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Summary

Governments worldwide have agreed that international climate policy should aim to limit the increase of global mean temperature to less than 2°C with respect to pre-industrial levels. The purpose of this paper is to analyse the emission reductions and related energy system changes in various countries in pathways consistent with the 2°C target. We synthesize and provide an overview of the national and regional information contained in different scenarios from various global models published over the last few years, as well as yet unpublished scenarios submitted by modelling teams participating in the MILES project (Modelling and Informing Low-Emission Strategies). We find that emissions in the mitigation scenarios are significantly reduced in all regions compared to the baseline without climate policies. The regional cumulative CO_2 emissions show on average a 76% reduction between the baseline and 450 scenario. The 450 scenarios show a reduction of primary energy demand in all countries of roughly 30-40% compared to the baseline. In the baseline scenario, the contribution of low-carbon energy technology remains around 15%, i.e. similar as today. In the mitigation scenario, these numbers are scaled up rapidly towards 2050. Looking at air quality, sulphur dioxide and black carbon emissions are strongly reduced as a co-benefit of greenhouse gas emission reductions, in both developing and developed countries. However, black carbon emissions increase in countries that strongly rely on bioenergy to reach mitigation targets. Concerning energy security, energy importing countries generally experience a decrease in net-energy imports in mitigation scenarios compared to the baseline development, while energy exporters experience a loss of energy export revenues.

Keywords: Climate policy, Mitigation, Global and national policy comparison

JEL Classification: Q54

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Regional Low-emission pathways from global models

Deliverable 1.1 for the MILES project

MILES: Modelling and Informing Low-Emission Strategies

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21 December, 2015

Abstract

Governments worldwide have agreed that international climate policy should aim to limit the increase of global mean temperature to less than 2°C with respect to pre-industrial levels. The purpose of this paper is to analyse the emission reductions and related energy system changes in various countries in pathways consistent with the 2°C target. We synthesize and provide an overview of the national and regional information contained in different scenarios from various global models published over the last few years, as well as yet unpublished scenarios submitted by modelling teams participating in the MILES project (Modelling and Informing Low-Emission Strategies). We find that emissions in the mitigation scenarios are significantly reduced in all regions compared to the baseline without climate policies. The regional cumulative CO_2 emissions show on average a 76% reduction between the baseline and 450 scenario. The 450 scenarios show a reduction of primary energy demand in all countries of roughly 30-40% compared to the baseline. In the baseline scenario, the contribution of low-carbon energy technology remains around 15%, i.e. similar as today. In the mitigation scenario, these numbers are scaled up rapidly towards 2050. Looking at air quality, sulphur dioxide and black carbon emissions are strongly reduced as a co-benefit of greenhouse gas emission reductions, in both developing and developed countries. However, black carbon emissions increase in countries that strongly rely on bioenergy to reach mitigation targets. Concerning energy security, energy importing countries generally experience a decrease in net-energy imports in mitigation scenarios compared to the baseline development, while energy exporters experience a loss of energy export revenues.

SUMMARY

The purpose of this paper is to synthesize and provide an overview of the national and regional information contained in different scenarios from various global models published over the last few years. We use this information to analyse the emission reductions and related energy system changes in various countries in pathways consistent with the 2°C target. This analysis provides input for international policy processes, and the context for more detailed analyses of meaningful indicators at the national level. We note that although we present the results of several models, these are used to build significant corridors and not as a basis for an inter-model comparison, which is not the scope of this work.

In our work, the scenarios were characterized on the basis of the assumed climate policies: i.e. baseline scenarios (no new policies), reference scenarios (existing policies) and scenarios aiming at 550 and 450 ppm CO_2-eq targets. The latter were divided into scenarios with and without assumed delay in policy implementation in the near term. Each of the global models contains information for about 10-30 regions and countries. The scenarios with delay implement prescribed policies per region. After the delay period, a uniform global carbon price is assumed. This implies that the contribution of each country (or region) is mostly determined by the marginal abatement costs. This is also the case for the scenarios without delay for the full scenario period. Differences in model outcomes have been used to indicate model uncertainty ranges for the various indicators that are shown.

Emission trends

In this summary, we focus on the baseline and 450 ppm CO_2-eq scenarios (see Box 1).

Box 1: Model-based scenario analysis

The baseline scenario shows the situation in the absence of climate policy. Such a scenario is not realistic (as most countries have indicated elaborate plans to implement policies), but forms a counterfactual scenario that can be used to show the effect of policies in each region in a compatible way. For the 450 ppm scenarios, two categories are shown, i.e. with and without delay. The scenarios without any policy delay are also not realistic, but again, provide a reference showing the situation if a globally cost-efficient response could be formulated. In the database, results from various models were available for 13 regions.

Models provide insights into cost-optimal trajectories for achieving specific climate goals given assumptions on the costs, efficiency and preferences for specific technologies, their interaction in the energy system and existing policies.

The information can be used to explore costs and benefits of alternate pathways. Future policy developments are beset with uncertainty. The use of multiple models is one way to obtain some insights into the impact of different model assumptions.

Figure S.1 shows the mean values of projected trends in per capita GDP levels and associated per capita emissions for all models (baseline and 450 ppm CO_2-eq) for 13 regions covered in this study. This figure leads to the following conclusions:

- Without climate policy, **greenhouse emissions are expected to increase rapidly in low-income regions, driven by a projected further increase in economic activity and population**. **Per capita emissions are projected to remain more or less stable in high-income regions**. The emissions per capita in high-income countries are expected to remain more or less stable as a result of opposing trends in activity growth, efficiency improvement and (slow) decarbonisation of fuel supply.
- **Emissions in the mitigation scenarios are significantly reduced compared to the baseline in all regions, independent of income-level.** Further analysis of the scenarios shows global average CO_2 emissions to range from about 0.3 to 2 tCO_2/capita in 2050 under delayed 450 scenarios. This range results from differences in non-CO_2 emissions assumptions and assumed mitigation action beyond 2050 (especially the use of negative emissions). Figure S.1 shows that low-income countries generally remain below the global average, although the upper end of the ranges for China, Indonesia and South Africa are slightly above the global average. Most OECD countries show per capita emissions ranges similar to or higher than the global average.
- **The results also show that CO_2 emissions from fossil fuels and industry represent the majority of global total emissions in the baseline, while the mitigation scenarios result in about equal shares of non-CO_2 emissions and CO_2 emissions from fossil fuels and industry globally in 2050.** CO_2 emissions are reduced more than non-CO_2 emissions. There are, however, regional differences in the contribution of the different emission categories. In China, for example, CO_2 emissions from fossil fuels and industry remain the major contributor to total emissions, while in Indonesia, land use emissions represent the lion's share. All countries show increasing shares of low-carbon primary energy sources (i.e. all energy sources except coal, oil and gas without carbon sequestration) with lower cumulative carbon emissions. For developed countries, this generally means a substantial increase on 2010 levels.

