribution of this study is the incorporation of detailed geographic information on water use, air pollution, and transmission and carbon capture and storage (CCS) networks. The inclusion of detailed geographic information in the analysis allows to combine environmental and societal impacts of climate mitigation efforts in a way that recognises the importance of the distributional impacts across communities. The research adopts a multi-step multi-criteria decision analysis (MCDA), using six large-scale Integrated Assessment Models (IAMs) and one energy-system model to derive the expansion plans; these reflect the necessary grid expansions for both generation and transmission to reach the desired energy portfolio in 2050, as well as the annual power production plans for each power plant from 2016 to 2050.

  The study finds that the expansion plans for the Mexican electricity grid with more than 20% of energy coming from CCS technologies tend to be less sustainable. This is because, although CCS technologies have low GHG emissions, they have high air

pollution and water use and require the development of extensive pipeline networks, which can have significant negative impacts on the local communities.

Policy implications: This analysis provides new insights on trade-offs that decision-makers should consider when looking at different sustainable development options to reach long term climate goals, in particular when considering innovative and costly solutions like carbon capture and storage.

Modelling developments linked to Mid-century strategies

- Researchers, led by Lund University in Sweden, have conducted a study, published on the *Energy and Climate Change* journal to explore decarbonisation pathways of four carbon and energy-intensive industries, the iron & steel, clinker & cement, chemicals, and pulp & paper industries using the Integrated Model to Assess the Global Environment (IMAGE) in the context of the 2050 global net-zero goals.

  Researchers conclude that full decarbonisation of industrial (sub)sector(s) is found to be possible, but only under very specific assumptions and likely outside of the 2050 timeline for the iron & steel, clinker & cement, and the chemical sector. Net zero emission pathways for industry should outpace or broadly align with the global economy-wide net-zero timeline. The electrification of the iron & steel sector, a full dependency on carbon removal technologies in the clinker & cement sector, the closing of carbon and material loops in the chemical sector, and zero-carbon heating for the pulp & paper sector are important considerations.

  Policy implications: Integrated assessment models (IAMs) play an important role for exploring solutions to achieve specific policy goals, therefore research in this area is essential. Nonetheless, with regard to the role of industry in a net-zero world, further research is needed within and beyond the IAM community to better support industrial decarbonisation strategies and policy makers.

- In a study published on *Nature,* researchers led by the University of California have built a model where climate policy and greenhouse gas emissions arise endogenously from the coupled interaction of the climate, social, political and energy systems rather than exogenously, as usually done in almost all climate change modelling. The aim of this research is to explore the space of possible emissions and policy trajectories over the twenty-first century. The behaviour of the model reveals that connections across the individual, community, national and global scales represented can be decisive for determining policy and emissions outcomes as they have the potential for nonlinearities and tipping points. Researchers simulate 100,000 possible future policy and emissions trajectories.

  The study shows that future policy and emission trajectory scenarios reaches a warming in 2100 that ranges between 1.8 °C and 3.6 °C above the 1880–1910 average. The study also shows that that socio-politico-technical feedback processes can be decisive for climate policy and emissions outcome, nonetheless this requires a distinct modelling approach.

  Policy implications: Public perceptions of climate change, the future cost and effectiveness of mitigation technologies, and the responsiveness of political institutions emerge as important in explaining variation in emissions pathways. These are important

constraints to consider when assessing policies to stop dangerous warming over the twenty-first century.

- A study, published on the international journal *Energy* and led by Utrecht University in the Netherlands, uses a regional energy system model with an explicit representation of residential energy use and building stocks, to assess the contribution of the residential sector in in long-term decarbonisation pathways. The analysis is carried out using an updated version of the TIMER-REMG energy system model, which forms the energy system component of the IMAGE Integrated Assessment Model. The updated model includes key dynamics such as building stock turnover, regional climate characteristics, and economic decision making.

  The projections show that in a 2°C scenario, global heating demand is expected to decrease from current levels by 27% and 66% by 2050 and 2100, respectively. Due to increasing affluence in warmer regions, cooling demand is expected to increase by 176% and 286% respectively. The study also shows that direct residential emissions can almost be eliminated by 2100 by combining increased envelope efficiency, increased efficiency in heating, and cooling technologies in a synergistic manner with rooftop PV.

  Policy implications: The modelling study suggests that efficiency improvements, heating and cooling technologies, building envelope efficiency, and fuel switching are solutions that play and important role in decarbonising the residential sector. Conclusions highlight that the energy use of residential sector can become net-zero by 2100, but the right policy response and strategies to achieve it should take into account the local climate, socio-economic, and building stock characteristics.

Modelling developments linked to SDGs

- A study, conducted by researchers from India and led by the Indian Institute of Technology Kharagpur of India, was published on the journal *Renewable Energy; it* focuses on two Sustainable Development Goals, global access to clean energy (SDG-7), and action to combat climate change (SDG-13). It assesses the impact of climate change on global solar energy potential up to 2040 and up to 2100. Researchers evaluate the percentage changes in photovoltaic (PV) potential and Concentrated Solar Power (CSP) using simulated energy variables for four seasons: boreal spring, summer, autumn, and winter.

