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ANALYSIS OF PROJECTED GREENHOUSE GAS EMISSION REDUCTION LEVELS BY 2040 FOR MAJOR EMITTING COUNTRIES

Reduction levels in line with the Paris climate goals based on the IPCC AR6 scenario database — Methodology report

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Summary

The achievement of the global climate goals of the Paris Agreement depends on the collective action by individual nations, which are reflected in their nationally determined contributions (NDCs). NDCs contain national mitigation targets, plans and measures, and were first submitted in the lead-up to the Conference of the Parties (COP) 21 in Paris (2015). To ensure continual progress, the Paris Agreement established a ratcheting process for evaluating and enhancing the NDCs over time. Parties were requested to submit new NDCs by 2020, as was done for COP26 in Glasgow, and will be required to do so every five years, thereafter (e.g. by 2025, 2030). In this context, greenhouse gas reduction targets for 2040 become increasingly important. This study, for which this report presents the methodology, aims to identify the necessary greenhouse gas emission reduction levels for 2040 and the corresponding 2030–2050 greenhouse gas emission budgets for major emitting economies to achieve the targets of 1.5 °C and well below 2 °C in maximum global temperature increases, at the lowest possible mitigation costs. Such long-term targets can be explored with recently developed long-term low greenhouse gas emission pathways calculated from global Integrated Assessment Models. This study uses the least mitigation costs scenarios for 1.5 °C and 2 °C from Integrated Assessment Models of the latest IPCC's Sixth Assessment Report scenario database. We focus on five major emitting economies (the European Union 27, China, India, Japan and the United States) and the world as a whole. We have downscaled the original emission pathways at the regional level for these five major economies and further harmonised the emission data with national inventory data. The results can inform policymakers on the required emission reductions for 2040 and greenhouse gas emission budgets for 2030–2050. The study will be presented in two parts, with this report intended to discuss the methodology for selecting global and regional pathways from the IPCC AR6 scenario database with experts. The final publication will present the overall study with results based on the agreed methodology.

Contents

1 Introduction

The Paris Agreement's long-term goal is to hold the increase in average global temperature to well below 2 °C above pre-industrial levels and to pursuing efforts to limit temperature increase to 1.5 °C (Article 2) (UNFCCC, 2015a). Achieving these global climate goals relies on collective action by individual nations, whose actions under the agreement are nationally determined contributions (NDCs). NDCs contain national mitigation targets, plans and measures, and were first submitted in the lead-up to the Conference of the Parties (COP) 21 in Paris (UNFCCC, 2015b). The Paris Agreement established a ratcheting process, through which the NDCs are evaluated and enhanced. The first facilitative (Talanoa) dialogue for this purpose started in 2018 and subsequent global stocktakes will take place every five years, beginning in 2023. Most countries updated their NDCs in 2021 in advance of the COP26 in Glasgow, and several other countries updated their NDCs in 2022. Globally, the updated NDCs as of 23 September 2022 are estimated to result in an annual additional reduction of 4.8 $GtCO_2e$ by 2030 relative to the initial NDCs of Paris, but they remain insufficient to meet the collective climate goals of the Paris Agreement (den Elzen et al., 2022; UNEP, 2022).

In this context, reduction targets for 2040 become increasingly important. In the lead-up to COP30 (in 2025), all countries need to submit new NDCs, which should cover intermediate targets for 2040 or 2035. Countries should start their preparations for updating their NDCs well before the COP, as this entails an iterative process informed by reviews of the status of contributions (the global stocktake). According to the European Climate Law, for instance, the European Commission should propose an EU climate target for 2040 and a projected indicative EU greenhouse gas budget for the 2030–2050 period within six months of the first global stocktake of 2023, at the latest (European Parliament and the Council of the European Union, 2021). In addition, Article 4 of the agreement sets out that '*all Parties should also strive to formulate and communicate long-term low GHG emission development strategies*' (UNFCCC, 2015a). The development of these long-term strategies, including quantifiable national targets, would also provide post-2030 constraints on the national emission pathways. As of 1 December 2022, 57 Parties, covering about 72% of global greenhouse gas emissions, have communicated a long-term strategy (Climate Watch, 2022) and 89 Parties, representing about 79% of global GHG emissions, have communicated a net-zero target.

