ENGAGE SUMMARY FOR POLICYMAKERS

International Institute for Applied Systems Analysis
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ENGAGE
FEASIBILITY OF CLIMATE PATHWAYS

About the ENGAGE Project

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 821471 (ENGAGE).

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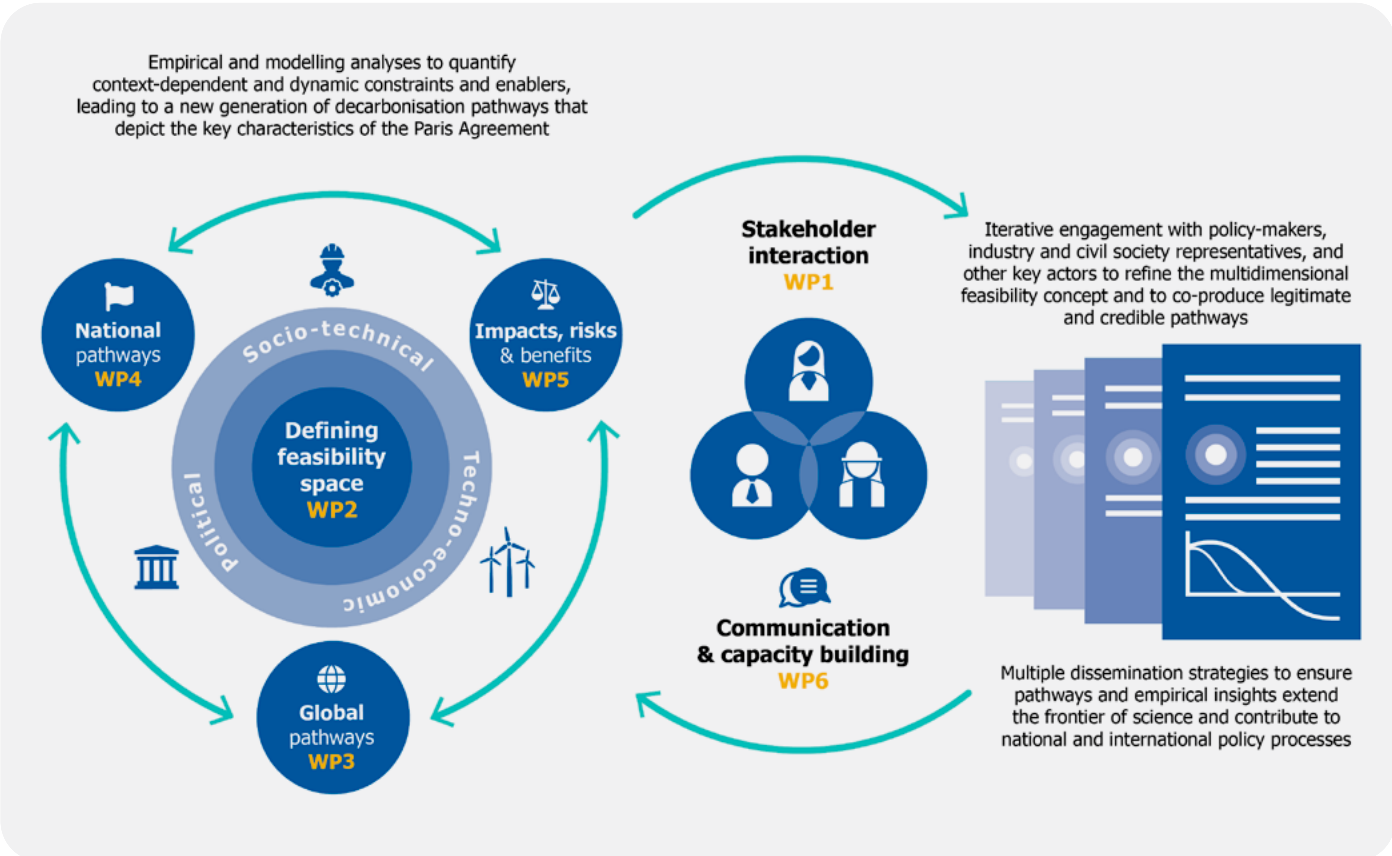
The International Institute for Applied Systems Analysis (IIASA) is an independent, international research institute with National and Regional Member Organizations in Africa, the Americas, Asia, and Europe. Through its research programs and initiatives, the institute conducts policy-oriented research into issues that are too large or complex to be solved by a single country or academic discipline. This includes pressing concerns that affects the future of all of humanity, such as climate change, energy security, population aging, and sustainable development. The results of IIASA research and the expertise of its researchers are made available to policymakers in countries around the world to help them produce effective, science-based policies that will enable them to face these challenges.

CONTENTS

1. Introduction

As the world faces the risks of dangerous climate change, policymakers, industry and civil society leaders are counting on Integrated Assessment Models (IAMs) to inform and guide strategies to deliver on the objectives of the Paris Agreement (PA) and subsequent agreements. ENGAGE has responded to this challenge by engaging these stakeholders (see Section 9) in co-producing a new generation of global and national decarbonization pathways (Sections 5 and 6). Tools and approaches have been developed to explore the multidimensional feasibility of these decarbonization pathways (Section 3) and identify opportunities to strengthen climate policies by minimizing feasibility risks. New emission pathways have been designed to minimize overshoot of the temperature target (Section 4), explore the timing of net-zero emissions to meet the Paris temperature target, and reduce the reliance on controversial negative emissions technologies. However, global decarbonization pathways are only feasible in as much as they are aligned with national policies and plans, so the project has paid particular attention to aligning and reconciling global decarbonization pathways with national emission reduction policies and pledges and international governance mechanisms (Sections 5 and 6). The project has also quantified avoided impacts of climate change, co-benefits, and trade-offs of climate policy (Section 8) and explored the effort-sharing implications of decarbonization pathways (Section 7).

FIGURE 1:
Conceptual overview of the ENGAGE project



The results summarized in the following sections could only be achieved with multi-, inter- and trans-disciplinary expertise. The project team brought together a global consortium of leading IAM teams from Europe and non-EU countries (Brazil, China, India, Indonesia, Japan, Korea, Mexico, Russia, Thailand, the USA, and Vietnam). In total 74% of global CO_2 emissions in 2015 were originating from countries represented in the consortium (incl. external partners), including 9 of the 11 largest emitters. The countries range between high-income countries (e.g., EU, Japan, USA) and lower middle-income countries (India, Vietnam). The ensemble of Integrated Assessment Models that has been used covers a wide range of approaches. The variety of different model types helped identify robust insights that hold across different models.

PROJECT INFORMATION

Exploring National and Global Actions to reduce Greenhouse gas Emissions

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Partners

International Institute for Applied Systems Analysis (Austria) – Project coordinator
Potsdam Institute for Climate Impact Research (Germany)
PBL Netherlands Environmental Assessment Agency (Netherlands)
Euro-Mediterranean Center on Climate Change (Italy)
E3 Modelling (Greece)
Central European University (Hungary)
COPPE, Universidade Federal do Rio de Janeiro (Brazil)
The Energy and Resources Institute (India)
National Institute for Environmental Studies (Japan)
NewClimate Institute (Germany)
Wageningen University (Netherlands)
National Research University Higher School of Economics (Russia | until April 2022)
Tsinghua University (China)
Energy Research Institute (China)
National Center for Climate Change Strategy and International Cooperation (China)
Indian Institute of Management (India)
Research Institute of Innovative Technology for the Earth (Japan)
Korea Advanced Institute of Science and Technology (Korea)
University of Seoul Industry Cooperation Foundation (Korea)
Sirindhorn International Institute of Technology – Thammasat University (Thailand)
International University – Vietnam National University Ho Chi Minh City (Vietnam)
Bandung Institute of Technology (Indonesia)
Jill Jaeger (Austria)
Utrecht University (Netherlands)
Kyoto University (Japan)
ENGAGE also has three external partners:
Joint Global Change Research Institute (United States)
SHURA Energy Transition Center (Turkey)
TNO (Netherlands)

2. Key Messages

Assessing feasibility of decarbonization pathways

- **Moving fast is more feasible overall.** The feasibility framework developed in the ENGAGE project shows that scenarios with immediate ambitious transformation to a low-carbon society face lower feasibility concerns in the long-term than delayed-action scenarios. Overcoming feasibility concerns in the near-term has clear long-term benefits.
- **Institutions are a major concern with regard to the feasibility of mitigation scenarios.** In many places, governments and other institutions may not have the capacity to deliver on the rapid mitigation needs in low-carbon scenarios. Focused international aid could make a big difference here, for example, by investing in education.
- **Demand and supply mitigation strategies should be balanced.** As both demand- and supply-side mitigation strategies have their own feasibility concerns, it is more robust overall to take a mixed approach.

Decarbonization pathways without temperature overshoot

- **Relying on net-negative scenarios leads to hazardous levels of overshoot.** Pathways that rely on net-negative emissions result in mid-century peak temperatures up to 0.15°C higher (for 1000 Gt CO_2 budgets) than if the budget is met by the time of net-zero. This would mean substantially higher climate impacts and risks of reaching tipping points.
- **Investment in low-carbon power should at least double by 2030 to avoid overshoot (under a 1000 Gt budget).** Meeting ambitious short-term investment needs in solar, wind, power grids, and storage helps to reach peak-warming targets.
- **Upfront investment brings long-term economic gains.** End-of-century GDP is higher in scenarios that avoid temperature overshoot.
- **There is an urgent need to develop and deploy carbon removal technologies.** Even in scenarios that avoid net-negative emissions, CO_2-removal is needed to accelerate near-term mitigation and to offset emissions from hard-to-abate sectors.

Decarbonization pathways including feasibility

- **Warming will probably pass 1.5°C, largely owing to low institutional capacity, so the world should prepare for a temperature overshoot.** In the most ambitious mitigation scenarios that consider feasibility constraints, the chance of keeping peak warming below 1.5°C is only 10-25%.
- **Reducing energy demand improves the likelihood of staying below 1.5°C and is even more important to help reduce temperatures after a peak.**
- **Countries with high institutional capacity should take more responsibility for near-term mitigation.** These countries include the EU, Japan, and the USA.
- **International support for institutional capacity is essential for achieving ambitious decarbonization.** An effective way to speed global climate action could be capacity building and knowledge transfer, focusing on institutional capacity in nations with high mitigation potential.

Global and national pathways that meet the Paris and Glasgow targets

- **Neither current policies nor existing nationally determined contributions (NDCs) come close to the Paris goals.** At best, current policies stabilize greenhouse gas emissions, whereas a deep cut is needed.
- **Recent net-zero targets are a big step forward.** These pledges, announced by several countries before and during COP26 in Glasgow, would bring global emissions down to a much lower level than current policies or NDCs. They are, however, still not enough to meet long-term climate goals.
- **To close the remaining gap, fossil fuel use must be cut sharply, and the reach of renewables must be further extended.**
- **The optimum mix of mitigation approaches differs a lot from country to country**, with varying combinations of solar, wind, biomass, hydro, geothermal, and carbon capture, as well as wave and tidal power.

Effort-sharing in meeting the Paris targets

- **Fairness is affordable.** Most effort-sharing schemes lead to only a very slight reduction in 2050 global GDP (well under 1% compared with cost-optimal scenarios).
- **Fairness-based emissions trading can cut costs further.** However, the scale of international transfers may make this unfeasible.
- **A climate club can bring the best of both worlds.** If a large enough group of willing nations makes extra effort, then the world can achieve low-cost, fair mitigation with limited financial transfers.
- **Developing nations are likely to benefit from any of these approaches.** India, Indonesia, Mexico, South Africa, and Thailand face lower mitigation effort in all these ethics-based schemes than in cost-optimal scenarios.

Stakeholder engagement in climate change solutions

- **Stakeholder dialogue is necessary.** Finding and implementing solutions to anthropogenic climate change requires a process of iterative and constructive dialogue between the research community and a wide range of other stakeholders. Funding, capacity building and exchange of experience with stakeholder engagement are needed to find and implement solutions to the complex problems that society is facing today.
- **Online activities cannot fully replace physical meetings.** To find and implement pathways that meet the Paris goals, stakeholders need enough time and space to get to know and understand diverse perspectives, to dive deep where necessary, and to engage in multiple, iterative dialogues.
- **A central platform is needed to document lessons learned in stakeholder engagement across projects.** In the ENGAGE project, a set of tools and approaches has been used in a carefully designed stakeholder engagement process, benefitting enormously from experience in designing and implementing stakeholder engagement activities in other EU-funded projects. A central platform for documenting lessons learned in stakeholder engagement would create a solid basis for designing and implementing effective co-creation processes in future projects.