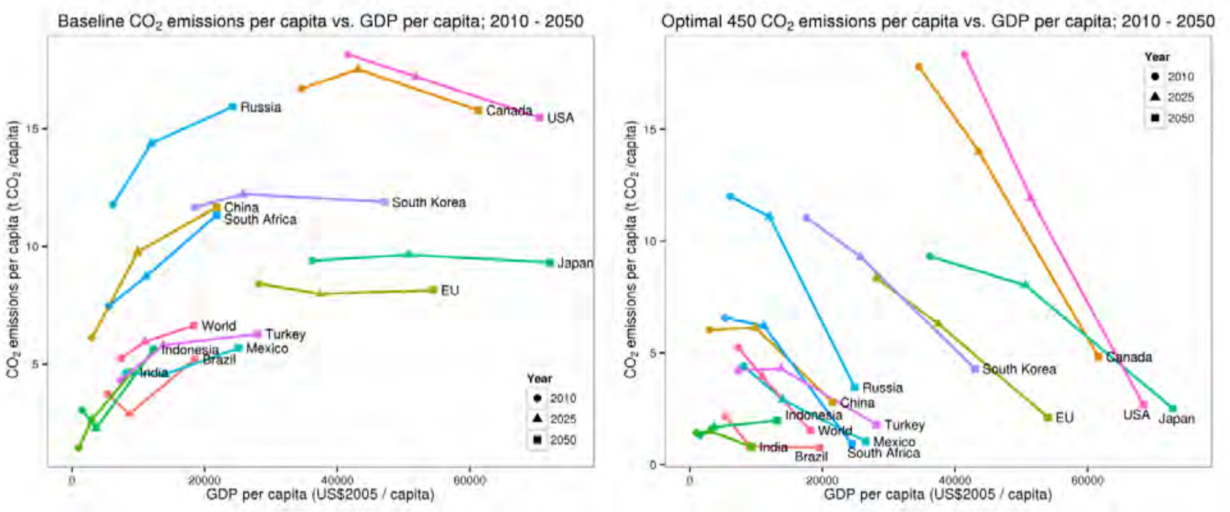

Figure S.1: CO_2 emissions per capita (tCO_2/capita) versus GDP per capita (US$2005/capita) between 2010 and 2050 for baseline scenarios (left panel) and cost-optimal 450 scenarios (right panel).

Greenhouse emissions in 2030

The results across the different models for 2030 greenhouse gas emissions are summarized in Figure S.2.

- The data show a **clear difference in 2030 emission levels between the baseline scenarios and the cost-optimal 450 ppm scenarios**. The delayed 450 ppm scenarios typically show slightly higher emissions than the cost-optimal 450 ppm scenarios.

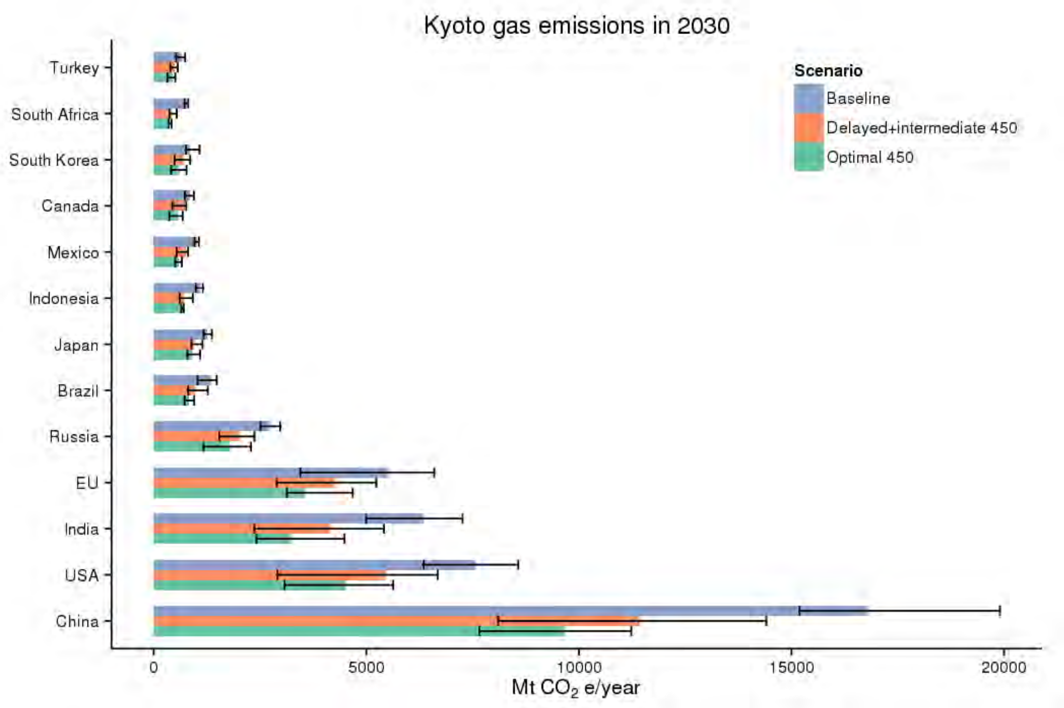

Figure S.2: Kyoto gas emissions ($MtCO_2e$) in 2030 for cost-optimal 450 ppm scenarios, delayed 450 ppm scenarios and baseline scenarios. Filled bars show the median value across models, error bars show the 10^{th} to 90^{th} percentile range.