Enhancing such mitigation components of the NDCs and long-term targets and learning how these can be aligned with the Paris Agreement temperature goal, can be explored with recently developed long-term low GHG emission pathways for meeting the climate targets of 1.5 °C and 2 °C as calculated from global Integrated Assessment Models (IAMs) (Riahi et al., 2021; Riahi et al., 2022; van Soest, Aleluia Reis, et al., 2021). These scenarios demonstrate how emission reductions can be distributed in time across regions, sectors and greenhouse gases at the lowest costs possible. A few studies have analysed the regional GHG emission trajectories of these least-cost scenarios in detail. Roelfsema et al. (2020) used nine different IAMs to compare the impact of national policies with emission pathways consistent with the NDCs and emission pathways well below 2 °C. Additionally, van Soest, den Elzen, et al. (2021) analysed national-level neutrality years based on least-cost 1.5 °C and 2 °C scenarios from six different IAMs.

This study, for which this report presents the methodology, aims to identify which greenhouse gas emission reduction levels for 2040 and which 2030–2050 greenhouse gas emission budgets for major emitting economies would lead to achieving the climate targets of 1.5 °C and 2 °C at lowest possible mitigation costs. It is based on the least-costs 1.5 °C and 2 °C scenarios from integrated assessment models (IAMs) of the latest IPCC's Sixth Assessment Report (AR6) scenario database, which was developed as part of the IPCC AR6 WGIII Report (Byers et al. 2022; Riahi et al. 2022). We focus on five major emitting economies (the European Union 27, China, India, Japan and the United States) and the world as a whole. For the analysis, we downscaled the original emission pathways at a level of model regions for these five major economies (which will be referred to as 'selected countries or regions'). Moreover, we harmonised the emission data with the national inventory data. It is important to note that the analysis is applied to global cost-effective pathways. When it comes to deriving emission levels, such perspective 'should be complemented with an assessment of feasible reductions at the national level, considerations of equity and national model results, among others' (van Soest, den Elzen, et al., 2021). This point is further discussed in Box 1.1.

The study will be presented in two parts. This first report is meant to discuss the methodology to select global and regional pathways from the IPCC AR6 database with experts. The final publication will present the overall study with the results based on the agreed methodology.

Box 1.1 Least-cost pathways and equity considerations
The IPCC AR6 scenario database contains least-cost scenarios only. This means that achieving climate targets and the regional distribution of mitigation actions are based on the lowest possible costs globally. However, the UNFCCC also refers to other important considerations, including equity principles, which can be important in regional distribution of reduction efforts: under the United Nations Framework Convention on Climate Change all countries agreed to 'common but differentiated responsibilities and respective capabilities' in mitigating climate change (UNFCCC, 1992). However, there is no commonly agreed methodology to define equity considerations, which is a topic of research (e.g. see Robiou du Pont et al. (2017) or van den Berg et al. (2020)). Different ways to operationalise this aspect in global climate policy have been proposed, such as adjustment of reduction targets, international emission trading instruments, international climate finance or support to capacity building or to technology transfer (Pachauri et al., 2022; Rajamani et al., 2021; Rogelj, 2019; van Soest, den Elzen et al., 2021).

2 Methods

In this study, we use the mitigation scenarios from the IPCC's Sixth Assessment Report (AR6) scenario database (Byers et al., 2022). From this database, we selected scenarios compatible with the climate goals of the Paris Agreement. Subsequently, we downscaled the emission pathways of the scenarios towards the selected countries of interest and harmonised the countries' emission pathways with emission inventory data.

2.1 Scenario selection

The IPCC AR6 scenario database is hosted by IIASA and includes results from all IAM scenarios used in the IPCC AR6 report and its chapter on mitigation pathways compatible with long-term goals (IPCC, 2022a; Riahi et al., 2022). The scenarios were developed for various research projects and afterwards collected to be included in the database.