3. Assessing feasibility of decarbonization pathways

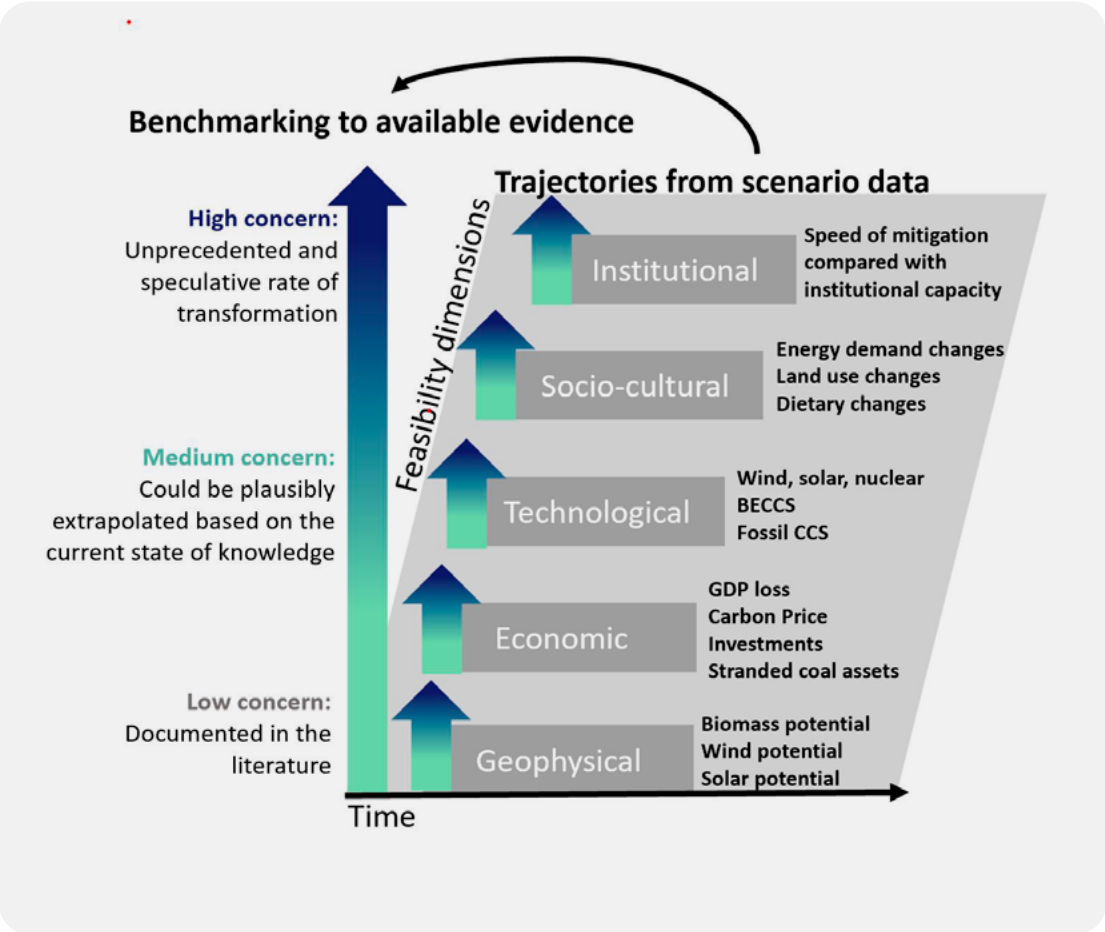
Developing a tool to assess the feasibility of decarbonization

Integrated assessment models (IAMs) calculate the most cost-effective mitigation scenarios for a given climate goal. With their focus on cost, these models cannot assess how feasible their scenarios are in a broad sense. To assess the feasibility concerns raised when looking at mitigation scenarios, a new framework has been developed and used.

The framework (Figure 2) looks at five dimensions where feasibility concerns could arise: geophysical, technological, economic, socio-cultural, and institutional. Each dimension is assessed through key indicators, such as carbon price, that are reported in scenarios. The framework assigns levels of feasibility concern (low, medium, and high) to different values of each indicator, based on insights from literature and empirical data. High concern means that the indicator reaches levels far above those observed in the past, which would demand some substantial enablers such as a technological breakthrough or unprecedented change in behavior.

FIGURE 2: Multidimensional feasibility framework based on Brutschin et al. (2021).

Interactive online feasibility app available at *feasibility.streamlit.app*

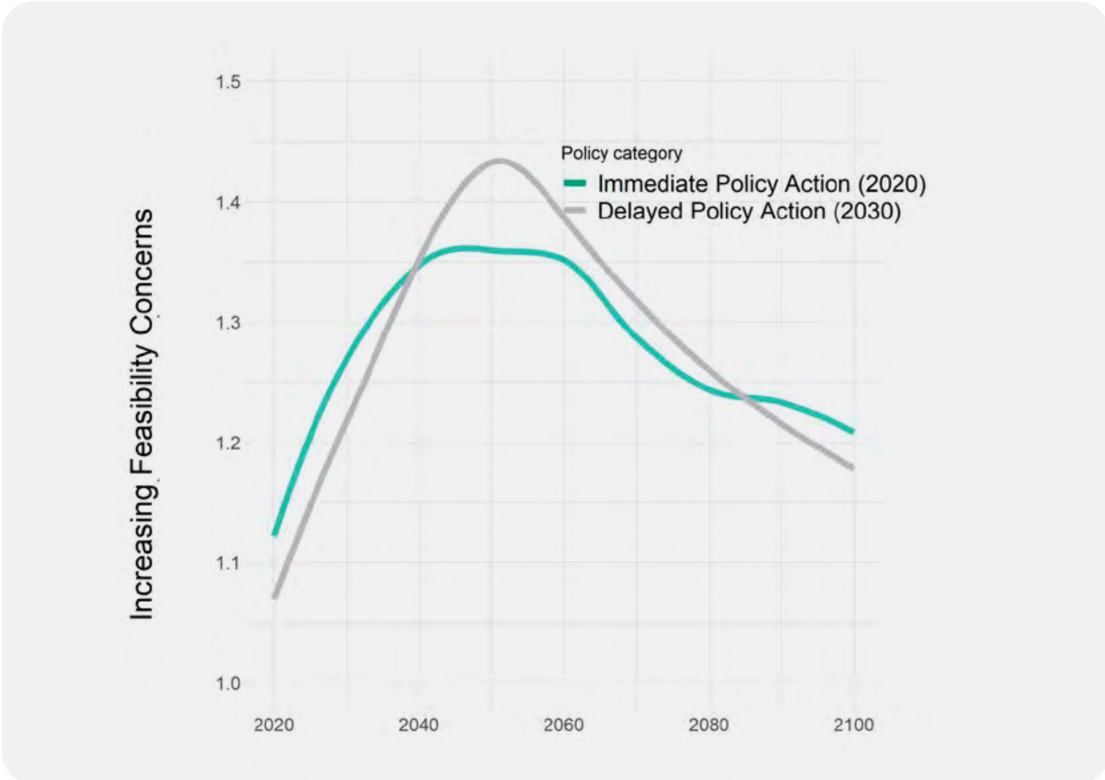


To analyze a scenario, the first step is to aggregate the concerns for each indicator. This can provide a breakdown of feasibility over time and across the five dimensions, as well as an overall feasibility concern over the century with respect to the scenario.

Rapid or slow change?

When applied to the scenarios from the Intergovernmental Panel on Climate Change (IPCC)'s report on Global Warming of 1.5°C, this framework shows the value of rapid action. An ambitious approach requiring rapid system transformation has somewhat higher feasibility concern in the short-term, but overall lower concern over the next few decades (Figure 3).

FIGURE 3:
Feasibility of two pathways, both aiming to limit warming to 1.5°C. The pathway "Immediate Policy Action" assumes that mitigation starts in 2020, while "Delayed policy action" assumes that mitigation starts only in 2030.



The team found similar results when they applied the framework to two more sets of scenarios. Half are forced to meet their carbon budget at the time the world reaches net-zero, which demands ambitious and immediate policy action; the others allow emissions to overshoot the budget, followed by net-negative emissions to eventually meet the budget by 2100. Across the century, feasibility concern is lower in the more ambitious net-zero-budget scenarios. This is for two main reasons: there is less reliance on very large-scale negative emissions, whose feasibility is uncertain; and with delayed action, carbon-intensive infrastructure such as coal power keeps growing, making it much harder to eventually move to greener options.

Empirical studies show that it is very difficult to retire coal power plants before the end of their natural lifetime. So far, they have been retired mainly in wealthy countries with old coal fleets and relatively transparent and independent governments. Based on this, the framework assigns high feasibility concern to retiring more than 50% of global coal power prematurely in a given decade.

The importance of governance and institutions

The same study found that institutional capacity is the dimension with the highest feasibility concerns.

Climate mitigation needs reliable planning, and therefore effective governance. Mounting evidence shows that countries with better governance have more effective climate policy – for example, having higher carbon prices, and being quicker to phase out coal and deploy renewable energy.

For the new framework, the project team quantified this relationship. They compared the World Bank's Worldwide Governance Indicators and the Environmental Performance Index, to reveal what levels of governance are needed for stringent climate policy. Historical data from the EU then showed the CO_2 reductions that can be reached under high governance levels.

IAM scenarios do not include the governance level, so the team had to find an indirect way to bring it into the framework. They used a study showing that GDP per capita, higher education, and gender equality in education are good predictors of governance level. These three indicators are quantified in the five Shared Socioeconomic Pathways (SSPs), which form a background for scenarios. The researchers used these indicators to project governance levels for each country until the end of the century. The framework adopts these governance levels, which are the same in all scenarios based on a particular SSP.

The indicator for this dimension compares the level of governance with speed of decrease in per-capita CO_2 emissions. If a scenario demands rapid mitigation in a region with a low projected governance level, that implies high feasibility concern.

Globally, across most of the IPCC 1.5°C scenarios, this is by far the largest single feasibility concern. Because they focus on monetary cost, IAMs tend to project a lot of mitigation in developing regions where it is most cost-effective. Many of these regions, however, have low projected governance levels, meaning that such mitigation efforts may be beyond their institutional capacity. From a feasibility perspective, it may therefore make sense to follow a scenario that puts more mitigation burden on developed nations, which are likely to have higher capacity.

Another solution could be through targeted international climate aid and cooperation. It may be effective to invest in education, especially for girls and women. Education and gender equality are among the key predictors of higher levels of governance, and education has been shown to increase pro-environmental behavior. This should also improve adaptation capacity in the most vulnerable regions.

Balance attention to supply and demand

Finally, the analysis showed that feasibility is improved by addressing both supply and demand. For example, the Low Energy Demand scenario developed at IIASA focuses on decreasing energy demand through behavioral change and improved energy efficiency. Although this avoids some of the risks of supply-side technological solutions, such as low-carbon power and carbon capture and storage, it is of relatively high feasibility concern in the first decade because it demands a rapid global change in behavior. Conversely, many scenarios focus mainly on supply-side options, and their feasibility would improve with somewhat more demand reduction.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

Brutschin, E., Pianta, S., Tavoni, M., Riahi, K., Bosetti, V., Marangoni, G., & van Ruijven, B.J. (2021). A multidimensional feasibility evaluation of low-carbon scenarios. Environmental Research Letters, 16 064069. [pure.iiasa.ac.at/17259]

4. Decarbonization pathways without temperature overshoot

Transformed energy systems

Meeting the Paris goals will require a transformation in energy systems. To explore how this might be done, integrated assessment models (IAMs) calculate scenarios that limit global warming through a portfolio of emissions cuts and land use change – all optimized for low cost. In most such studies, temperature goals must be met only in 2100, allowing scenarios the freedom to temporarily overshoot those goals. This is the lowest-cost approach across most scenarios, notably those in the IPCC's Fifth Assessment Report and Special Report on Global Warming of 1.5°C.

These scenarios rely heavily on net-negative emissions later in the century to reverse the overshoot. CO_2 removal on such a large scale puts a burden on later generations and may turn out to be unsustainable or unfeasible (see Section 3).

Capped peaks

To explore the implications of being more ambitious, the ENGAGE project compared two approaches: traditional emissions pathways that focus only on end-of-century temperature goals, versus pathways that explicitly limit peak temperature.

Peak temperature depends mainly on the total cumulative CO_2 emitted when the world reaches net-zero emissions. Each pathway in the second set requires that the carbon budget is met at the time of net-zero, with little or no overshoot. (A small overshoot can occur due to other greenhouse gases.)

Nine modeling teams fed these pathways into different IAMs to generate mitigation scenarios, revealing the consequences for climate and the economy.

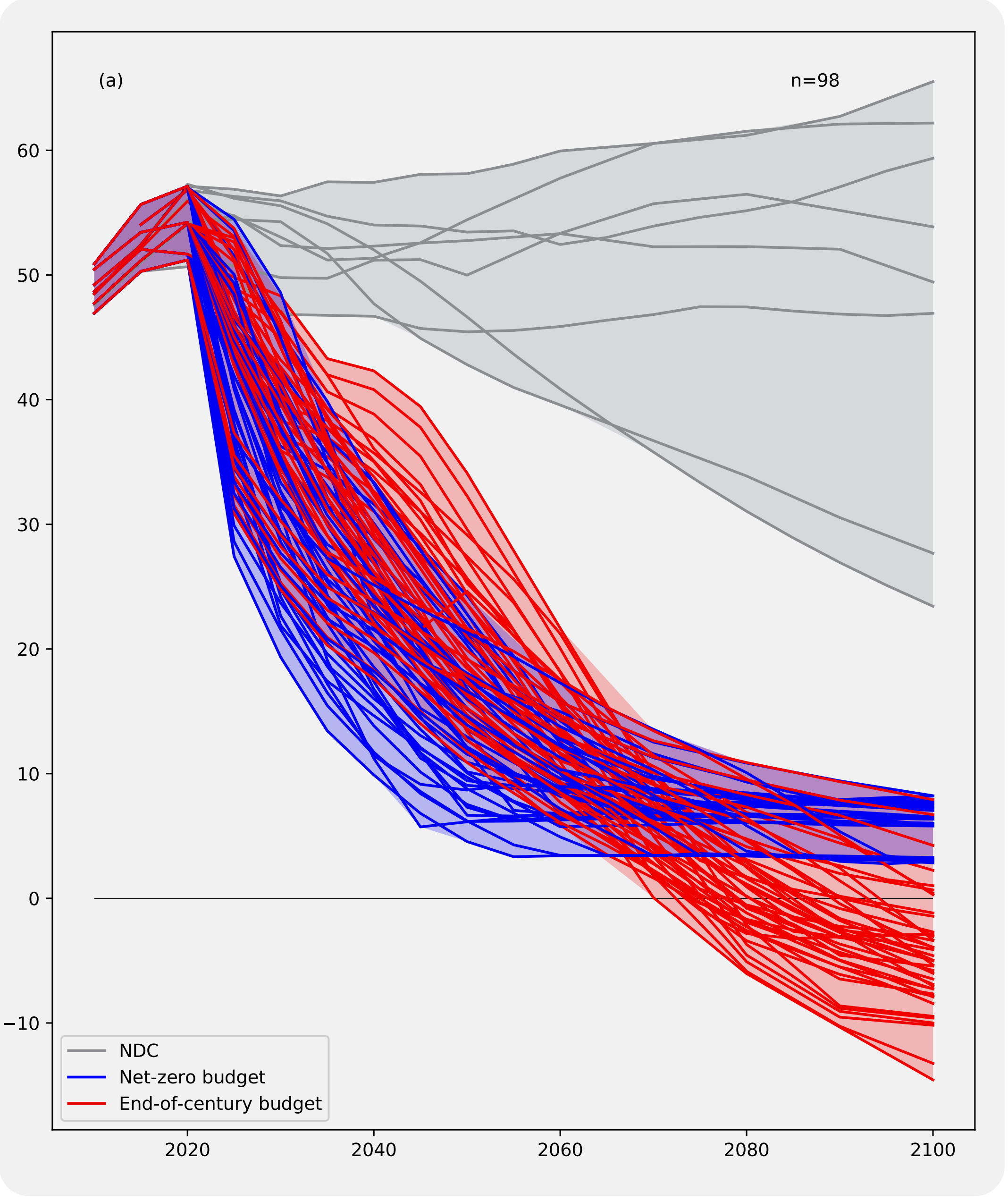
Climate risks

Results (Figure 4) indicate that scenarios with a carbon budget of 1000 Gt CO_2 have an end-of-century warming of 1.7-2.1°C. Among these, scenarios relying on net-negative emissions have peak temperatures up to 0.15°C higher than those without.