Cumulative emissions

A key outcome of the models are the **regional cumulative emissions consistent with different global climate targets**. These can be interpreted as regional emission constraints assuming cost-efficient implementation of the global target across all regions. Note that the cumulative emissions linked to e.g. a <2°C temperature outcome need to be constantly updated to account for revised estimates of past, current and future emissions as well as developments in climate science.

- Figure S.3 shows the regional cumulative emissions for the baseline and optimal 450 scenarios for the period 2010-2100. The results indicate the actual emissions in the cost-optimal scenarios and do not make any assumptions as to who pays for the emission reductions. **The cumulative emissions between the baseline and 450 scenario are very different, showing on average around 76% reduction across all regions.** The important role of China, India, and the USA is illustrated by the fact that in the baseline scenario, each of these regions alone accounts for at least half the global cumulative emissions consistent with the 2°C target. The different ratios between baseline emissions and the cost-optimal 450 emissions mostly reflect abatement opportunities in the various regions.

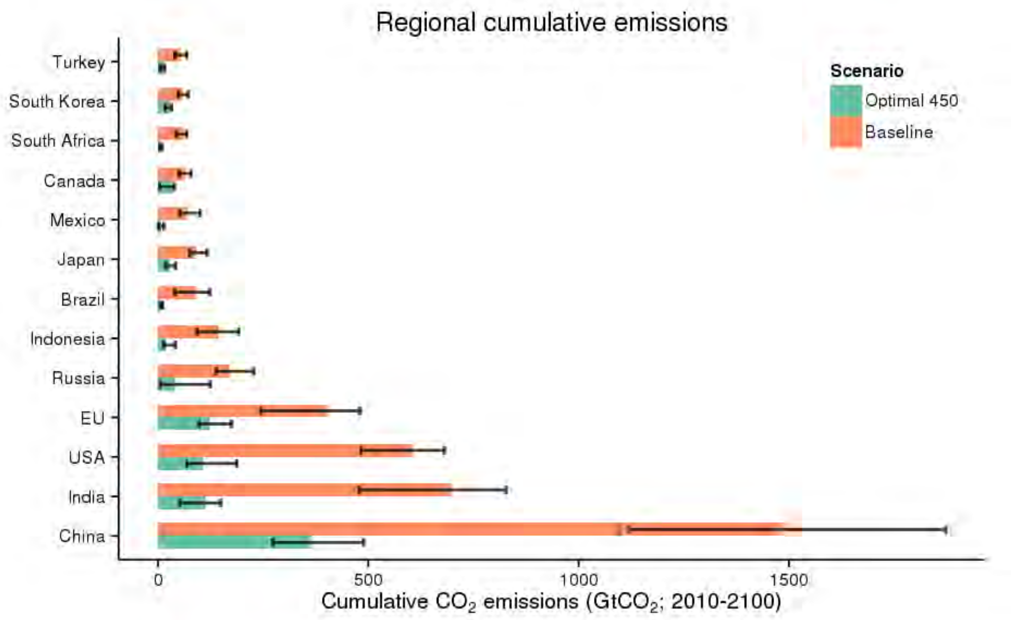

Figure S.3: Regional cumulative CO_2 emissions between 2010 and 2100, for cost-optimal 450 ppm and baseline scenarios. Filled bars represent the median, error bars give the 10^th^ to 90^th^ percentile ranges across models.

Emissions peak

- A similar picture of stringent climate action in all regions emerges when looking at the peak year of CO_2 emissions (Figure S.4). Under the optimal 450 scenarios that assume direct implementation of policies, most countries' CO_2 emissions peak before 2025 (except for India). Under delayed 450 scenarios (taking into account 2020 pledges and introducing cost-optimal policies between 2020 and 2025), this peak generally shifts to later in the century, although not by much.

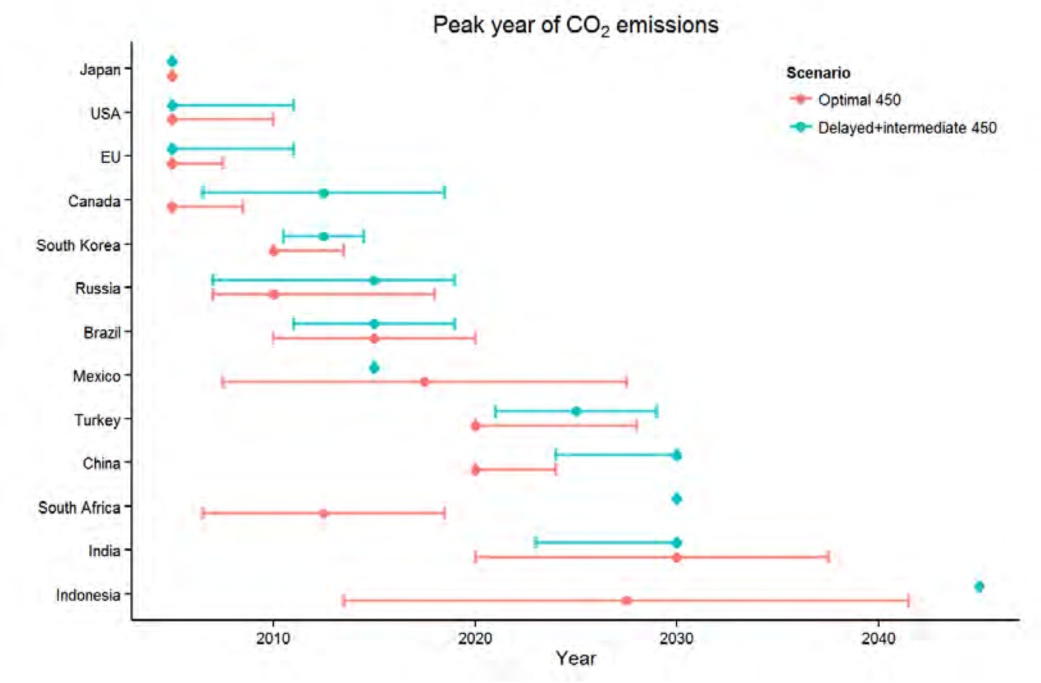

Figure S.4: Regional peak years of CO_2 emissions for cost-optimal 450 ppm, delayed 450 ppm and baseline scenarios. Dots give the median of the models, error bars give the 10^{th} to 90^{th} percentile ranges. The median results can be at the outer end of the range, for instance for OECD countries, as a majority of these regions show an immediate peak with only a few exceptions.