From the scenario database, we have selected all available scenarios of climate categories C1 (limit 1.5 °C with at least 50% chance, with limited or no overshoot), C2 (limit 1.5 °C with at least 50% chance, with high overshoot) and C3 (limit 2 °C with at least 67% chance). These scenarios can be considered to be consistent with the climate goal of the Paris Agreement, i.e., *'holding the increase in average global temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels'* (UNFCCC, 2015a).

Next to these categories we highlight scenarios of category C1a, which is a subcategory of C1 with scenarios reaching global net-zero greenhouse emissions in the second half of this century. The latter is consistent with the Article 4 of the Paris Agreement, i.e. *'reach global peaking of greenhouse gas emissions as soon as possible [...] and [...] to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century.'*

Table 2.1 shows the compatibility of scenarios in all selected climate categories with the climate goal and net-zero greenhouse gas target of the Paris Agreement, i.e. achieving net-zero greenhouse gas emissions before the end of the century. It shows that only C1a scenarios are compatible with keeping temperature increase below 2 °C with a very likely chance, and also keep the overshoot in temperature increase of 1.5 °C limited (0.1 °C). C1 achieves the net-zero target in the second half of the 21st century, as well. C1 is also compatible with the 1.5 °C and 2 °C goal, but does not the net-zero target. C2 has a higher overshoot of 1.5 °C and a lower likelihood for meeting 2 °C, but achieves the net-zero target in the second half of the 21st century. C3 only achieves the below 2 °C target of the climate goal.

The selection of scenarios based on climate categories is narrowed further by two restrictions. Firstly, we only select scenarios that are labelled 'historically vetted'. This means we solely included scenarios with a small deviation from the historical trend. Secondly, we focus on long-term least-cost pathways starting from 2020 and consistent with keeping the warming below temperature limits (1.5 °C or 2 °C). Therefore, we exclude scenarios entailing delayed action and prescribing nonleast-cost pathways until 2030 from our selection[1]. Figure 2.1 shows per selected country or region the numbers of scenarios including and excluding delayed action scenarios.

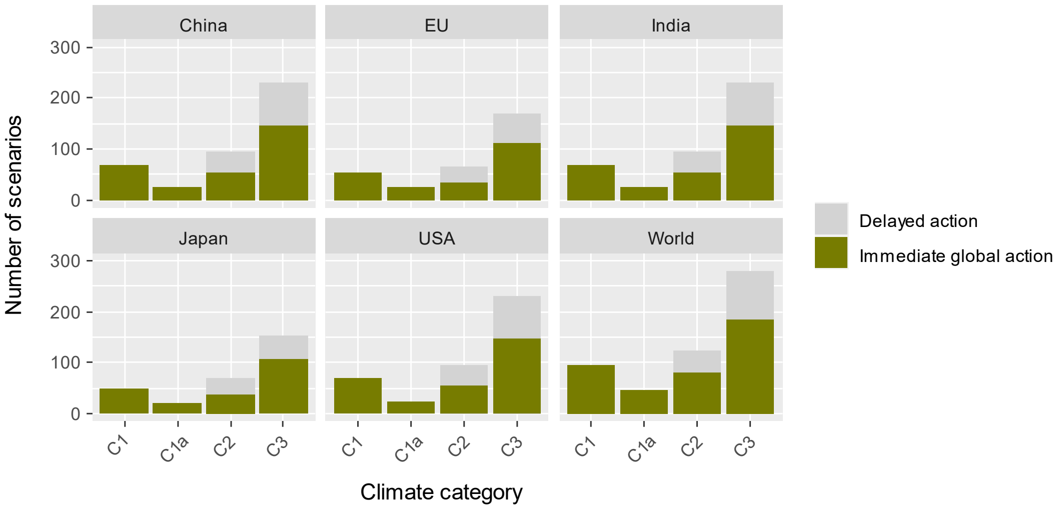
The IAMs covered in the final selection of scenarios are AIM, C-ROADS, COFFEE, EPPA, GCAM, GEM-E3, IMAGE, MESSAGE, POLES, REMIND and WITCH. Some characteristics are unequally represented: scenarios of specific models (e.g. MESSAGE and REMIND) and specific research projects (e.g. ENGAGE) appear more often in the IPCC AR6 scenario database and in our selection than others, and almost all scenarios are based on socioeconomic pathway SSP2. Appendix A contains an overview of the number of selected scenarios per model, research project, climate category (C1, C2, C3), assumed SSP and policy category.