This is a considerable climate risk, liable to expose many millions more people to climate extremes, and increasing the risk of climate tipping points and other changes that cannot be readily reversed. According to the IPCC Special Report on Global Warming of 1.5°C: "Overshooting poses large risks for natural and human systems, especially if the temperature at peak warming is high, because some risks may be long-lasting and irreversible, such as the loss of some ecosystems."

All pathways in which emissions follow current NDCs until 2030 put a 1.5°C world out of reach. The late start means it is simply impossible to scale up decarbonization quickly enough. The lowest attainable peak temperature is 1.6 to 1.9°C.

FIGURE 4: Emissions in all scenarios where warming is 2°C or below. Red lines show scenarios with overshoot and net negative emissions. Blue lines show net-zero-budget scenarios with little or no overshoot. Grey lines show NDC scenarios.

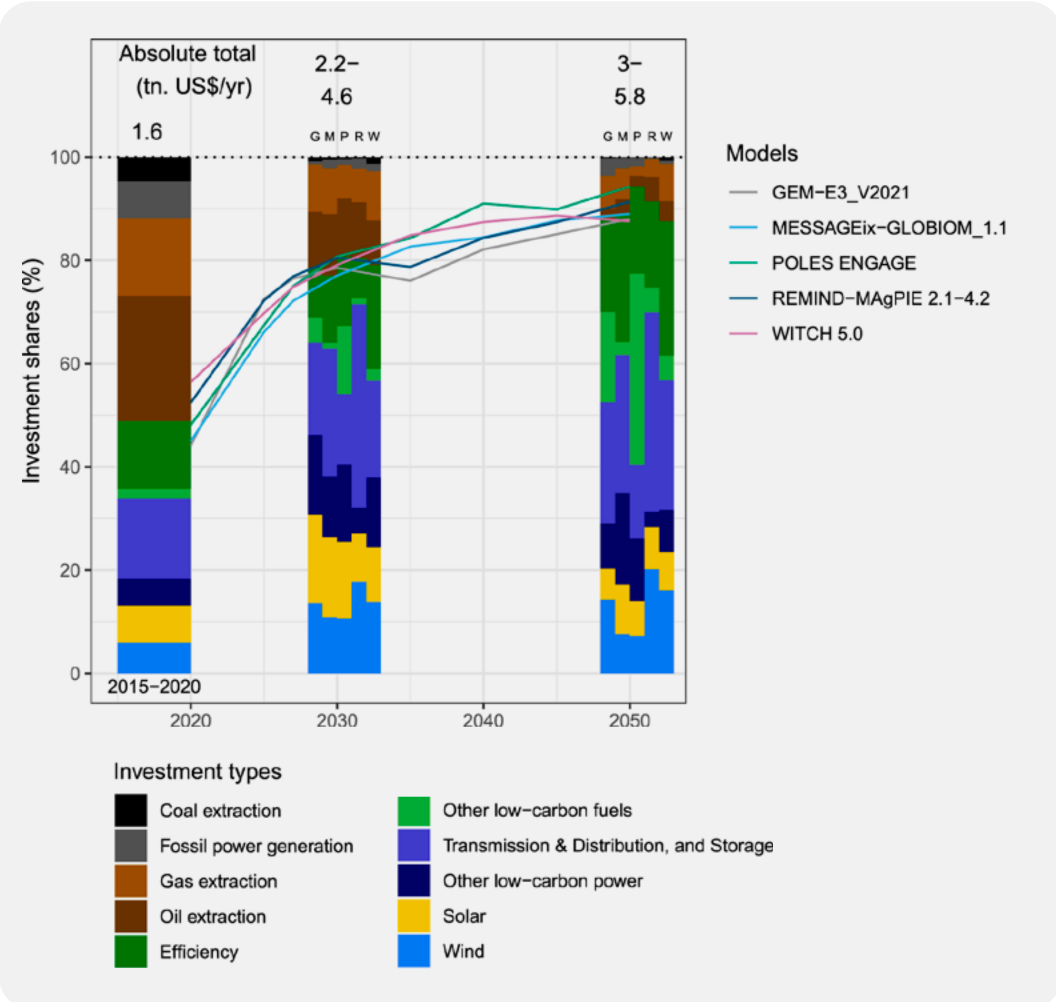


Doubled investments

Another study took a detailed look at the investments needed to transform the energy system. Scenarios with a 1000 Gt budget (Figure 5) require annual investment in low-carbon energy from 2025 to 2030 to be at least twice as high as 2020 levels. Most of this is in solar, wind, power grids, and storage. In all scenarios that limit peak warming to below 2°C, coal is phased out quickly, with considerable reductions in oil and gas.

As well as decarbonizing the power system, this allows other sectors to be cleaned up. Where possible, that will be through direct electrification. In hard-to-abate sectors such as heavy industry it will mean using renewable power indirectly, requiring considerable investment in green hydrogen.

FIGURE 5:
Projected sector investments for all 1000 Gt net-zero-budget scenarios.

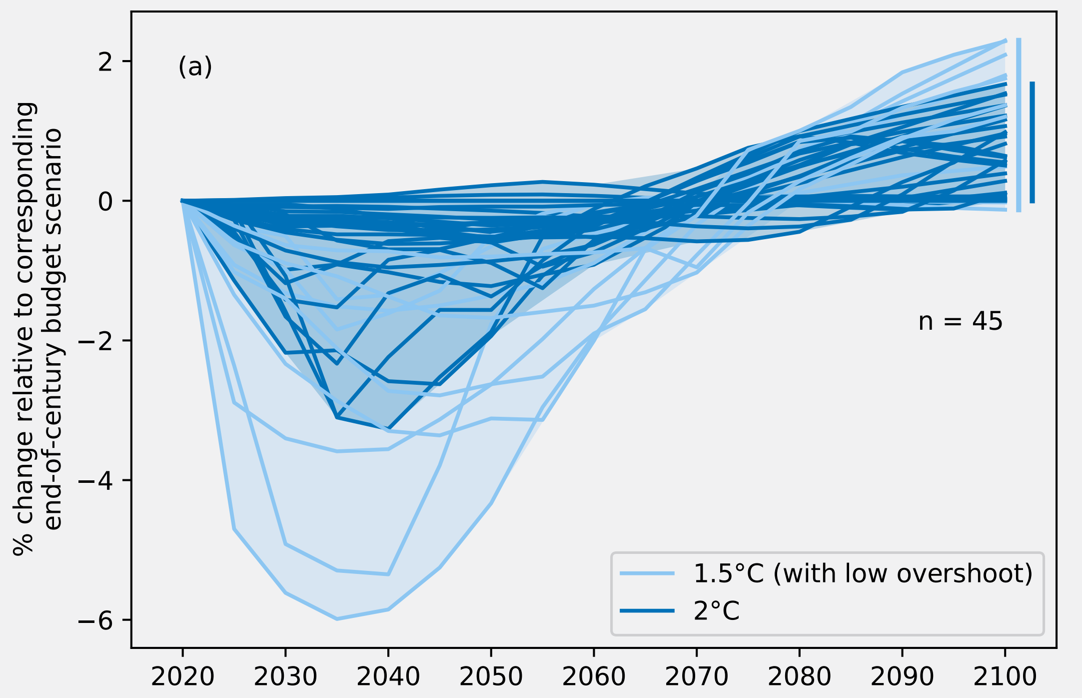


Economic rewards

Avoiding overshoot brings long-term economic benefits. Over the next few decades, the cost of ambitious early mitigation means that global GDP is projected to be lower than in net-negative pathways (Figure 6). In the latter half of the century, this is however reversed, with GDP higher in pathways that avoid net negative CO_2 emissions and do not overshoot. That is partly because overshoot scenarios must keep raising the price of carbon to maintain net-negative emissions.

This is a conservative conclusion, as it does not include the economic impact of climate change. That impact would reduce GDP more in overshoot scenarios, making a stronger case for accelerated action.

FIGURE 6:
Difference in projected global GDP between net-zero- budget scenarios (no overshoot) and those relying on net-negative emissions. In the long term, GDP is higher with net-zero budgets.



Removals required

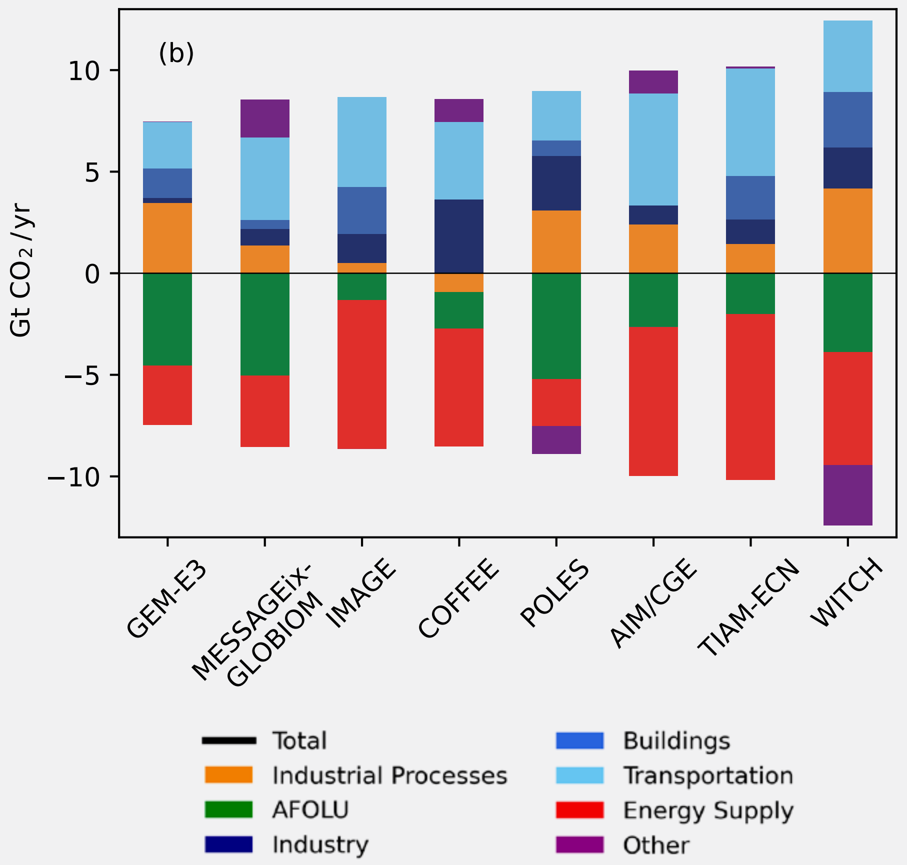
Carbon removal is still needed. Even in scenarios that do not explicity rely on net-negative emissions, removing CO_2 from the atmosphere accelerates mitigation in the near term, and offsets residual emissions in hard-to-abate sectors such as cement manufacturing. In these scenarios, models project carbon removal of 5 to 10 Gt per year at the time of net-zero under a 1000 Gt budget (Figure 7). Some models favor afforestation and reforestation; some favor removal technologies, especially bioenergy with carbon capture and storage; some prefer a balance between the two.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

Riahi, Keywan, Christoph Bertram, Daniel Huppmann, Joeri Rogelj, Valentina Bosetti, Anique-Marie Cabardos, Andre Deppermann, et al. "Cost and Attainability of Meeting Stringent Climate Targets without Overshoot." Nature Climate Change 11, no. 12 (December 2021): 1063–69. https://doi.org/10.1038/s41558-021-01215-2.

Bertram, C., Riahi, K., Hilaire, J., Bosetti, V., Drouet, L., Fricko, O., Malik, A., Nogueira, L.P., et al. (2021). Energy system developments and investments in the decisive decade for the Paris Agreement goals. Environmental Research Letters 16 (7) 074020. [pure.iiasa.ac.at/17288]

FIGURE 7:
Emissions by sector in a 1000 Gt net-zero-budget scenario at the time of reaching net zero. All models require considerable negative emissions in the energy sector to offset emissions elsewhere.



5. Decarbonization pathways including feasibility

Embracing the notion of feasibility (See Section 3), this new research shows that the world will probably overshoot 1.5°C, largely owing to low institutional capacity. Energy demand reduction and electrification are two options to turn down the heat; and addressing weak institutions may be even more effective.

As discussed in Section 3, the ENGAGE project has developed a framework (see Figure 1) to assess feasibility concerns stemming from natural resources, technology, behavior, and institutions. This framework has been used in eight different IAMs to explore the feasibility of ambitious climate targets.