Consequences for energy use

- Primary energy demand decreases strongly in the mitigation scenarios, compared to the baseline scenario, especially in developing countries. **The 450 scenarios show a reduction in all countries of roughly 30-40% compared to the baseline.** There are regional differences, with e.g. South Africa halving its primary energy demand under mitigation scenarios.
- **Key differences between the baseline scenario and the 450 ppm scenario occur for the composition of the energy mix** (Figure S.5). In the baseline scenario, the contribution of low-carbon energy technology remains around 15%, i.e. similar as today. Large differences across the different regions can be seen in the baseline projections for 2030 and 2050, with Brazil showing significantly higher shares of low-carbon energy technology than other regions. In the mitigation scenario, the shares of low-carbon energy technology are scaled up rapidly towards 2050. While some differences across the regions can be noticed, the large model uncertainty ranges indicate that this differs strongly across the models.

Policy costs

- **There is a cost advantage to starting mitigation early.** Delayed 450 scenarios show lower median policy costs in the short term in some regions (China and World), but higher policy costs in the long term in all regions, compared to the optimal 450 scenarios.

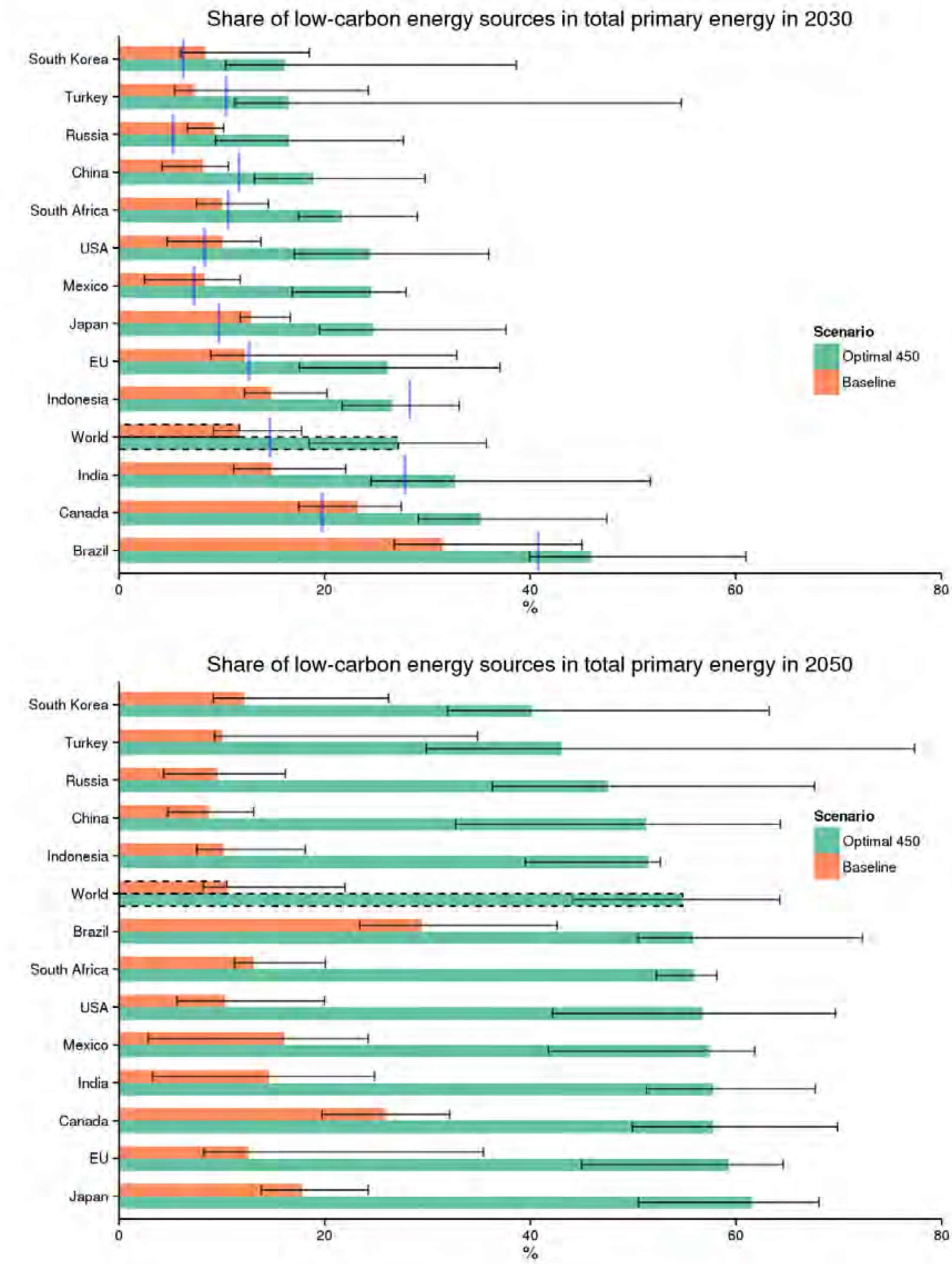

Figure S.5: Share (%) of low-carbon primary energy sources (all energy sources except oil, coal and gas without carbon sequestration) in total primary energy supply in 2030 (upper panel) and 2050 (lower panel), for cost-optimal 450 ppm and baseline scenarios. Filled bars represent the median, error bars give the 10th to 90th percentile ranges across models, and vertical blue lines give the 2010 shares.

Co-benefits

Mitigation action does not only impact greenhouse gas emissions, but also the energy mix – and thus energy security and air pollution. Overall, it has been shown on the global level that mitigation action is likely to result in co-benefits. The analysis here shows such co-benefits for air pollution (although showing clear regional differences), but for energy security, the impacts of mitigation action are dependent on the region.