Table 2.1
Compatibility of climate categories with the climate goal and greenhouse gas neutrality target of the Paris Agreement. Source: adjusted from table SPM.2 in IPCC (2022b).

Characteristics of scenarios	**C1**	**C1a**	**C2**	**C3**
Temperature increase (50% probability) at peak / in 2100	1.6 °C / 1.3 °C	1.6 °C / 1.2 °C	1.7 °C / 1.4 °C	1.7 °C / 1.6 °C
Likelihood of staying below 2 °C throughout the century	90% (86%–98%)	90% (85%–98%)	82% (71%–95%)	76% (68%–91%)
Median timing of reaching global net-zero GHGs (% net-zero pathways)	2095–2100 (52%)	2070–2075 (100%)	2070–2075 (87%)	
Median timing of reaching global net-zero CO_2 (% net-zero pathways)*	2050–2055	2050–2055	2055–2060	2070–2075

** Although reaching net-zero CO_2 is not mentioned the Paris Agreement, it was added for the sake of completeness.*

Figure 2.1
Numbers of scenarios per climate category and per selected country or region, including and excluding delayed action scenarios.



[1] We exclude scenarios with delayed action by excluding scenarios labelled with policy category P3: 'globally coordinate climate policies with delayed (i.e., from 2030 onwards or after 2030) action'.

2.2 Regional downscaling

The models in our selection involve various definitions of regions. For some models, the modelled regions containing China, India or EU27 include other countries as well. For example, three selected models contain a region 'Europe' which covers the EU27 plus the United Kingdom and several other countries, while the 'Europe' region of another model covers the EU27 plus the United Kingdom but without Croatia. To estimate the emission pathway of the selected country or region from the emission pathway of a similar region modelled by the IAM, we use two scaling methods: simple linear scaling and a more advanced method based on van Vuuren et al. (2007). Which method is used depends on characteristics of the region. Box 2.1 contains an overview of the definitions of regions per model, the selected countries or regions for this study and which method is used to estimate the emission pathway of the selected country or region from the modelled region.

2.2.1 Linear downscaling: model region Europe to EU28

We perform a linear scaling if the emissions of the selected country or region are strongly dominant in the modelled region. In the example of Europe, we therefore use simple scaling to estimate emission pathways of EU28 (EU27 plus the United Kingdom) from the emission pathways for model region Europe (e.g. EU28 plus Norway, Switzerland, Iceland, Bosnia Herzegovina, Servia, Montenegro, North Macedonia and Albania). The modelled emissions of the EU28 for a certain year ($GHG_{sc;y}$) are estimated by assuming that the relative difference in emissions between the modelled region and the selected country or region stays the same. This difference is calculated as the ratio of EU28 emissions ($GHG_{sc;2015}$) in 2015 to the emissions in 2015 of the modelled region ($GHG_{mr;2015}$). We use 2015 emissions as this is the most recent year for which emission data are available for all regions. National inventory data retrieved from UNFCCC (2022) are used when possible. If the data are unavailable from UNFCCC, data from EDGAR (Olivier & Peters, 2020) and FAOSTAT (FAOSTAT, 2020) are used. The 2015 fraction is multiplied with model-region emissions for all future years ($GHG_{mr;y}$) to determine future EU28 emissions.

$$GHG_{sc;y} = \left(\frac{GHG_{sc;2015}}{GHG_{mr;2015}}\right) * GHG_{mr;y}$$

National emission inventory data for 2019 or 2020 could have been used to calculate the fraction as well, but as 2015 levels are used to determine reduction targets it was chosen to use this year as a basis throughout the research. In addition, national emission inventory data were not available for more recent reporting years for all the selected economies.