  The study found that there is a 6-10% decrease (with respect to 1981-2014 climatology) in photovoltaic potential in the Indian subcontinent and China in the boreal autumn – this is possibly linked to increased post-monsoon cloud cover. A consistent decrease is also noticed in North America and Australia, whereas in Europe, the projected decrease in PV potential, even for the worst emission scenario (SSP5-8.5), is restricted only to the boreal winter season, thereby posing no real threat to future PV power planning. However, a mild decrease in PV potential is observed in Africa during austral summer and a consistent decrease in Concentrated Solar Power (CSP) all over the world.

  Policy implications: The study is a first step towards supporting the plans for future investment in solar energy. The study highlights the importance of enhancing international cooperation in harvesting renewable energy sources to contribute to the achievement of SDG-7 and SDG-13.

- A research, published on the *Environmental Science & Policy* journal and led by the Research Centre for Climate Change and Energy of the Hallym University in the Republic of Korea, analyses the co-benefits of air pollution control, health, and climate change mitigation strategies in Pakistan. Researchers use two scientific modelling tools, the Greenhouse Gas Air Pollution Interactions and Synergies (GAINS model), an IAM developed by the International Institute for Applied Systems Analysis (IIASA), coupled with the EnerNEO Pakistan model, an energy-economic model developed by Enerdata for the Government of Pakistan. They examine air quality under different scenarios.

  Results shows that current air pollution control measures are insufficient to meet Pakistan's air quality standards as they would rise PM2.5 levels by 2050. Whereas implementing sustainable development strategies would reduce nationwide $PM_{2.5}$-related mortalities by 24% in 2050 compared to the baseline. Advanced control measures have the potential to improve air quality and public health in Pakistan - they have the potential to halve greenhouse gas emissions and save on emission control costs approximately by a quarter by 2050.

  Policy implications: The study demonstrate the greater effectiveness of an integrated approach to pollution control, which includes sustainable development strategies, compared to a conventional approach, and the cost-saving benefits that could result from it. In the context of Pakistan, the study highlights that future policymaking should prioritise solutions that deliver a cost-effective combined control of air pollution and greenhouse gases.

- Researchers led by Politecnico di Milano in Italy published an article on Nature Climate Change that aims to quantify local-scale impacts of global climate change mitigation policies in one of the largest transboundary river basins in the world, located in Africa. Researchers investigated how these policies impact multisector dynamics across interconnected water–energy–food (WEF) systems at local scale. The analysis is performed using an integrated modelling approach which combines a river basin-scale model of the Zambezi Watercourse (ZW) in southern Africa; climate scenarios and irrigation demand scenarios, through the Global Change Analysis Model (GCAM) – a model widely used in major integrated climate-energy-economic assessments.

  Researchers found that ZW will be exposed to severe risks of performance degradation across all the components of the water-energy-food system. They demonstrated that these future vulnerabilities are mostly generated by global socio-economic drivers, namely, the land-use-change policies that have negative side effects on the local water demand, rather than changes in water availability due to climate change. Analogous vulnerabilities could impact many river basins in southern and western Africa.

  Policy implications: It is critical to connect global climate change mitigation policies to local dynamics to better explore and understand the full range of possible future scenarios for sustainable mitigation and adaptation solutions. Policymakers should look beyond their borders to avoid water-use outsourcing and to ensure environmental and climate justice for all.

Events

Event	Date and location	Objectives	Topics covered / relevance to climate change modelling	Number of participants and deadlines	Comment / Action
2022 EMCC-VI : Econometric Models of Climate Change Conference	25-26 August 2022, university of Toulouse, Toulouse, France	The Conference on Econometric Models of Climate Change has been taking place annually since 2016 and aims to promote an interdisciplinary approach to the detection and attribution of climate change, knowledge exchange between climate science, economics and econometrics, and econometric estimates of climate impacts and policy evaluation.		Papers submission is closed.	
Energy Modelling Forum Snowmass Workshop	TBC	The Energy Modeling Forum brings together climate change experts to discuss the state of the art in climate policy analysis. These annual workshops take place in Snowmass, Colorado.	The workshop covers the latest developments in energy and environment modelling, with specific topics changing annually	n/a	
15th IAMC Annual Meeting 2022	28 November – 2 December 2022, College Park Marriott Hotel & Conference Center, College Park, MD, USA	The purpose of IAMC Annual Meetings is to: • Present and discuss the state of the art in integrated assessment modelling; • Review the status of ongoing community activities including both		Registrations will open in September 2022 and will close on November 25th, 2022. Abstracts submissions	The event will be held in person, hosted by the University of Maryland (USA), with a portfolio of online events as part of the programme

Event	Date and location	Objectives	Topics covered / relevance to climate change modelling	Number of participants and deadlines	Comment / Action
		multi-model studies and the activities of the IAMC Scientific Working Groups; • Facilitate interaction with collaborating communities; • Evaluate and revisit the priorities of the integrated assessment community.		deadline is June 30th, 2022.	
The International Society for Ecological Modelling Global Conference	2-6 May 2023, University of Toronto, 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.	Abstract submission timeframe is 5 October - 25 November 2022	