Institutional constraints turn out to be the most substantial. Several empirical studies have shown that implementation of climate policies, such as carbon taxes and phasing out coal, is affected by institutional capacity. To represent this constraint, the studies first estimate countries' institutional capacity, which, as discussed in Section 3, can empirically be related to their GDP per capita, levels of higher education and gender equality in education. The models then set limits on carbon prices and the pace of emission reductions as a function of institutional capacity, which evolve over time as governance improves.

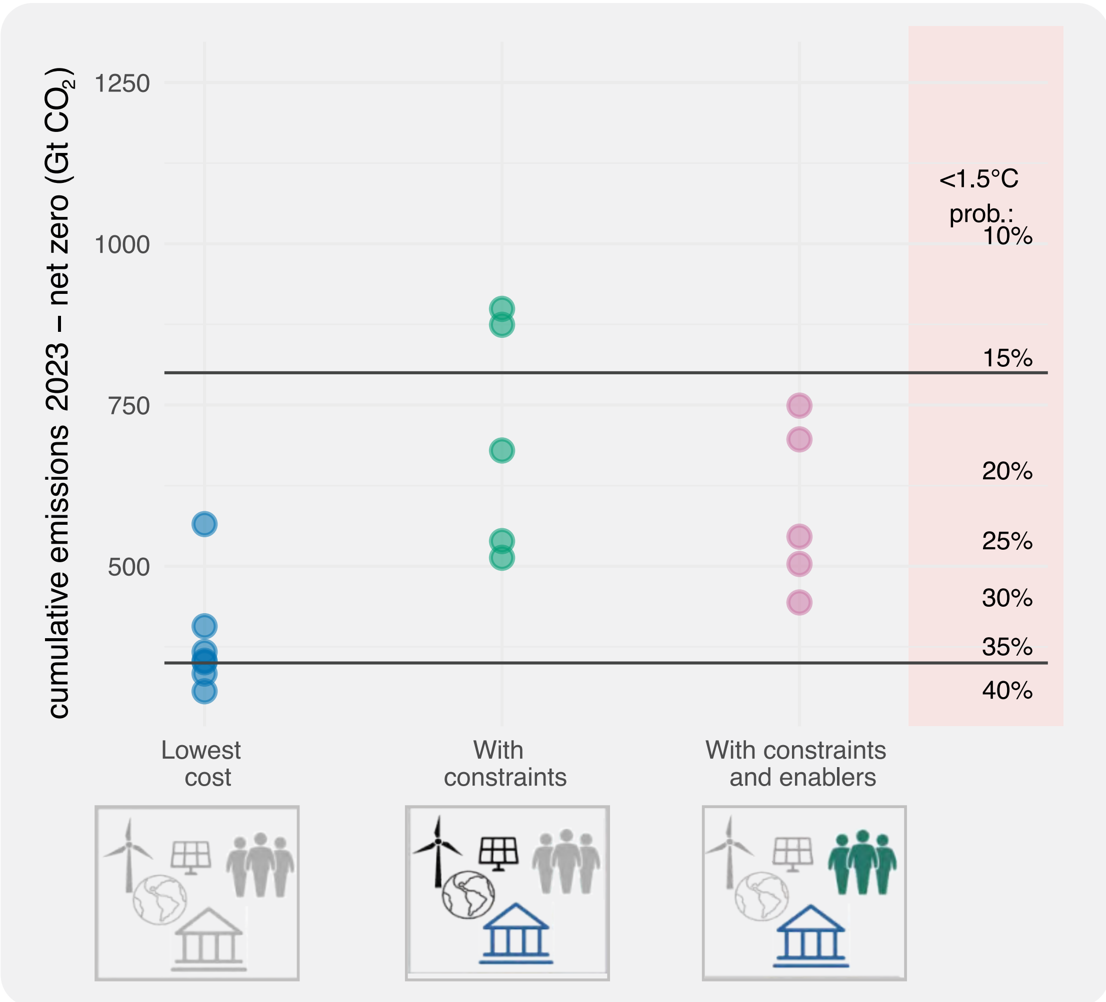


FIGURE 8:
Carbon budget outcomes across the models and the probability of staying below 1.5°C. Solid icons indicate that the scenario considers harmonized technological and geophysical constraints (black technologies), institutional constraints and differentiation (blue building), and social enablers of demand and electrification (green people), while grey semi-transparent icons indicate only model default assumptions.

The studies also look at constraints from technological and geophysical perspectives. Based on a wide literature review, they put plausible limits on: energy generation from biomass; the total amount of CO_2 that can be stored in geological formations; and how fast different countries and regions can be expected to ramp up solar, wind, and other low-carbon technologies.

Be prepared

These feasibility constraints make it more difficult to achieve the Paris targets. Without a major systemic change, the world is unlikely to constrain peak warming to 1.5°C above pre-industrial levels.
The studies focus on two temperature goals: 2°C and 1.5°C[1]. The tighter target has been made more difficult by increasing global emissions over the past two years since the end of the COVID-19 pandemic. Even without imposing feasibility constraints, the models struggle to achieve it[2], because of inertia in replacing high-carbon infrastructure with cleaner technology -- offering a less than 40% chance of holding peak warming below 1.5°C. Adding feasibility constraints on institutions, technology, and geophysics, the models show this probability falling to 10-25%.

This can be improved by assuming two enablers: lower energy demand and greater electrification than models assume under default settings. But they only have a limited effect, improving the chance by 5 to 10 percentage points.

Assuming both constraints and enablers leads to a projected median overshoot of 0.2°C, there is a need to prepare to adapt to at least that level of warming, and prepare to draw down temperatures again with carbon removal after reaching net-zero. That will mean reducing residual emissions to the lowest possible levels and scaling up carbon removal technologies.

Be frugal

Reducing energy demand would enable high-governance countries to take on more responsibility for emission reduction. While probably not enough to hit 1.5°C, it should help a lot in recovering from an overshoot. Pulling global temperature down by just 0.1°C will require about 220 gigatons of CO_2 to be removed from the atmosphere (roughly 5 times current annual emissions), which will need a lot of energy. Reduced demand from other quarters will leave more energy available for that task. And by pioneering demand reduction, rich countries can also learn lessons for other countries to follow, and so improve the medium- and long-term feasibility of global mitigation.

Be responsible

Countries that can do more, must do more. Least-cost scenarios foresee most mitigation happening in countries with lower institutional capacity, where it tends to be cheaper. Institutional constraints shift that responsibility. In the ENGAGE studies, scenarios with feasibility constraints allocate most near-term mitigation to regions with high institutional capacity such as the EU, North America, and Pacific OECD. These countries should achieve emissions cuts by 2040 of greater than 80% in order to align with peak warming of well below 2°C. The scenarios also show a growing share of mitigation in China from 2040 onwards.

This takes a lot of pressure off the rest of the world (especially the poorest countries), which in the 2°C scenarios that include all feasibility constraints are projected to need emission cuts of 44% in 2050, instead of the 68% in the cost-effective scenario.

1 For 2°C, scenarios have a budget of roughly 800 gigatonnes (Gt) total CO_2 emissions since 2023 – giving 66% chance of staying under 2°C, according to climate models. For the 1.5°C goal, the target is 350 gigatonnes, or the lowest emission pathway that is still achievable in each model. In both cases, the budget is defined until the time of reaching global net zero, thus limiting peak temperature.

2 The models struggle to hit 350 Gt from 2023 and average around 440 Gt, which gives a less than 40% chance of holding peak warming below 1.5°C.

Pull the big lever

Mitigation faces its most significant challenge in institutional capacity, and enhancing this capacity may offer the most effective means to improve the situation. The research also examines two governance scenarios: one with carbon price capping but no restrictions on emission reductions, and another with no improvements in capacity over time. These scenarios reveal substantial variations in carbon budgets, spanning several hundred gigatons.

An effective way to speed global climate action could therefore be capacity building and knowledge transfer, focusing on institutional capacity in nations with high mitigation potential. Technology transfer will also remain important, because making technologies cost-competitive across the world enables faster scaling.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

The research for this summary was led by Christoph Bertram (PIK/University of Maryland), Elina Brutschin, Keywan Riahi, and Bas van Ruijven (IIASA). The work was published in an internal report to the European Commission in August 2023.

Preprints of forthcoming publications will be posted on www.engage-climate.org

6. Comparable national decarbonization pathways

The ENGAGE project has brought together results from a new set of standardized national scenarios. For the first time, these allow a direct comparison between the climate targets of different countries. This reveals gaps in the global effort, measures the fairness of national targets, and identifies particular challenges.

Reaching global goals requires national action
Meeting the global climate goals of the Paris Agreement requires action at the national level. Tailor-made national scenarios are valuable for informing climate policies, but they are difficult to compare. They all have different assumptions, and are rarely published in open academic papers. The ENGAGE project has developed and compared a new set of standardized national scenarios. Each national modeling team was asked to run one business-as-usual scenario plus a set of climate mitigation scenarios spanning a wide range of cuts in 2050 – ideally in 10% increments from 10% to 100% (relative to emissions in 2010).

Using such standardized scenarios enables a fair comparison of each nation's energy and land-use systems under a given level of mitigation, which brings several benefits.

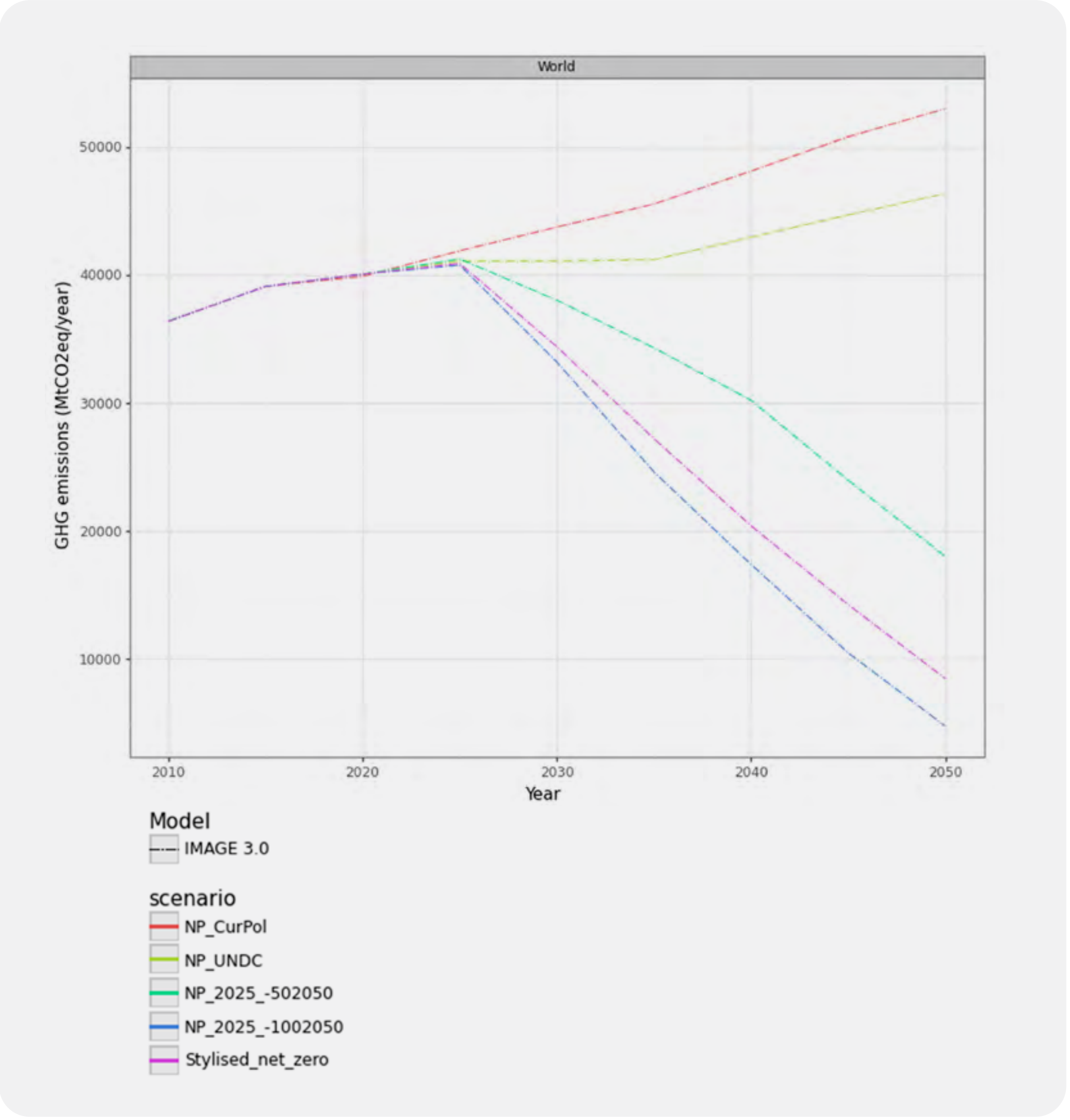
Falling short
The comparisons reveal that short-term policies do not match long-term mitigation ambitions.

We have compared standardized sets of scenarios from nine countries. Each set includes one deep mitigation scenario, which follows the country's published long-term mitigation strategy, if that exists; otherwise, it uses a target based on income (100% emissions cut for high-income countries, 80% for middle income, and 50% for low-income).

The analysis shows that if every country followed these long-term deep mitigation pathways, global emissions would be low enough to meet the Paris goal of keeping warming to well below 2°C (based on results from a global integrated assessment model, IMAGE).

For each country, the team also ran a scenario that follows its short-term climate commitments up to 2030: the unconditional nationally determined contributions (NDCs). In seven of the nine countries, these NDCs are clearly inconsistent with the deep mitigation pathways, sometimes with a very large emissions gap. If every country follows its existing unconditional NDCs, that would lead to global emissions far above the trajectory required for 2°C (Figure 9).

FIGURE 9:
Modeled emissions following some of the scenarios specified in the new standardized framework.