2.2.2 Advanced downscaling: EU28 to EU27

If the selected country or region is less dominant in the modelled region or if the modelled region consists of various countries that are less homogeneous and show different economic and emission trends, we use a more advanced downscaling method based on van Vuuren et al. (2007). The method is applied on CO_2 emissions excluding LULUCF (land use, land-use change and forestry), and we use it for instance to estimate EU27 emission pathways from EU28 emission pathways. For some models, these EU28 emission pathways are a result of linear downscaling from regions slightly different from EU28, as explained in the previous section. The idea of the method is that, while CO_2 emission intensities may differ among countries within the modelled region for historical years, the CO_2 emission intensity for those countries within the region are assumed to converge to the same level in 2100. In detail, the method entails the following: First, we determine CO_2 emission intensity pathways for the selected country or region and other countries within the available region (in the example, these are EU27 and the United Kingdom). For each country or region, a constant annual linear growth rate ($CO_2I_{c;lgr}$) is determined starting from 2015 CO_2 emission intensity levels (national inventory data retrieved from UNFCCC (2022) when possible, or else from Olivier and Peters (2020) and FAOSTAT (2020)) ($CO_2I_{c;h;2015}$, $MtCO_2e\ GDP^{-1}$) and ending at the 2100 levels projected for the available region (e.g. EU28) ($CO_2I_{m;2100}$).

$$CO_2I_{c;lgr} = \frac{CO_2I_{c;h;2015} - CO_2I_{m;2100}}{2100 - 2015}$$

For each year (y), the CO_2 emission intensity level is determined by multiplying the linear growth rate with the number of years between y and 2015, and adding this to 2015 levels.

$$CO_2I_{c;y} = CO_2I_{c;h;2015} + (y - 2015) * CO_2I_{c;lgr}$$

In order to determine CO_2 emission levels for the country ($CO_{2_{c;y}}$), the resulting CO_2 emission intensity values for the country or region are multiplied with its GDP projections derived from SSPs (Gidden et al., 2019).

$$CO_{2_{c;y}} = CO_2I_{c;y} * GDP_{SSP;y}$$

Finally, we multiply the CO_2 emission levels of each country or region with a common scaling factor to ensure consistency between the summed CO_2 emission levels of the downscaled regions and the CO_2 emission level projected by the model for the whole region.

$$CO_{2_{c;y;consistent}} = \left(\frac{\sum CO_{2_{c;y}}}{CO_{2_{m;y}}}\right) * \ CO_{2_{c;y}}$$

For LULUCF CO_2 emissions and general non-CO_2 emissions, we assume that they follow the original regional emission growth trend and apply a linear scaling factor as described in 2.2.1.

Box 2.1 EU regions

Table 2.2 shows per model for the EU the European model region and the modifications we did to scale towards the selected region. Information about AIM/CGE, GCAM, GEM-E3, IMAGE, POLES, REMIND and WITCH was retrieved from respectively National Institute for Environmental Studies and Kyoto University (2020), Joint Global Change Research Institute (2022), Institute of Communication And Computer Systems (2016), PBL Netherlands Environmental Assessment Agency (PBL) (2020), Joint Research Centre - European Commission (2016), Luderer et al. (2015) and European Institute of Economics and the Environment (2020). Information about MESSAGE and COFFEE was retrieved from Krey and Natsuo Kishimoto (2021) and Rochedo (2016). These two models are not selected for EU27 because they include Turkey in their European region. This region is difficult to downscale, as Turkeys emission pathway is very different from the average European trend.

Table 2.2
Selected models, their regional coverage regarding Europe and modifications to estimate the emission pathway of EU27.

Model	Selected country or region in this analysis	Coverage of model region	Modifications to downscale model region towards selected country or region
AIM/CGE	EU27	Europe: EU28, Norway, Switzerland, Iceland, Bosnia Herzegovina, Servia, Montenegro, North Macedonia, Albania	Simple scaling to estimate the emission pathway of EU28, advanced downscaling method to estimate emission pathway of EU27
GCAM	EU27	EU28 without Croatia	Simple scaling to estimate the emission pathway of EU28, advanced downscaling method to estimate emission pathway of EU27
GEM-E3	EU27	EU28	Advanced downscaling method to estimate emission pathway of EU27
IMAGE	EU27	Europe: EU28, Norway, Switzerland, Iceland, Bosnia Herzegovina, Servia, Montenegro, North Macedonia, Albania	Simple scaling to estimate the emission pathway of EU28, advanced downscaling method to estimate emission pathway of EU27
POLES	EU27	EU28	Advanced downscaling method to estimate emission pathway of EU27
REMIND	EU27	EU28	Advanced downscaling method to estimate emission pathway of EU27
WITCH	EU27	Europe: EU28, Norway, Switzerland, Iceland, Bosnia Herzegovina, Servia, Montenegro, North Macedonia, Albania	Simple scaling to estimate the emission pathway of EU28, advanced downscaling method to estimate emission pathway of EU27