- Looking at **air quality**, **sulphur dioxide emissions are strongly reduced as a co-benefit of greenhouse gas emission reductions**, in both developing and developed countries (Figure S.6). Also **significant reductions of black carbon emissions** can be found, although emissions increase in countries that strongly rely on bioenergy to reach mitigation targets. In these cases, additional policies are required to reduce air pollution from black carbon.

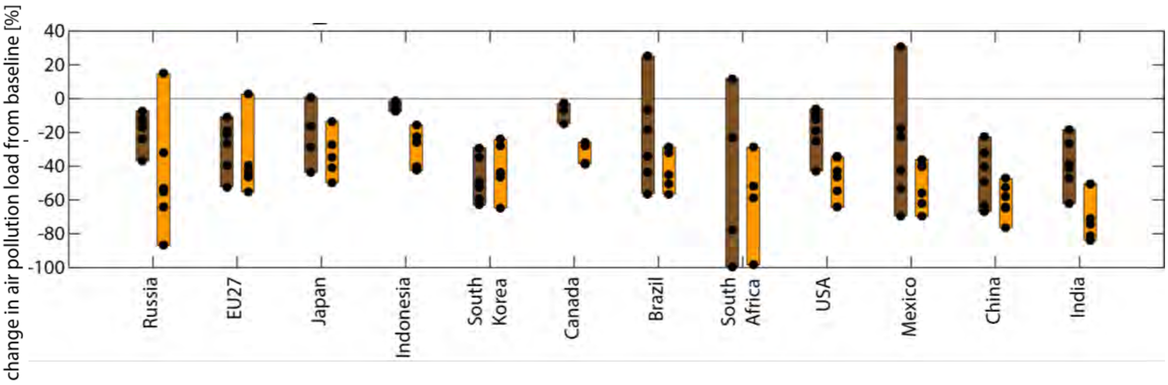

Figure S.6: Changes, in 2050, in black carbon (brown) and sulphur dioxide (orange) emissions when moving from a baseline without new climate policies to a pathway in line with stabilizing atmospheric CO_2-equivalent concentrations at 450 ppm. Dots show single model results, bars the full range.

- Concerning **energy security**, energy importing countries generally experience a decrease in net-energy imports in climate stabilization scenarios compared to the baseline development, while energy exporters experience a loss of energy export revenues from climate stabilization policies (Figure S.7).

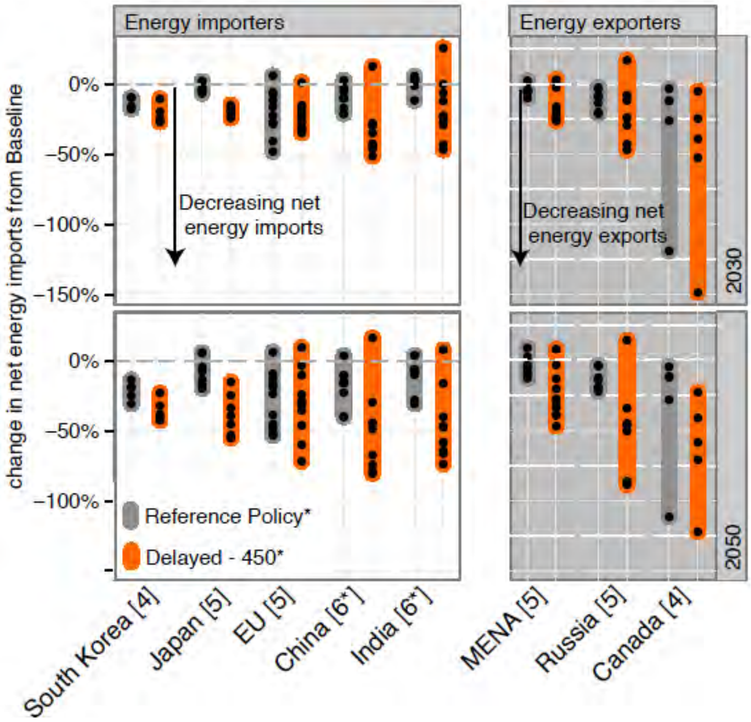

Figure S.7: Change in net-energy imports (left) and net-energy exports (right) for major energy importers and exporters. The number for each country represents the number of models.

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Introduction

Governments worldwide have agreed that international climate policy should aim to limit the increase of global mean temperature to less than 2^{o}C with respect to pre-industrial levels (UNFCCC, 2010). The IPCC Fifth Assessment Report (AR5) indicates that scenarios without new climate policies typically result in a an increase of global mean temperature of around 3-4°C by 2100 (Clarke et al., 2014). In order to reach the 2^{o}C target, urgent and drastic emission reductions are required. Such reductions are needed in all regions around the world (Tavoni et al., 2014).

Global modelling teams have worked on developing a set of scenarios for international climate policy in projects such as AMPERE (Kriegler et al., 2014a), LIMITS (Kriegler et al., 2014b, Riahi et al., 2014, Tavoni et al., 2014) and EMF27 (Kriegler et al., 2014c). These scenarios look into possible emission trajectories without new climate policies, estimates of current policies and different variants of scenarios aiming at the 2^{o}C target (these scenarios vary in terms of the probability of achieving the target, technology assumptions and the timing of climate policy). The scenarios also played an important role in the analysis performed in the last report of IPCC (Clarke et al., 2014). Typically, these models contain around 10–30 regions in order to describe trends in global emissions. While several projects have started to use the regional information of the global models to look into climate policy strategies at the scale of countries and regions (e.g. Herreras Martínez et al., 2015, Tavoni et al., 2014, Van Sluisveld et al., 2013), in general, the regional information has not been used extensively.

The purpose of this paper, therefore, is to analyse the energy system changes in various countries in pathways consistent with the 2^{o}C target, by looking into the national/regional information contained in different global scenarios from various global models. The objectives of this study are:

- To better understand the transition pathways at the level of major economies in a set of global scenarios developed over the past few years;
- To specifically investigate various policy relevant indicators such as peak years and cumulative emissions at the level of major economies;
- To provide insights in potential co-benefits of different pathways.

The information presented here was evaluated by both national and international modelling teams. This analysis could in particular help positioning the different countries regarding low-emission pathways. The focus of the analysis is on regional results (and thus not on a model comparison).