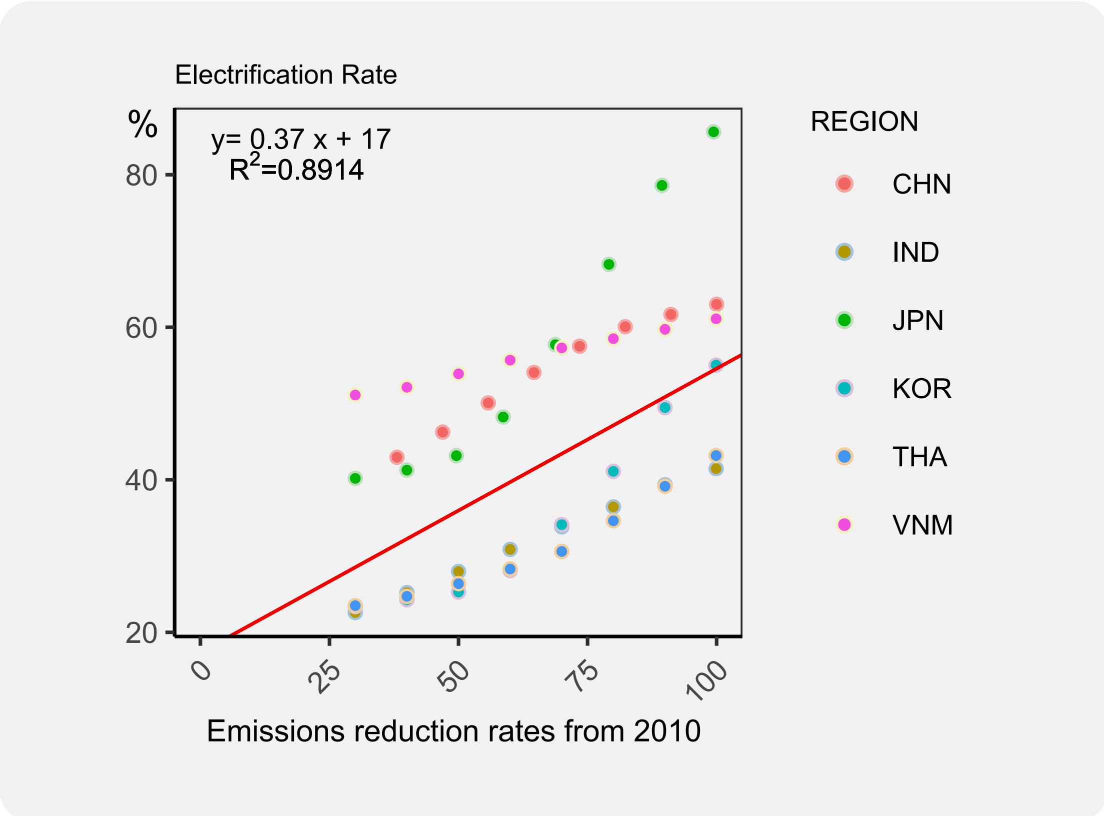


Economic imbalances

A given level of mitigation might have very different economic impacts in countries characterized by different endowment of natural resources, institutions and governments, economic development, and innovation capabilities.

Here we show ENGAGE results on the effect of mitigation on the GDP for six countries: China, India, Japan, Korea, Thailand, and Vietnam. The differences are stark. For example, India is projected to face a higher GDP loss to reach a target of only 30% than Korea faces to cut emissions by 100% (Figure 10). These imbalances could be used to judge the economic fairness of alternative effort-sharing scenarios revealing what emissions reductions in a developing nation would be economically equivalent to carbon neutrality in wealthier countries.

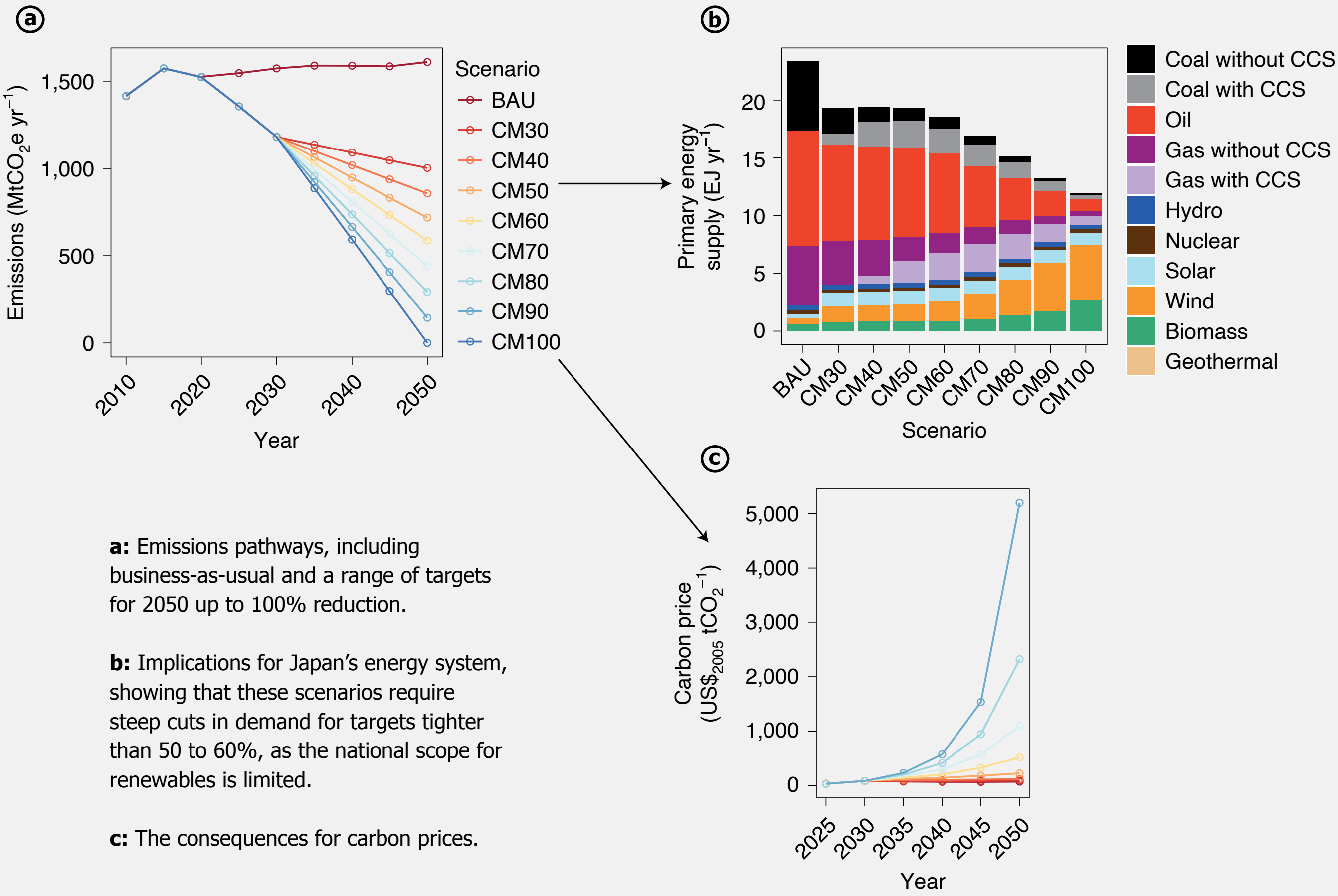
FIGURE 10:
GDP loss (%) versus emissions reduction for the six countries studied. On average an additional 10% emission reduction leads to 0.5% GDP loss in 2050.



This type of insight can also reveal where special solutions are needed. For example, in the study, some countries see high GDP impact for even modest levels of mitigation.

Where that is in a developing country, international cooperation and assistance may be required. If costs are especially high in a wealthy nation, a different solution is suggested. Research found that in Japan, targets close to 100% were very difficult to achieve with projected carbon prices reaching US$500 because of the country's limited potential for solar and wind power (Figure 11). In this case, Japan could outsource its mitigation efforts, financially supporting other countries to make more cost-effective emission cuts on its behalf.
These results also show that the most cost-effective approach to mitigation will vary a lot. The nine countries compared in a separate study all have very different projected energy mixes in 2050. Some

FIGURE 11:
Scenario comparison for Japan.



a: Emissions pathways, including business-as-usual and a range of targets for 2050 up to 100% reduction.

b: Implications for Japan's energy system, showing that these scenarios require steep cuts in demand for targets tighter than 50 to 60%, as the national scope for renewables is limited.

c: The consequences for carbon prices.

countries are projected to get much of their low-carbon energy from biomass, nuclear, or hydropower rather than from solar and wind.

Wider engagement

This framework could act as a spur for some nations to improve their modeling capability and look at deeper cuts than they might otherwise have considered – potentially revealing that an ambitious target is more achievable than expected. However, further capacity-building and support from governments will be needed.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

Fujimori, S., Krey, V., van Vuuren, D., Oshiro, K., Sugiyama, M., Chunark, P., Limmeechokchai, B., Mittal, S., et al. (2021). A framework for national scenarios with varying emission reductions. Nature Climate Change 11, 472-480. [pure.iiasa.ac.at/17229]

van Soest et al. (2021). Report on national decarbonization pathways considering current policies and NDCs and long term strategies. Internal report to the European Commission.

7. Plausible pathways that meet the Paris and Glasgow targets

A crucial question is, how close do the ambitions (NDCs and Net-Zero Goals) take us to the Paris goals? Answering this question is more complex than simply adding up promised emissions. For a start, many countries do not have targets beyond 2030. Even where mid-century net-zero pledges exist, they do not specify the emissions pathway that will be followed to reach that target. Integrated assessment models are therefore useful to calculate plausible emissions pathways, and show which technologies and other mitigation options are most likely to minimize cost.

To plot global emissions, the consortium has used several different integrated assessment models, which take economics, industry, land use, and other global systems into account. Given a particular set of policies or other assumptions, the models calculate likely emissions and climate effects over time.

Seven futures
Each global model in the project has tackled seven broad scenarios:
2°C and 1.5°C scenarios: models calculate global cost-optimal ways of meeting these temperature goals in 2100, ignoring all stated policies.

Current policies: including all climate policies that have already been implemented. Results show global emissions continuing to climb (Figure 12), with warming projected to be around 3.3°C at the end of the century.

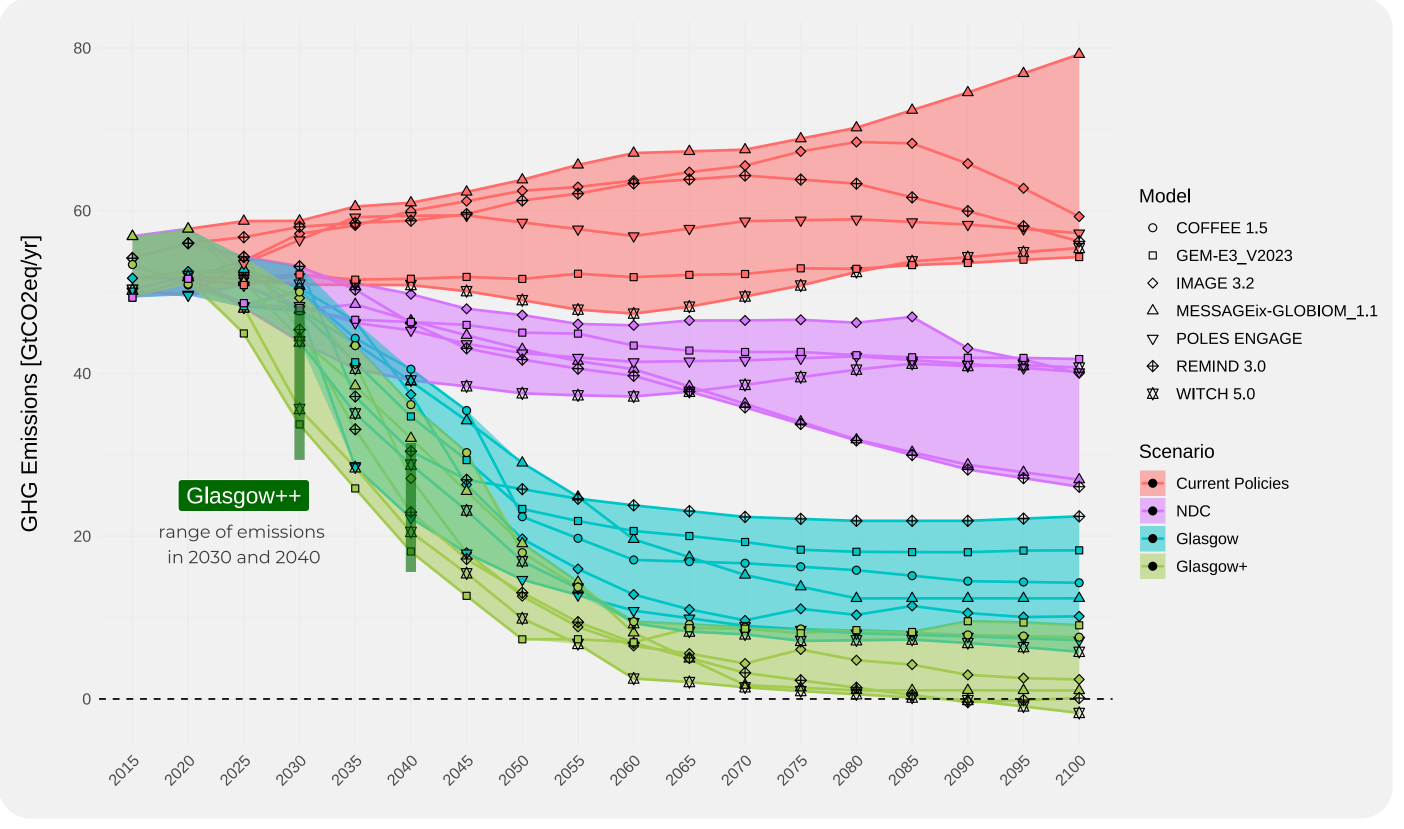
NDC scenario: fully implementing all NDCs to 2030, with ambition levels remaining constant after that. This leads to warming of around 2.7°C, still substantially above the Paris goals. Note that emissions under current policies are far above these NDC projections, revealing a clear implementation gap.