2.3 Harmonisation to emission inventory data

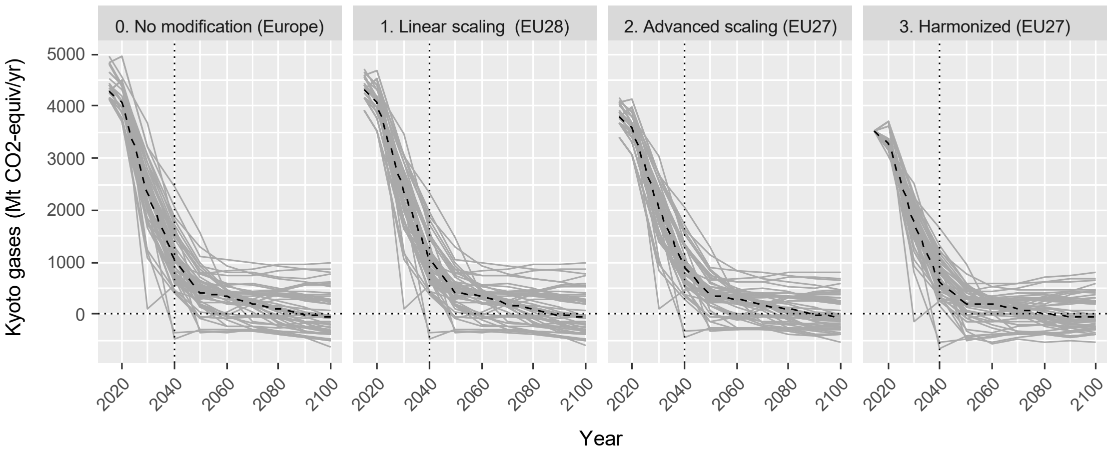
Historical emissions officially reported by countries to the UNFCCC generally differ from the historical emissions used by IAMs (Rogelj et al., 2016). Especially differences in land-use emissions are substantial, because of simplified and/or incomplete representation of forest management in global models, inaccurate and/or incomplete estimation of LULUCF fluxes in national greenhouse gas inventory data (NGHGIs), and conceptual differences in how global models and NGHGIs define 'anthropogenic' CO_2 flux from land (Grassi et al., 2018). We use the offset method based on convergence as proposed by Rogelj et al. (2011) to harmonise the emission pathways of countries and regions to the latest NGHGI data. More specifically, we harmonise LULUCF CO_2 and all other GHG model emissions with the inventory emissions of the country or region (UNFCCC, 2022) from 2015 on, and converge the difference between the two in 2015 linearly to 0 in 2100 (Rogelj et al., 2011). For the harmonisation of the global emission pathways, we applied the same method as adopted in the UNEP Emissions Gap Report 2022: the discrepancy between scenarios from the IPCC AR6 WG III scenario database and historical 2015 emissions based on the IPCC AR6 historical emission database were harmonised. This latter data set was drawn from a variety of sources, but largely from the Community Emissions Data System (CEDS) database by Hoesly et al. (2018) (Kikstra et al., 2022).

Box 2.2 Impact of modifications on pathways

We applied three modifications of the regional emission pathways of the selected scenarios from the different models: linear scaling, advanced scaling and harmonisation. Figure 2.2 shows each modification step and its impact from translating the emission pathways for the model region Europe towards harmonised emission pathways for the EU27 for all selected scenarios from category C1.