Methodology

Main Method

In this paper, we compare scenarios developed in previous studies using global models in terms of the results for key countries/regions. We use data from the following studies: AMPERE, LIMITS, and EMF27 (see earlier references), which include several models such as DNE21+, GCAM, GEM-E3, IMAGE, MESSAGE, POLES, REMIND, and WITCH.

In addition, new scenarios, developed after these previous studies or specifically for the MILES project, have been added by the teams participating in MILES. The MILES project (Modelling and Informing Low Emission Strategies) is an international cooperation project between 19 international research teams[1]. Key objectives of the project are: 1) to explore different country-level strategies consistent with the 2°C target, 2) to increase understanding of differences between strategies in different parts of the world, and 3) to enhance in all participating countries the capacity to perform analysis of mitigation strategies.

In this study, we look into regional results evaluating the drivers, emission trajectories, and energy system changes. The national and regional emission pathways in the global studies provide insight into the required energy transitions at this level. It should be noted that in these studies, the contribution of each country (or region) in global reductions is determined by the marginal abatement costs. The results of the global models have been compared with the results of the national models.

The discussion of the results is divided into three parts, each of them oriented at the following key questions:

- What do regional/national emission and energy system pathways consistent with different assumptions on international climate policy look like?
- How do assumptions on the availability of different technologies influence these results?
- What are important co-benefits at the national/regional level of the different policies?

For this analysis, existing scenarios were characterized as indicated in Table 1.

[1] ERI, RUC, TU, TERI, IIM, COPPE, PNNL, NIES, RITE, ICCS, IIASA, PIK, PBL, CMCC, CLU, IDDRI, CCROM, CRE, INECC

Table 1: Scenario categories used in this study.

Category	*Description*
Baseline	Scenarios that do not include new climate policies other than via the calibration to the historical period. This scenario category thus acts as a counterfactual scenario providing a consistent reference across all regions for showing the impact of climate policies.
Reference policy	Describes possible development assuming implementation of existing policies and some continuation of these policies in the longer term (without strengthening these policies).
Cost-optimal 500-550 ppm CO_2eq	Scenarios aimed at stabilizing GHG concentrations at the level of 500-550 ppm CO_2-eq at the lowest costs (within the model).
Cost-optimal 450	A universal global carbon tax is implemented immediately in order to research a target of 450 ppm CO_2eq, resulting in the lowest costs (within the model).
Intermediate 450	This scenario type follows the implementation of the pledges in 2020 and assumes cost-optimal policies (based on intermediate policies) to be introduced after 2020-2025.
Delayed 450 ppm CO_2eq	Scenarios that include the current description of pledges until 2020, and assume some further delayed policies up to 2025. In the longer term, cost-optimal policies are implemented. As a result, global emissions peak after 2025.

Regional Coverage of the Models

Table 2 indicates how the information of the different models was used in this study to look into regional trends. Table 3 provides the main characteristics of the models included in this study.

Table 2: Regional coverage per model (X indicates that the region is represented in the model; in case slightly different regions were used this is indicated in the Table).

	DNE21+	GCAM	GEM-E3	IMAGE	MESSAGE	POLES	Remind	WITCH
Brazil	X	X	X	X		X		
Canada	X	X	X	X		X		
China	X *Includes Hong Kong*	X *Includes Hong Kong, Macau*	X *Includes Hong Kong, Macau*	X *Includes Mongolia and Taiwan*	X *Centrally planned Asia and China*	X *Includes Hong Kong, Macau, Taiwan*	X *Includes Hong Kong*	X
EU	X *Includes Greenland*		X	X *Includes Norway, Switzerland, Iceland, Balkan countries*	X *Includes Iceland, Turkey, Norway, Switzerland, Greenland*	X	X	X Includes EFTA
India	X	X	X	X	X *South Asia*	X	X	X
Indonesia		X	X	X		X		
Japan	X	X	X	X		X	X	
Mexico	X	X	X	X		X		
Russia	X	X	X	X		X	X	
South Africa		X	X	X		X		
South Korea	X	X	X	*Includes North Korea*		X		
USA	X	X *Includes Puerto Rico*	X	X	X *North America (includes Canada, Guam, Puerto Rico)*	X	X *Includes Puerto Rico*	X
World	X	X	X	X	X	X	X	X

Table 3: Main characteristics of the models included in this study

		DNE21+	GCAM	GEM-E3	IMAGE	MESSAGE	POLES	Remind	WITCH
Model objective		DNE21+ is a linear programming model that seeks the optimal strategy to minimize the cost of world energy systems and mitigate climate change. The model is composed of three sub-models: an energy systems, a macro economic and a climate change model and is useful at the global level, divided into 10 regions.	GCAM is an integrated assessment model that couples representation of energy, agriculture, emissions, climate, and water. Originally, the model focused on energy-emissions-climate interactions.	The purpose of GEM-E3 is to provide long-term quantitative model-based assessment in the fields of energy and climate policies, economic and employment policies, tax & price reform, environmental regulation, trade and competitiveness policies	IMAGE represents interactions between society, the biosphere and the climate system to assess sustainability issues such as climate change, biodiversity and human well-being, to explore long-term dynamics and impacts of global changes that result from interacting demographic, technological, economic, social, cultural and political factors.	MESSAGE at its core is a technology-detailed energy-engineering optimization model used for energy planning. Through linkage to macro-economic, land-use and climate models it is capable of taking into account important feedbacks and limitations in these areas outside of the energy system.	Detailed global energy system model, with module to cover industry GHGs, Agriculture and LULUCF GHG coming from GLOBIOM	Construct self-consistent optimal benchmark scenarios for the transformation of the global energy-economy system, for different assumptions on climate policies or targets. Comparison with no-policy benchmark scenarios allows for the calculation of mitigation costs.	The model is designed to assist in the study of the socio-economic dimensions of climate change and to help policy makers understand the economic consequences of climate policies.
Model type:	Solution concept	Energy systems model with minimizing world energy system cost	Partial equilibrium (price elastic demand)	General equilibrium (closed economy)	Partial equilibrium (price elastic demand)	General equilibrium (closed economy)	Partial equilibrium (price elastic demand)	General equilibrium (closed economy)	General equilibrium (closed economy)
	Solution horizon	Inter-temporal (foresight)	Recursive-dynamic (myopic)	Recursive-dynamic (myopic)	Recursive-dynamic (myopic)	Inter-temporal (foresight) Recursive-dynamic (myopic)	Recursive-dynamic (myopic)	Inter-temporal (foresight)	Inter-temporal (foresight)
	Solution method	Optimization	Simulation	Optimization	Simulation	Optimization	Simulation	Optimization	Optimization
Time		2050; 5	2100; 5	2050; 5	2100; 1	2110; 5	2100; 1	2100; 5	2150; 5