Glasgow scenario: fully implementing NDCs and the net-zero pledges announced by the end of COP26. All models show that this is more ambitious than NDCs, with a much lower global emissions pathway. However, this still doesn't meet the Paris goals, with models projecting end-of century warming in this scenario of around 2.1°C.

Glasgow+ scenario: fully implementing the net-zero pledges announced by the end of COP26 and expanding their coverage to all countries. For countries that currently do not have an established net-zero strategy, the assumed net-zero target year is calculated based on their income level. Expanding the coverage of net-zero pledges to all regions worldwide leads the GHG emissions trajectory to go below the 2°C target (warming of around 1.6°C).

Glasgow++ scenario: this scenario builds on the Glasgow+ scenario but moves the net-zero target year for each region forward by 5-10 years. Moving the target forward drives steeper emissions reductions in the short-term, aligning their trajectory with the 1.5°C target.

FIGURE 12:
Global emissions pathways for four scenarios, each according to seven different models. Greenhouse gas emissions are shown in billion tonnes of CO_2 equivalent per year.



Closing the gap

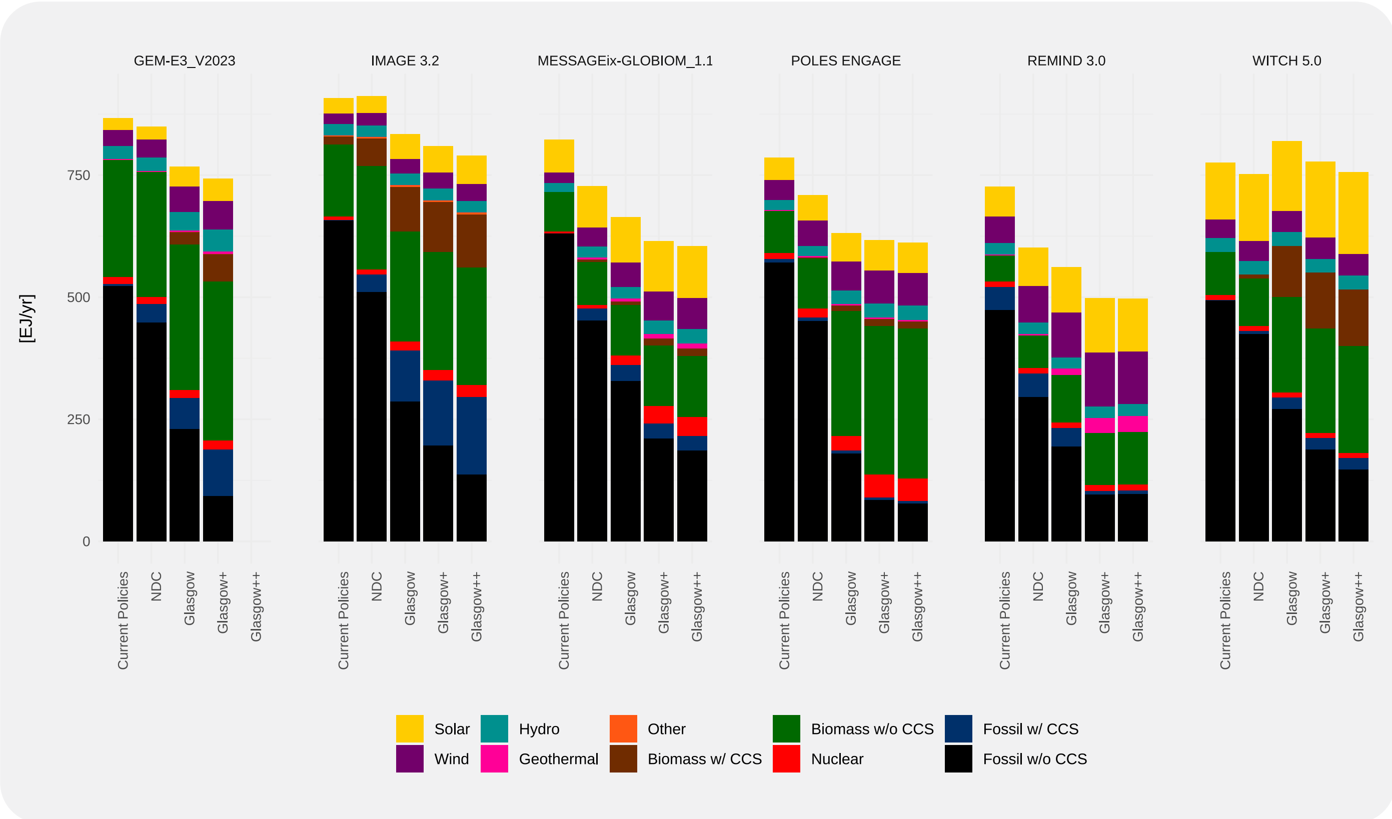
The gap between the Glasgow scenario and 2°C is small, but bear in mind that the Paris goal is to limit warming to *well below* 2°C. The results show that it should be feasible to close the gap between Glasgow and 1.5°C by increasing national and global ambition, expanding the coverage of net-zero pledges by more countries committing to net-zero emissions and bring climate targets forward in time.

The Glasgow++ scenario modeled here would require phasing out coal, and a rapid cut in oil and gas, as well as further expanding the use of renewables. Existing net-zero pledges imply that renewables should meet around 40-45% of global primary energy in 2050. Meeting 1.5°C would require that share to grow to 50-75%.

Some models show other technologies playing a role, notably fossils with carbon capture and storage (CCS), wave and tidal power, and nuclear. Global projected energy balances are shown in Figure 13.

A crucial question is how to distribute this extra effort between countries. The ENGAGE project has also investigated various ethics-based schemes for effort-sharing (See Section 7).

FIGURE 13:
Global primary energy mix in 2050 for each scenario and models.

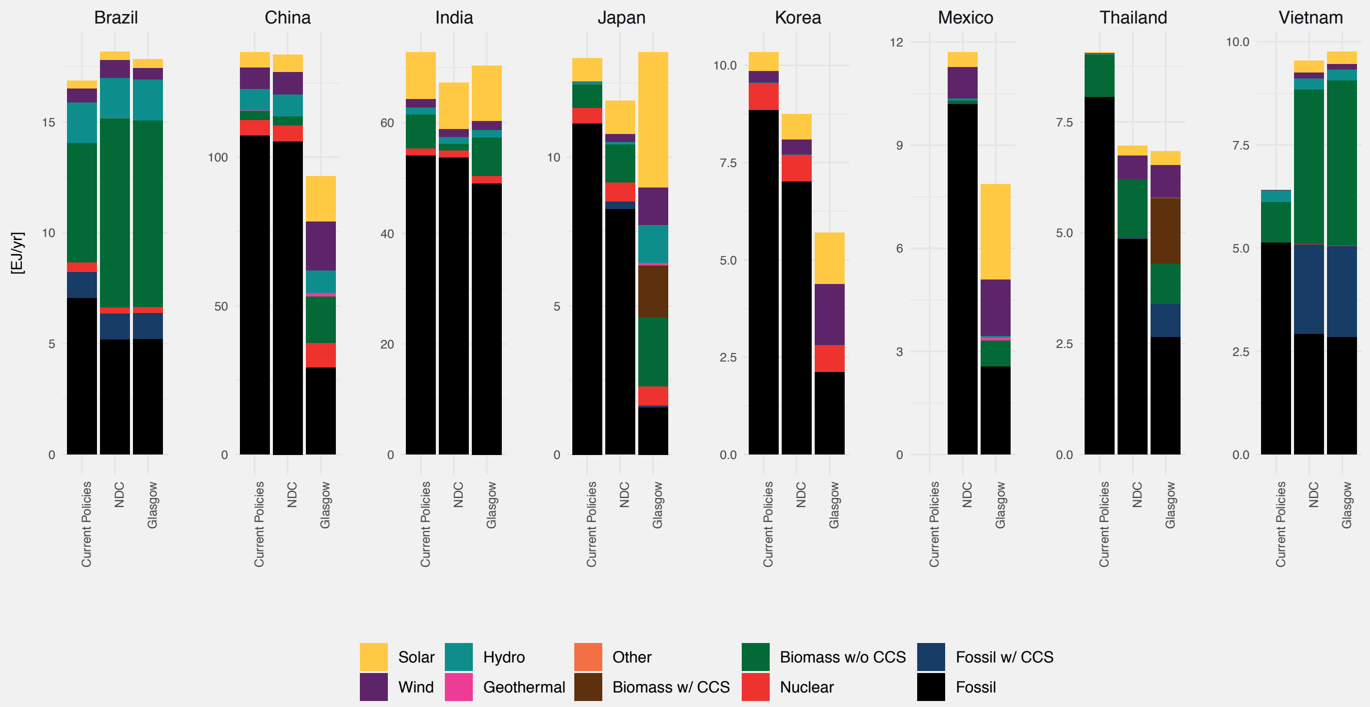


Contrasting strategies

Achieving net-zero targets will require nations to move to more sustainable energy and land systems. ENGAGE has developed a standardized framework for national modeling to provide a fair assessment of each country's cost-optimal mitigation strategy.

These national models project very diverse approaches (Figure 14), depending on local economics and renewable resources. For instance, Japan combines large reductions in the use of oil and gas with strong investment in solar, biomass, and wind. China achieves net-zero emissions by heavily reducing coal use and spreading investments across a wide range of low- carbon solutions, including nuclear and CCS, as well as renewables. Brazil, Thailand, and Vietnam, with higher shares of land available, increase use of biomass. Thailand and Korea continue to use a lot of oil.

FIGURE 14:
Primary energy mixes in 2050 for selected countries.



Stand and deliver

This work shows that recent net-zero pledges could be a big step towards meeting the Paris goals, as long as governments deliver the promised cuts. To actually meet those climate goals, global ambition on fossils and renewables must be increased further – perhaps through international cooperation and by more countries standing up to commit to net-zero and increasing efforts to bring climate targets forward in time.

PUBLICATION ON WHICH THIS SUMMARY IS BASED
The research for this summary was led by Isabela Schmidt Tagomori, Michel den Elzen, Detlef van Vuuren (all PBL Netherlands Environmental Assessment Agency), Fabio Amendola Diuana, and Roberto Schaefer (COPPE). The work was published in an internal report to the European Commission in June 2023.

Preprints of forthcoming publications will be posted on www.engage-climate.org

8. Exploring the options for effort-sharing to meet the Paris targets

Introduction

Meeting the Paris climate goals will require a huge mitigation effort. To find out how and where it might happen, scenarios are usually designed to minimize global economic cost. This approach however assigns most of the effort to developing nations, which have the least resources to deploy carbon cuts, and the least responsibility for past emissions.

Instead, the world must find a way to share the effort fairly between nations by considering ethical principles such as ability to pay. Otherwise, there is little hope for the robust global cooperation required.

The ENGAGE project has explored various effort-sharing schemes, based on a range of ethical principles.

Ethical range

Effort-sharing schemes have been discussed for decades. Is there a fair, affordable, and feasible way to share the burden of mitigation? Within the ENGAGE project, national and global teams have used integrated assessment models to assess emission and cost implications for the world and for individual countries.

Each sharing approach in the study reflects one or more ethical principles, such as equality, responsibility for past emissions, and capacity to deliver mitigation. Modeled approaches are:

- **Ability to pay (AP)** – mitigation depends on per-capita GDP
- **Immediate Emissions Per Capita (IEPC)** – emissions per person are equal
- **Per-capita convergence (PCC)** – emissions per person converge to the same level by 2050
- **Grandfathering (GF)** – future national emissions are in proportion to historical emissions[1]
- **Greenhouse Development Rights (GDR)** – a formula that includes past emissions, GDP per capita, and income distribution, reflecting both responsibility and ability to deliver

Each of these approaches is first modeled in a domestic scenario, assuming that each country must physically carry out its allocated mitigation. It is then examined again in an international scenario, where wealthy countries can pay developing nations to mitigate on their behalf (when it is cheaper to do so).

Two more scenarios foresee a hybrid world: one group of countries chooses low-effort options, while the rest form a climate club to take ambitious action.

For comparison, the models also generate scenarios to reflect current policies, current nationally determined contributions (NDCs), and cost optimal mitigation. To meet the Paris goal, all scenarios stick to a strict global emissions pathway[2] projected to limit peak warming to about 1.7°C.

1 While this principle is not ethical in the usual sense of the word, it is considered here because it has been adopted by several emissions trading schemes.