Figure 2.2

Pathways for EU GHG emissions resulting from each modification step for category C1. (a) No modification pathways are for various model-dependent Europe regions, (b) linear scaling of the pathways from the Europe regions towards the EU28, (c) advanced scaling from the pathways of the EU28 towards EU27. (d) the harmonisation of the pathways of the EU27 to the national inventory emission data. The black dashed line represents the median of the scenarios.



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Appendices

Appendix A: Characteristics of scenario selection

Figure A.1
Number of scenarios in our selection per model and per selected country or region. The figure shows the final selection of scenarios: it includes all climate categories, and does not contain scenarios involving delayed action.

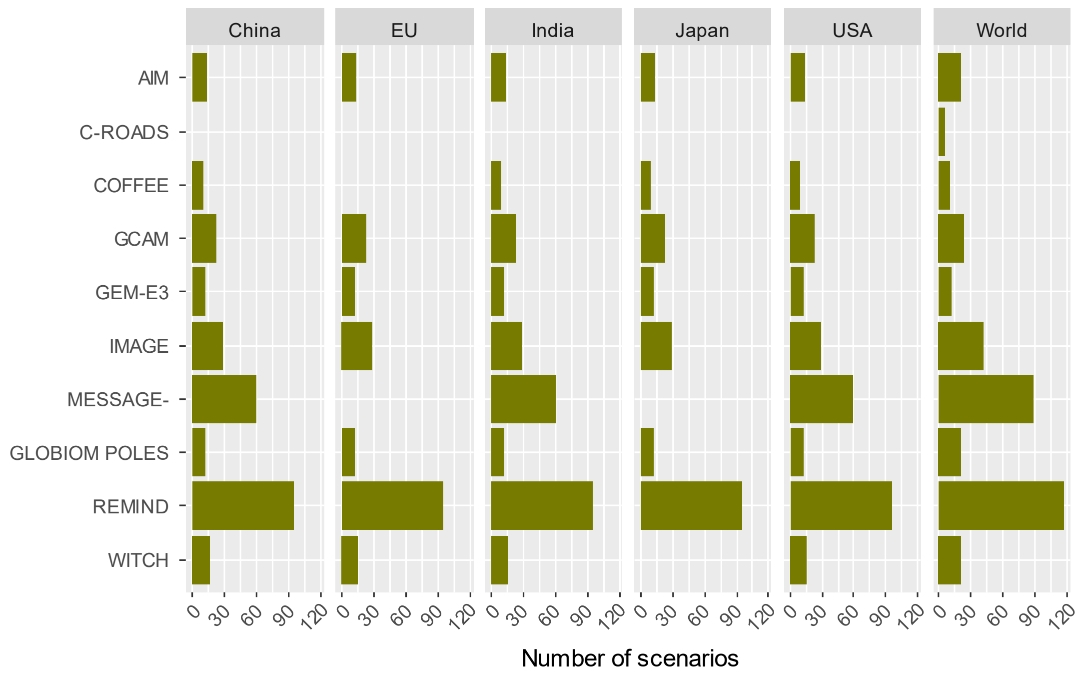

Figure A.2
Number of scenarios in our selection per climate category and per selected region or region. The figure shows the final selection of scenarios. Therefore it does not contain scenarios involving delayed action.

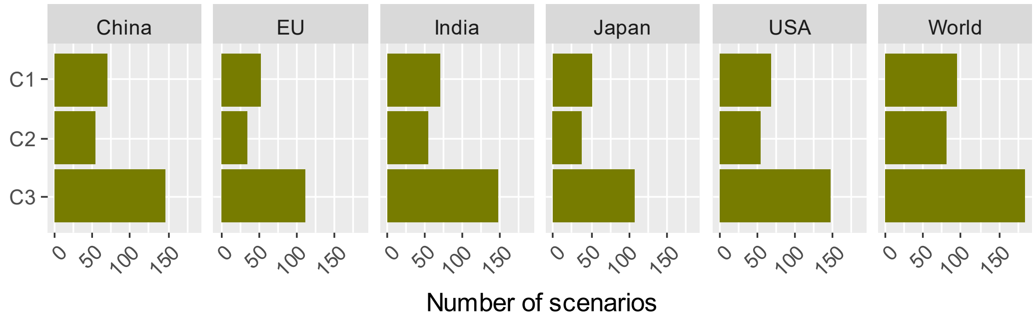

Figure A.3
Number of scenarios in our selection per study and per selected country or region. The figure shows the final selection of scenarios: it includes all climate categories, and does not contain scenarios involving delayed action.