horizon and time step	years (2005-2030); 10 years (2030-2050)	years	years	year	years; 10 years	year	years	years
Number of energy conversion technologies (rough estimate)	50	50	10	50	200	100	60	25
Energy technology substitution	Linear choice (lowest cost)	Logit choice model	Production function	Logit choice model	Linear choice (lowest cost)	Logit choice model	Production function	No discrete technology choices

Results

What do regional / national emission and energy system pathways consistent with different assumptions on international climate policy look like?

We selected a set of variables, presented hereafter, which are relevant for the analysis of national emission and energy system pathways consistent with the 2°C target. The selection includes: population, GDP, primary energy demand, energy intensity, GHG emissions, cumulative emissions, peak years, shares of low-carbon energy sources, and policy costs.

Population and GDP are two important socio-economic drivers that have a direct influence on primary energy demand and GHG emissions. The energy intensity variable is a measure of the energy use per unit of economic activity and informs about the general level of efficiency of a given region. Another widely used indicator is cumulative emissions, which correlates well with the temperature at the end of the century. The study of peak years allows us to compare countries in terms of stringency of emission pathways. The shares of low-carbon energy sources show the transitions needed in energy systems to meet the long-term climate target. Finally, policy costs are relevant in this study in order to address the regional impacts of delaying optimal mitigation.

Population and GDP

Figure 1 and Table 4 show the population and GDP per capita projections for the different countries. Assumptions on the trends in these drivers do not vary across different scenario categories.

The global population growth in the 2010–2050 period is projected to be about 30–40%. The GDP per capita growth over the same period is considerably faster and the range in the assumed GDP growth across models is large for individual regions, but also for the projected global GDP growth (i.e. 110–210%).

Table 4: Projected change in population and GDP per capita per region between 2010 and 2050 (2050 values expressed relative to 2010). UN population projections (medium variant) are also included for reference.

Region	Population	Population (UN medium)	Population (national scenarios)	GDP per capita	GDP per capita (national scenarios)
Brazil	[1.12, 1.19]	1.18	1.11	[2.53, 5.35]	3.14
Canada	[1.29, 1.33]	1.33		[1.69, 1.87]	
China	[0.97, 1.07]	1.02		[4.91, 10.53]	
EU	[1, 1.05]	0.96	1.05	[1.77, 2.22]	1.71
India	[1.33, 1.45]	1.34		[6.29, 14.65]	
Indonesia	[1.24, 1.34]	1.34		[4.82, 10.68]	
Japan	[0.81, 0.86]	0.85	0.80	[1.72, 2.19]	1.75
Mexico	[1.17, 1.33]	1.32		[2.78, 4.01]	
Russia	[0.85, 0.91]	0.84		[2.44, 4.45]	
South Africa	[1.13, 1.24]	1.23		[3.28, 5.48]	
South Korea	[0.91, 1.06]	1.05		[2.36, 2.79]	
USA	[1.28, 1.3]	1.28		[1.25, 1.88]	
World	[1.33, 1.39]	1.38		[2.09, 3.12]	

Population growth

The projected population growth rates of the OECD countries lie well below the global average. The populations of Japan and the Russian Federation are projected to fall. In general, the different global model-based scenarios do not include a very wide range of population projections, and agree well with UN population projections. A notable exception is the EU, which shows slightly higher population projections than the UN medium scenario. A key reason is that some models include more countries in their EU region than the 28 EU member states (e.g. Turkey, Greenland or Iceland).

The projected population growth rate of the low-income countries covered in this study also lies below the global average. Again, the regional model projections correspond well with the UN medium scenario, with a relatively small range across the different models. The projected global average population growth rate is higher than the growth rates of all countries covered in this study (except India) due to high growth rates in other regions not covered here, most notably Africa, and India.

Comparison with the national model results

The projections for Brazil are similar to the population projections by the national modelling team. The Brazilian population is projected to reach around 200 million inhabitants by 2030 and 230 million by 2050, which is based on the official projections by the Brazilian Institute of Geography and Statistics (Herreras Martínez et al., 2015). The projections for Mexico are in line with the findings by Veysey et al. (2015), reporting on *The Climate Modeling and Capacity Building in Latin America* project (CLIMACAP) and the *Latin American Modeling Project* (LAMP). They project the Mexican population to reach about 150 million by 2050, with MILES projections for Mexico reaching about 125 – 175 million.

GDP growth

GDP per capita is projected to increase in all countries. Again, the average of the OECD countries lies significantly below the global average – although here Russia forms an exception. The projected increase of other OECD countries is around 1–1.7% per year, while the Russian growth included in the projections is 2.3-3.8% per year.

The projected growth rate of the non-OECD countries is more than twice as high as in OECD countries. The average growth rate of GDP per capita between 2010 and 2050 is projected to be around 3-6% per year in non-OECD countries, and up to 4.7-6.8% per year for India.

Comparison with the national model results

Growth rates projected by the Indian team are slightly higher than most global model projections (around 6.5% per year). Also the Brazilian national team's GDP projections were higher than those of (most of) the global models, with a growth rate of 2.3–3.5% in the 2010-2030 period. These national GDP projections are based on the Brazilian long term National Energy Plan, which projects an average GDP growth of 4% per year until 2050. Mexico's GDP in the global model projections reaches a level of about US$ 2 – 4 trillion by 2050, which is the same as the range reported by Veysey et al. (2015).