2 The specific pathway, developed within the ENGAGE project, meets a total emissions budget of 800 Gt CO_2e (800 billion tonnes of carbon dioxide equivalent), using rapid early mitigation rather than relying on negative emissions later in the century. Riahi, K., Bertram, C., Huppmann, D. et al. (2021). Cost and attainability of meeting stringent climate targets without overshoot. *Nature Climate Change* 11, 1063–1069. doi.org/10.1038/s41558-021-01215-2

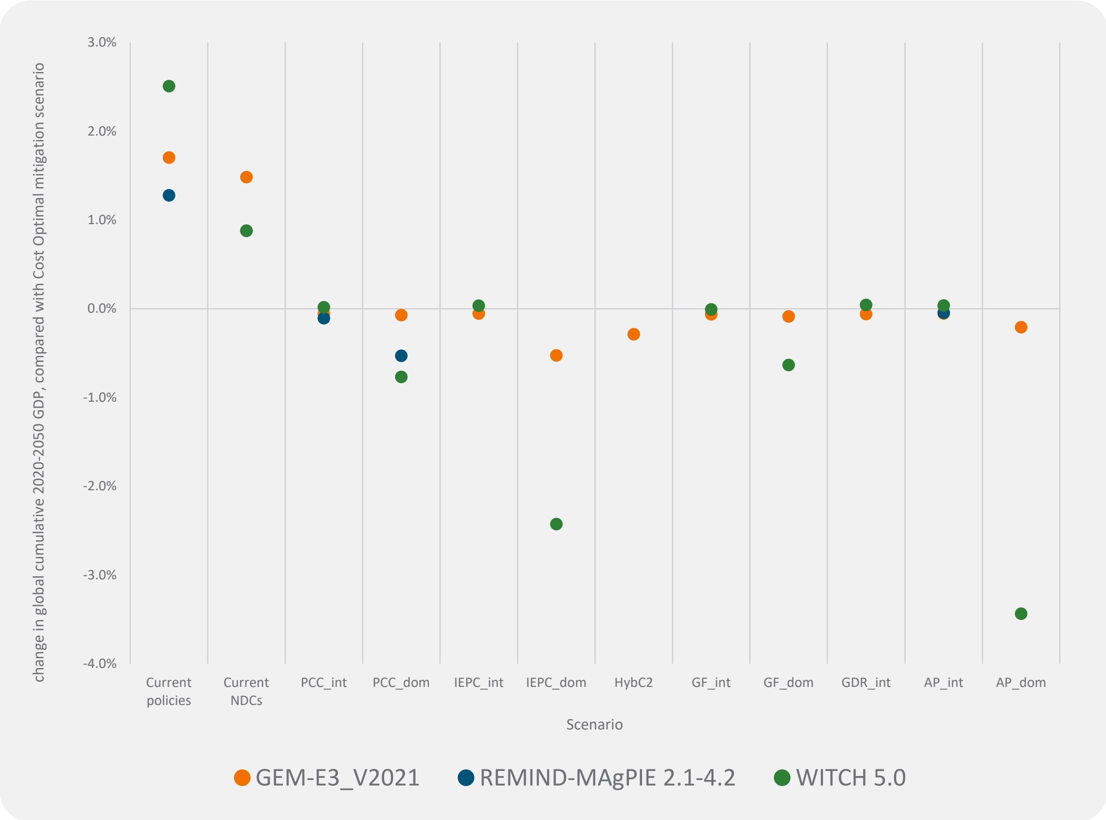
Low costs

Economic costs are measured by their effect on cumulative global GDP between 2020 and 2050 (Figure 15). Among the domestic scenarios, PCC is shown to be affordable by all models. Compared with cost-optimal mitigation, it reduces GDP by less than 1%. The costs of IEPC and AP are less clear. One model projects low costs similar to PCC; another projects substantial costs of a few % of GDP. GF has similar costs to PCC, but is ethically questionable, favoring countries that have been heavy emitters in the past. The models could not make GDR work at all, as it requires unfeasibly rapid emission reductions in developed countries (reaching negative emissions early in 2030).

When international emissions trading is allowed, the impact on GDP is close to zero, with mitigation mostly taking place in the lowest-cost locations. The problem is that this requires huge international payments, amounting to several hundred billion dollars per year. Developed countries may be unwilling to transfer so much capital, and reluctant to rely on other countries to fulfil climate commitments for them.

FIGURE 15:
Global mitigation costs of alternative sharing approaches and governance schemes, calculated by up to three different models.

All are given in % change of 2020-2050 cumulative GDP relative to cost optimal mitigation.



Join the club

If global emissions trading proves unfeasible, a hybrid approach could be the answer: many countries go their own way, and a climate club of willing nations makes up the difference.

ENGAGE has modeled this with two hybrid scenarios. These assume that nations outside the climate club make a least-effort contribution (choosing their lowest contribution from among the five ethical approaches modeled here under the _dom governance scheme). Then the climate club commits to closing the emissions gap to the global NPi2020_800 emissions pathway. To achieve cost-optimal mitigation within the club, emissions are traded with a common carbon price. Financial transfers are much lower than in the global emissions trading scenarios.

This can work well if the club is large enough. In one scenario, the club includes countries committed to net-zero in 2050 (as stated by December 2021), amounting to 40% of current global greenhouse gas emissions. Models were unable to make this work, since the scenario requires emissions cuts among club members that are too steep to be technically feasible.

The second hybrid scenario expands the club to countries committed to net-zero by 2060, amounting to 75% of current emissions. This is much more effective, and able to meet the 1.7°C pathway with very little impact on GDP. However, only one model has reported results for this scenario as yet, so more work is needed to test this conclusion.

Reasonable demands

The study also looked at effects on individual countries, confirming that effort-sharing reduces the unfair burden on developing countries. In all the schemes considered here, Brazil, India, Indonesia, and South Africa need to deliver less ambitious emission reductions than in the global cost-optimal scenario.

Even so, both developing and developed nations need to increase their climate ambition. In all countries, every effort-sharing scheme requires faster cuts this decade than existing NDCs.

As long as that can be achieved, this work shows that fairness-based approaches to mitigation can reduce effort for developing nations without high economic costs. This should help to get all nations onboard, making the transition to a zero-carbon world both more feasible and more just.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

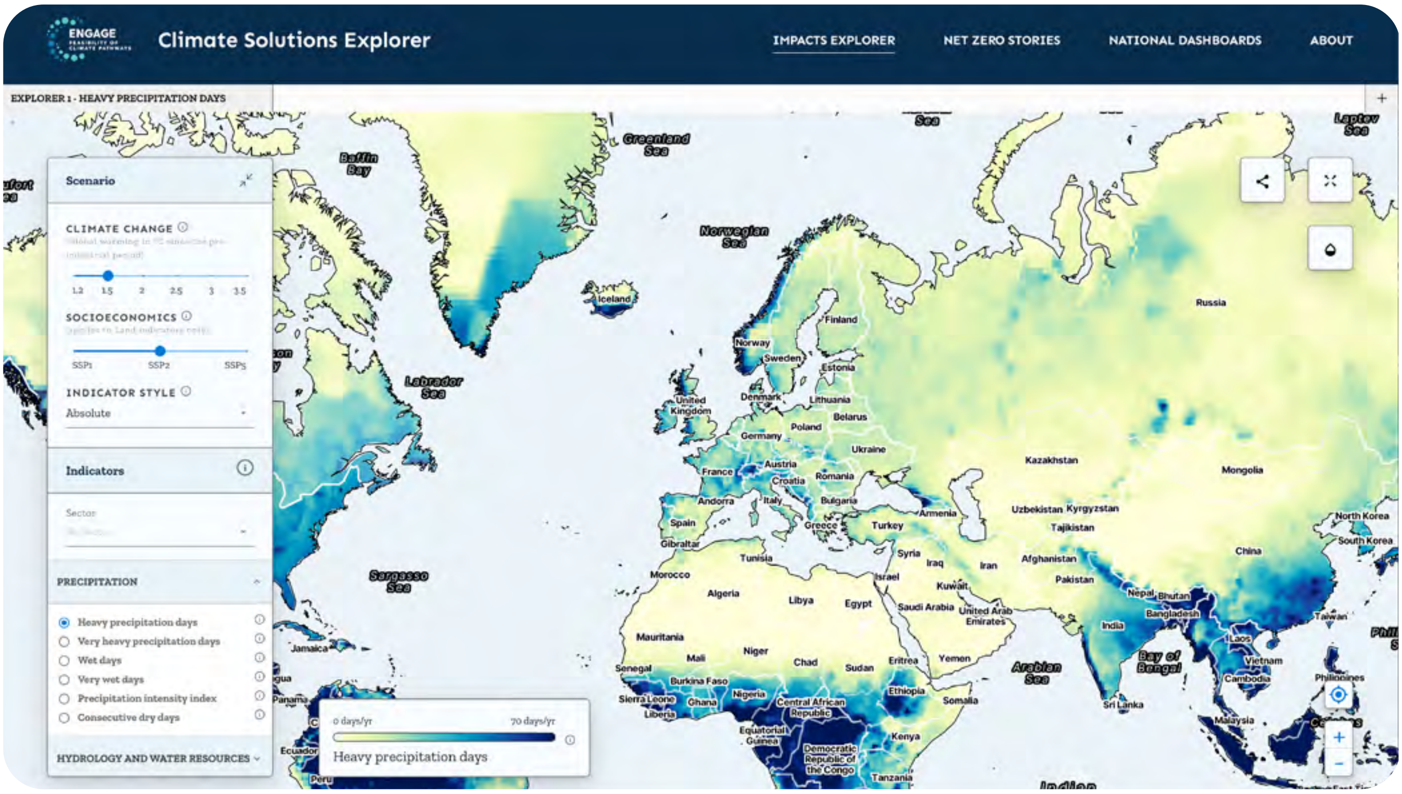
The research for this summary was led by Zoi Vrontisi and Dimitris Fragkiadakis at E3M Modelling.
The work was published in an internal report to the European Commission in September 2022.

Preprints of forthcoming publications will be posted on www.engage-climate.org

9. Communicating results on trade-offs, co-benefits and avoided impacts

The Climate Solutions Explorer (CSE) (www.climate-solutions-explorer.eu) presents information about mitigation pathways, climate impacts, avoided climate exposure and trade-offs and synergies of net-zero mitigation pathways.

FIGURE 16:
Screenshot of the Impacts Explorer page



Improved understanding and communication of the impacts and risks of climate change are a key mechanism for informing policy and decision making on mitigation and adaptation. By extension, a key novelty has been the framing of "avoided impacts" and avoided exposure – that is, if the world successfully mitigates global warming to 1.5°C, what impacts are avoided compared to higher levels of warming, such as 2 or 3°C? Framed in such a way, particularly at the national level, the National Dashboards present the benefits of mitigation more clearly. The Dashboards section features individual pages for almost 200 countries and 10 global macro-regions, combining mitigation and impacts data and analysis.

This information builds on new and updated climate risk analysis using the latest CMIP6 climate and impacts model data, covering global mean temperature increases between 1.2 (current) to 3.5°C.

Presented on a full-screen interactive map, comparisons between indicators, regions and scenarios can be made. Figure 16 shows an example page from the CSE.

Mitigation policies can be implemented in a variety of ways, even if the goal is to achieve the same levels of emissions mitigation. Enacted through different sectors, the selection of mitigation policies can result in trade-offs and co-benefits, that are often manifested along different sustainability dimensions. For key countries for which ENGAGE partners could provide model results and case studies, deep-dive analysis is presented in the format of "Stories", which are written in a policy brief style but also include interactive charts and maps. They cover different trade-off and co-benefit angles of net-zero transitions most relevant to the country or sector in question.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

The research and webtool development for this summary was led by Ed Byers (IIASA). The work was published in an internal report to the European Commission in May 2023.

All data used on the website are available to download and accompanied by documentation.

10. Engaging stakeholders in a co-creation process

Climate change is an extremely complex challenge, requiring transformative changes in society. Experience has demonstrated that this requires a process of iterative and constructive dialogue between the research community and a wide range of other stakeholders from governments, non-governmental organizations, businesses, financial institutions, industry, international organizations, and civil society. Such a process can enhance the use of local and specialized knowledge in research, and also support buy-in, as people are more willing to accept results and insights if they are part of the process. Stakeholder involvement has become a key element of EU policy development in order to enable stakeholders to express their view over the entire lifecycle of a policy. It is also recognized as a key component of responsible research and innovation.

An important element of good practice in stakeholder engagement is skilled facilitation that opens a safe space for participants to discuss complex or emotional issues in an open way. This encourages a deeper connection between the participants and the emergence of new, creative ideas. An approach known as the Art of Hosting serves these objectives, using processes such as informal interactions to help make people feel comfortable, and was used for designing stakeholder engagement in this ENGAGE project.

In the ENGAGE project, there were two streams of stakeholder engagement:

- stakeholder co-design and assessment of **global** decarbonization pathways;
- stakeholder dialogues on **national/regional** policies and pathways.

We held nine workshops: three at the global level and six at the national/regional level (Figure 17). The first five workshops were held online due to the COVID-19 pandemic. The last four were physical meetings.

FIGURE 17: Stakeholder engagement workshops in the project. Global workshops in grey; national/regional workshops in blue.