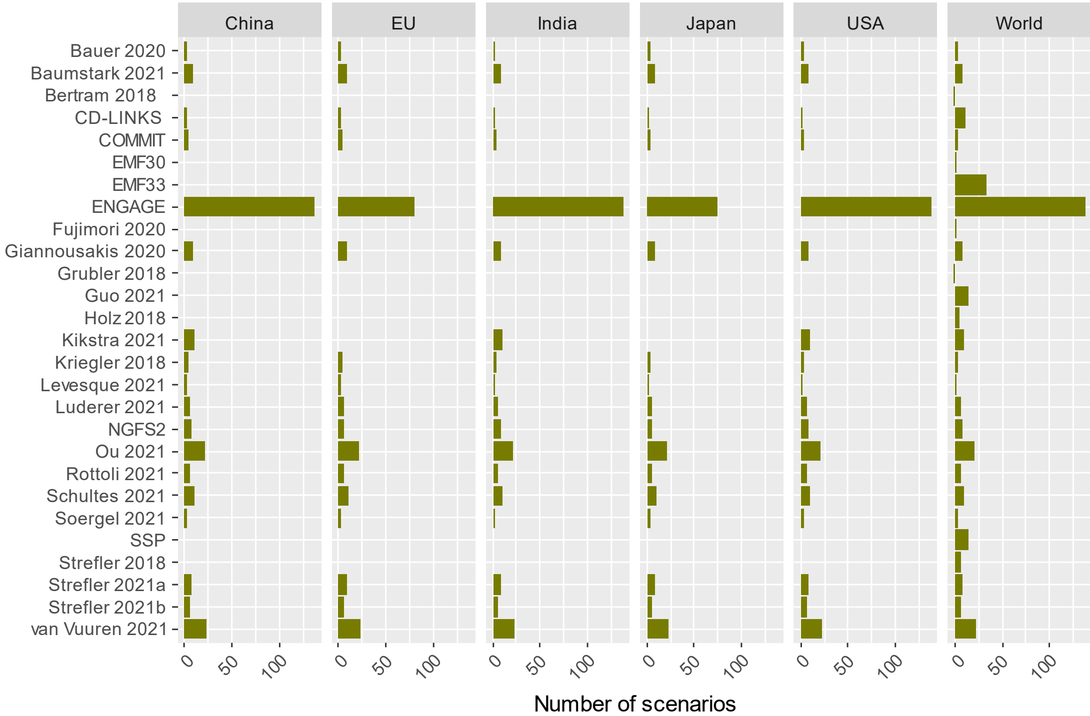

Figure A.4
Number of scenarios in our selection per SSP and per selected country or region. The figure shows the final selection of scenarios: it includes all climate categories, and does not contain scenarios involving delayed action.

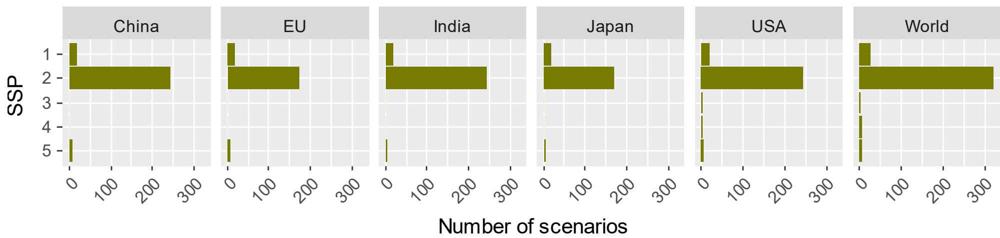

Figure A.5
Number of scenarios in our selection per policy category and per selected country or region. The figure shows the final selection of scenarios: it includes all climate categories, and does not contain scenarios involving delayed action.