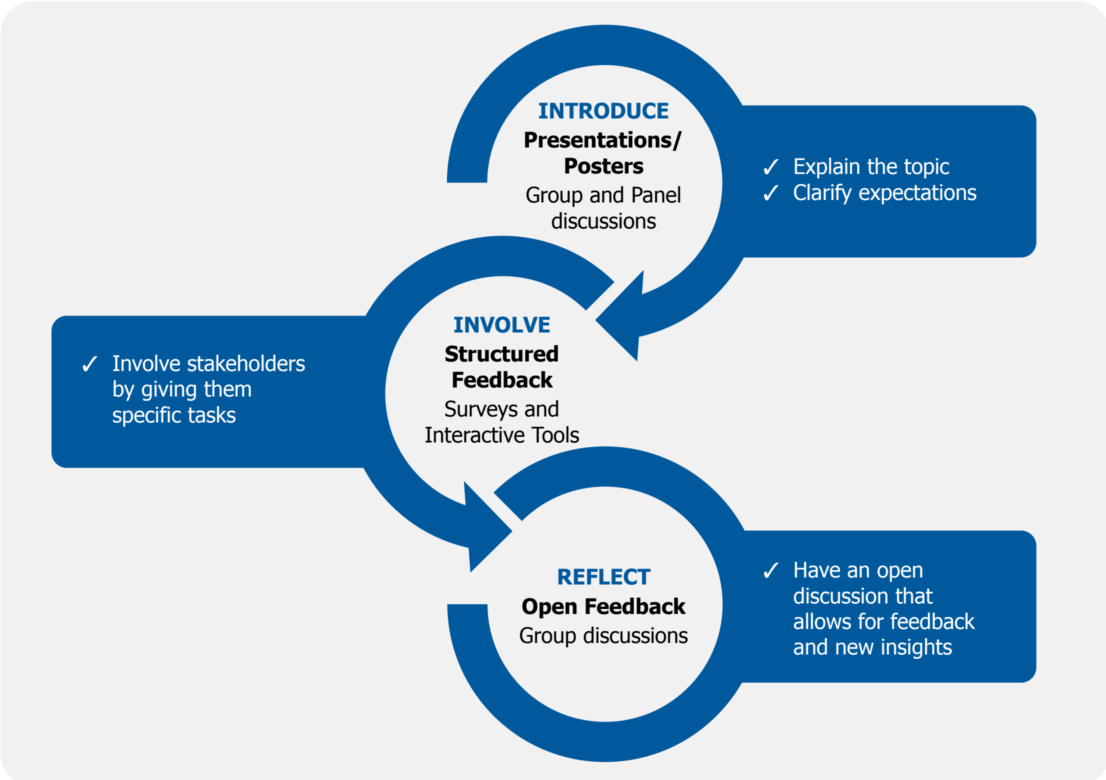
MARCH 2020	• Decarbonisation pathways, enablers and barriers, game-changers • Europe
JUNE 2021	• Pathways to net-zero, feasibility • Global
SEPT. 2021	• Pathways to net-zero, feasibility, equity • Asia
JAN. 2022	• Implications of COP26 for research • Global
APRIL 2022	• Pathways to net-zero, feasibility, equity • Brazil and Latin America
OCT. 2022	• Energy security, avoided impacts, trade-offs and co-benefits of mitigation pathways, effort sharing • Europe
MARCH 2023	• Achieving net-zero in Brazil and Latin America, sub-national implementation of pathways • Brazil and Latin America
JUNE 2023	• Policy analysis for increasing ambition in 2030 and beyond, just transition, net-zero targets • Global
JUNE 2023	• NDCs, co-benefits, sectoral decarbonisation pathways • China

The process in each workshop was split into *introduce*, *involve, reflect* and a variety of tools and approaches (Figure 18) was used to *introduce* topics to stakeholders, especially presentations on model results, panel discussions, and storytelling; and in two workshops, posters. Prominent speakers were invited for introductory presentations.

Then, to *involve* stakeholders in our work, we used surveys and interactive tools pertaining to key concepts or model results to collect structured feedback from all stakeholders.

Finally, moderated discussions in small groups provided an open space to *reflect*, to collect more general feedback and provide new insights.

FIGURE 18:
Various forms of engagement used in the workshops.



For example, a workshop might begin with a brief presentation on model results, showing a set of possible scenarios that limit warming to 2°C. Then we might use an online tool combined with a survey of the participants to assess the feasibility of the scenarios. While the stakeholders might respond that some scenarios are feasible, they might find that others are infeasible, perhaps due to technological constraints or lack of governance mechanisms. This process contributes to the co-design of emissions scenarios, as stakeholders provide their perspectives, which can be taken up by researchers.

After each workshop, evaluation by the project team played an important role in improving tools and approaches. While we succeeded in most cases to stimulate a two-way dialogue with stakeholders, we also learned that some changes to the interactive tools were necessary. For example, we found that the first version of the feasibility tool was too complex to be grasped in the limited time available, so it was simplified for later online workshops.

We found that combining approaches and tools brought added value. In particular, linking surveys, visual tools, presentation, and open discussion worked well, and provided valuable insights for stakeholders and the project team.

One insight was that participants believed that social movements, finance, and political leadership could have a strong impact on decarbonization. This led to the ENGAGE project paying more attention to social dimensions in its work on decarbonization pathways. Stakeholders also highlighted the need to consider the role of institutions in determining the feasibility of decarbonization, and this was also taken up in subsequent work in the ENGAGE project.

The need for physical meetings

Our experience in this project shows that online activities cannot replace physical meetings for effective co-creation of decarbonization pathways – or, more generally, to find solutions to the complex problems of unsustainability.

Online dialogues have one major disadvantage: the need to keep them short. We found that online meetings had to be kept to no more than two hours, or a large proportion of participants would leave early. As a result, there is little or no time for participant introductions, and no opportunity to get to know other participants in informal group activities. Nor is there enough time in breakout groups to cover more than one or two key questions or engage in in-depth discussion. There is also no time for a feedback round and workshop evaluation at the end of the session.

To find and implement pathways that meet the Paris goals, stakeholders need enough time and space to get to know and understand diverse perspectives, to dive deep where necessary, and to engage in multiple, iterative dialogues. An open knowledge system to find solutions for problems of unsustainability can be supported by online meetings, but also needs longer physical meetings that are part of a longer-term social learning process.

Capacity building

A co-creation process depends on the willingness of the project management team and partners to invest time and resources in the activities throughout the course of the project. So, the project coordinator needs to understand fully the importance and value of a two-way dialogue, the steps that need to be taken and their role in the process, as well as nurturing this understanding from all project partners by capacity building on the one hand and being a role model on the other.

This requires continuous capacity building for partners, teaching them, for example, the art of facilitation – such as how to pose questions, take care of a breakout group, and report succinctly. Within the ENGAGE project, a capacity building workshop was held early in the project in collaboration with the NEW HORRIZON project (https://newhorrizon.eu/). This was mainly for students rather than project partners, but it provided a template for an effective capacity-building initiative, following the Art of Hosting approach.

The project also showed a need for capacity building for other stakeholders. Participants in several workshops wanted to learn more about how integrated assessment models work and how to interpret the results.

Missing platform

The ENGAGE project has benefitted enormously from experience in the design and implementation of stakeholder engagement activities in other EU-funded projects. What seems to be missing, however, is a central platform for documenting lessons learned in stakeholder engagement, so that future projects have a solid basis for design and implementation of effective co-creation processes.

Preparation, culture, and funding

Other lessons from the project include:
Detailed preparation and briefings for the project team before the stakeholder event were essential for both online and physical workshops, especially when new tools and approaches were introduced.

A clear goal to have a positive impact on policy, and support from the project coordinator and partners, are also vital for successful stakeholder engagement.

It is important to recognize cultural differences in the willingness to engage in a dialogue, for example in answering direct questions. Whether in an online or a physical meeting, all participants need time to build trust in the process, and this requires careful facilitation. Given the need for careful preparation of the process and substantial involvement of a large number of partners in an iterative process of dialogue with the other stakeholders, adequate funding is essential.

PUBLICATION ON WHICH THIS SUMMARY IS BASED

Jäger, J., Brutschin, E., Pianta, S., Omann, I., Kammerlander, M., Sudharmma Vishwanathan, S., Vrontisi, Z., MacDonald, J., & van Ruijven, B. (2023). Stakeholder engagement and decarbonization pathways: Meeting the challenges of the COVID-19 pandemic. Frontiers in Sustainability, 3. https://www.frontiersin.org/articles/10.3389/frsus.2022.1063719

Further information on the workshops at www.engage-climate.org/stakeholders

11. ENGAGE capacity building

Beyond performing scientific research, increasing the capacity for carrying out scientific research was another essential objective of the ENGAGE project. The three research networking and capacity building programs within ENGAGE were the capacity building workshops, the research exchange program, and the ENGAGE summer school.

The **capacity building workshops** in ENGAGE ensure that less experienced teams of the consortium can learn about the new methodologies and practices from the more experienced teams. The topics for capacity building workshops were chosen based on general consensus of the consortium. Topics of the workshops were the inclusion of air pollution in Integrated Assessment Models (AIMs), improving IAM documentation, model validation, good practices in modeling, and water, energy, land nexus modeling.

The **research exchange program** enabled 11 young scholars from varied institutes globally to collaborate with project institutions to research topics such as the sustainable transition of the agricultural sector into global integrated assessment models, scenarios for ammonia use in the Chinese shipping sector, and learning to work with open-source modeling tools.

The **ENGAGE summer school**, organized in cooperation with the NAVIGATE project, was held at Lake Como in July 2023, and hosted 25 students from 13 countries, including Brazil, China, Lebanon, South Korea, and many others. The school courses, taught by key scientists involved in the ENGAGE project, covered topics like IAM History and their Role in Climate Negotiations, Ex-ante Socioeconomic Assessment of climate policies with IAMs, and Just transitions towards net-zero emissions. The students carried out hands-on exercises with analysis tools for IAM output, and developed new components for IAM models.

Participants and faculty of the ENGAGE/NAVIGATE summer school in July 2023

All materials and recordings of ENGAGE capacity building activities are available at ***www.engage-climate.org/capacity-building/***

12. Concluding remarks

The multidisciplinary team of the ENGAGE project and the transdisciplinary approach taken throughout the project show clearly that:

- **Neither current policies nor existing nationally determined contributions (NDCs) bring emissions close to levels required to meet the Paris goals.** While recent net-zero targets are a big step forward, they are still not enough to meet long-term climate goals. To close the remaining gap, fossil fuel use must be cut sharply, and the reach of renewables must be further extended.
- **Overcoming feasibility concerns in the near-term has clear long-term benefits. Moving fast creates fewer feasibility concerns overall.** Institutions are a major concern with regard to feasibility of mitigation scenarios. Focused international aid could make a big difference here, for example by investing in education.
- **Relying on net-negative scenarios leads to hazardous levels of overshoot.** Investment in low-carbon power should at least double by 2030 to avoid overshoot (under a 1000 Gt budget). Upfront investment brings long-term economic gains. CO_2-removal is needed to accelerate near-term mitigation and to offset emissions from hard-to-abate sectors.
- **Warming will probably pass 1.5°C, largely owing to low institutional capacity, so the world should prepare for a temperature overshoot.** Reducing energy demand improves the likelihood of staying below 1.5°C and is even more important to help reduce temperatures after a peak. Countries with high institutional capacity should take more responsibility for near-term mitigation.
- **Most effort-sharing schemes lead to only a very slight reduction in 2050 global GDP (well under 1% compared with cost-optimal scenarios).** Fairness-based emissions trading can cut costs further, but the scale of international transfers may make this unfeasible. A climate club can bring the best of both worlds. Developing nations are likely to benefit from any of the effort-sharing approaches.
- **Stakeholder dialogue is necessary.** Finding and implementing solutions to anthropogenic climate change requires a process of iterative and constructive dialogue between the research community and a wide range of other stakeholders. To find and implement pathways that meet the Paris goals, stakeholders need enough time and space to get to know and understand diverse perspectives and to dive deep where necessary.

ENGAGE publications:
www.engage-climate.org/publications/

For more information on the ENGAGE project, please visit
www.engage-climate.org

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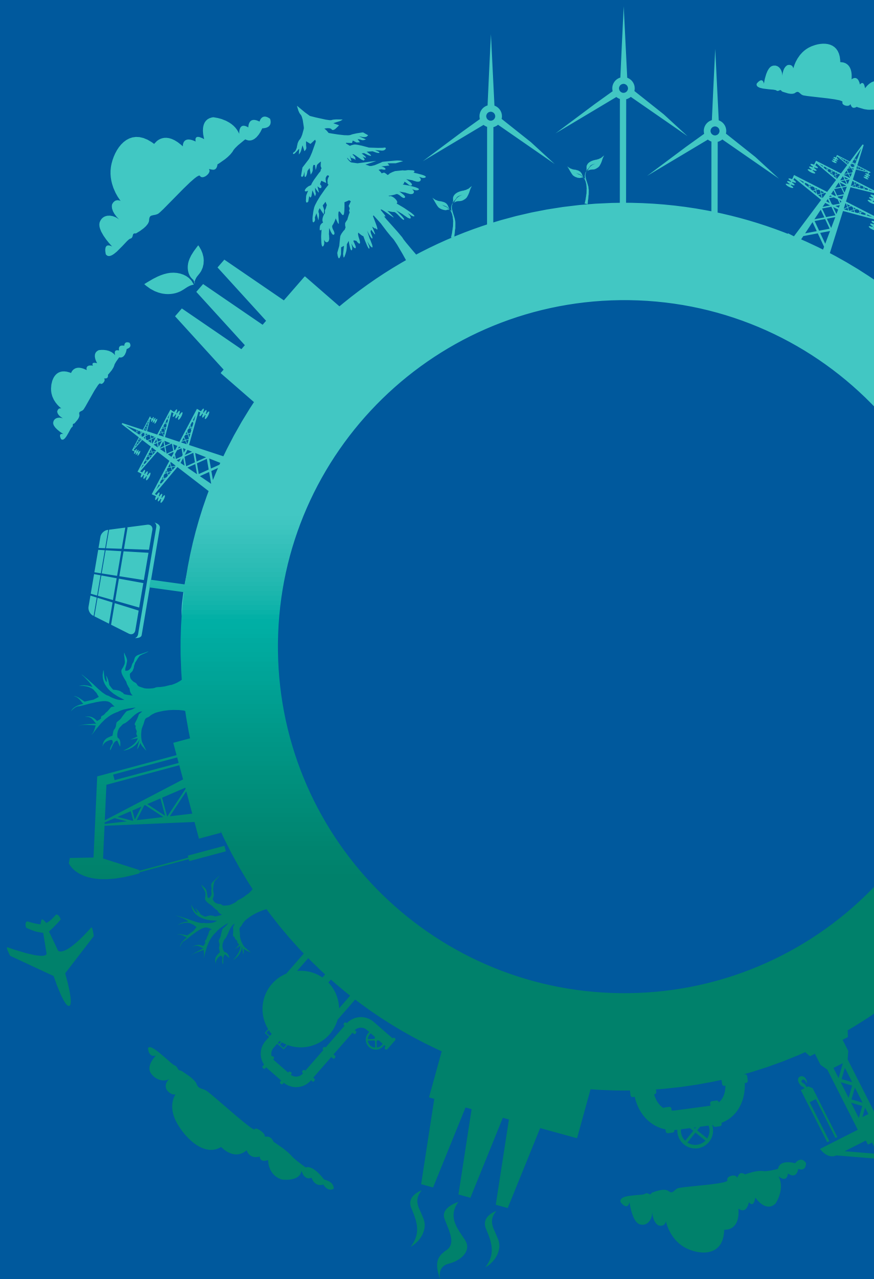

About the ENGAGE Project
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