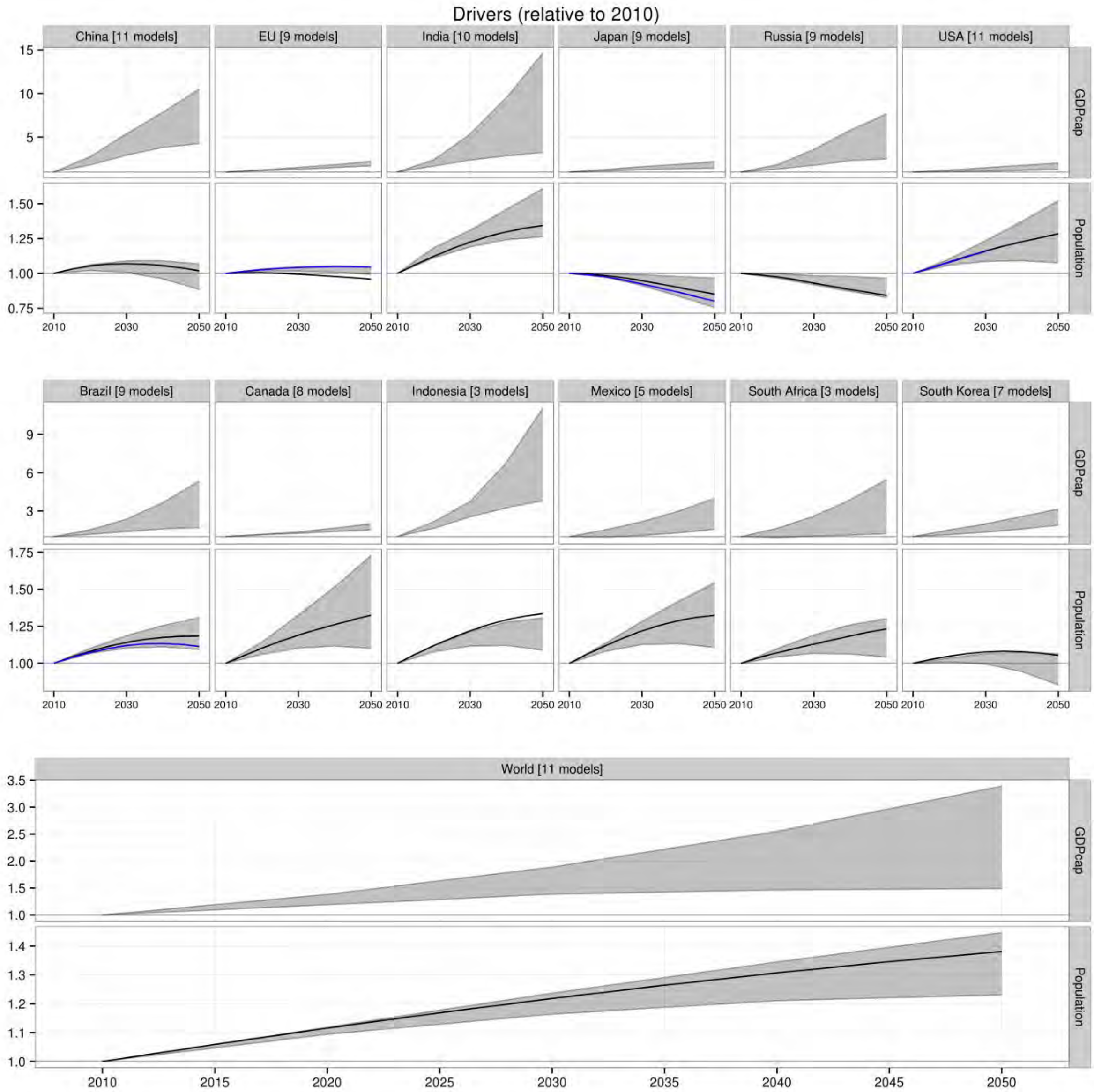

Figure 1: Population and GDP per capita in the 12 countries + world, relative to 2010 values. The number of models per country reporting these variables is indicated[2]. No scenario category dimension is shown here, as assumptions on trends in drivers do not vary across scenario categories. Solid black lines show UN population projections (medium variant), solid blue lines show available national scenario projections.

Primary Energy

Primary energy demand projections under baseline, delayed, intermediate, and optimal 450 scenarios are shown in Figure 2 (delayed and intermediate 450 scenarios are combined into one category). Primary energy demand decreases strongly in the mitigation scenarios compared to the baseline scenario. This

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[2] Some regions and variables may show a larger number of models than the eight reported in Table 2, because models exist in different versions and with results of various studies in the database; these different model versions are counted individually.

effect is strongest in developing countries. For most countries, the scenarios from the global models encompass the IEA's World Energy Outlook projections. The largest difference can be observed in China. Here baseline results are quite comparable, but the models show an outcome range for the optimal 450 scenarios that lies significantly below the IEA's 2^{o}C scenario. This may be explained by the different accounting methods for total primary energy supply applied by the IEA and official Chinese statistics. The Figure also emphasises the considerable model uncertainty ranges for individual countries in the scenarios in the literature.

OECD countries

In general, the primary energy projections for the OECD countries under baseline assumptions show relatively small changes over time (increase or decrease). The projections for the 450 scenarios show typically a 30-40% reduction compared to the baseline scenarios by 2050.

Non-OECD countries

In baseline scenarios, the primary energy demand is projected to increase strongly in most of the non-OECD countries. In contrast, the 450 scenarios show a reduction of roughly 30-40% compared to the baseline by 2050, the same order of magnitude as the reduction in the OECD countries. There are regional differences, with e.g. South Africa showing a reduction up to 50% between the baseline and the delayed + intermediate 450 scenarios.

Comparison with the national model results

Compared to national projections, not all global models show a similar reduction of Indian energy demand (implying that the IEA scenarios are closer to the national scenario projections than some of the global model projections). The global model projections for Brazil are slightly lower than the projections by the national modelling team. Primary energy demand is projected to be about 15 EJ by 2050 under the intermediate 450 scenario in the global models, compared to 20 EJ according to the national model, which used the same carbon tax to create a scenario similar to the ones developed by the global models. For the delayed 450 scenario, the Brazilian national model projection shows a slightly different trajectory but a similar total primary energy demand in 2050 (about 40 EJ).

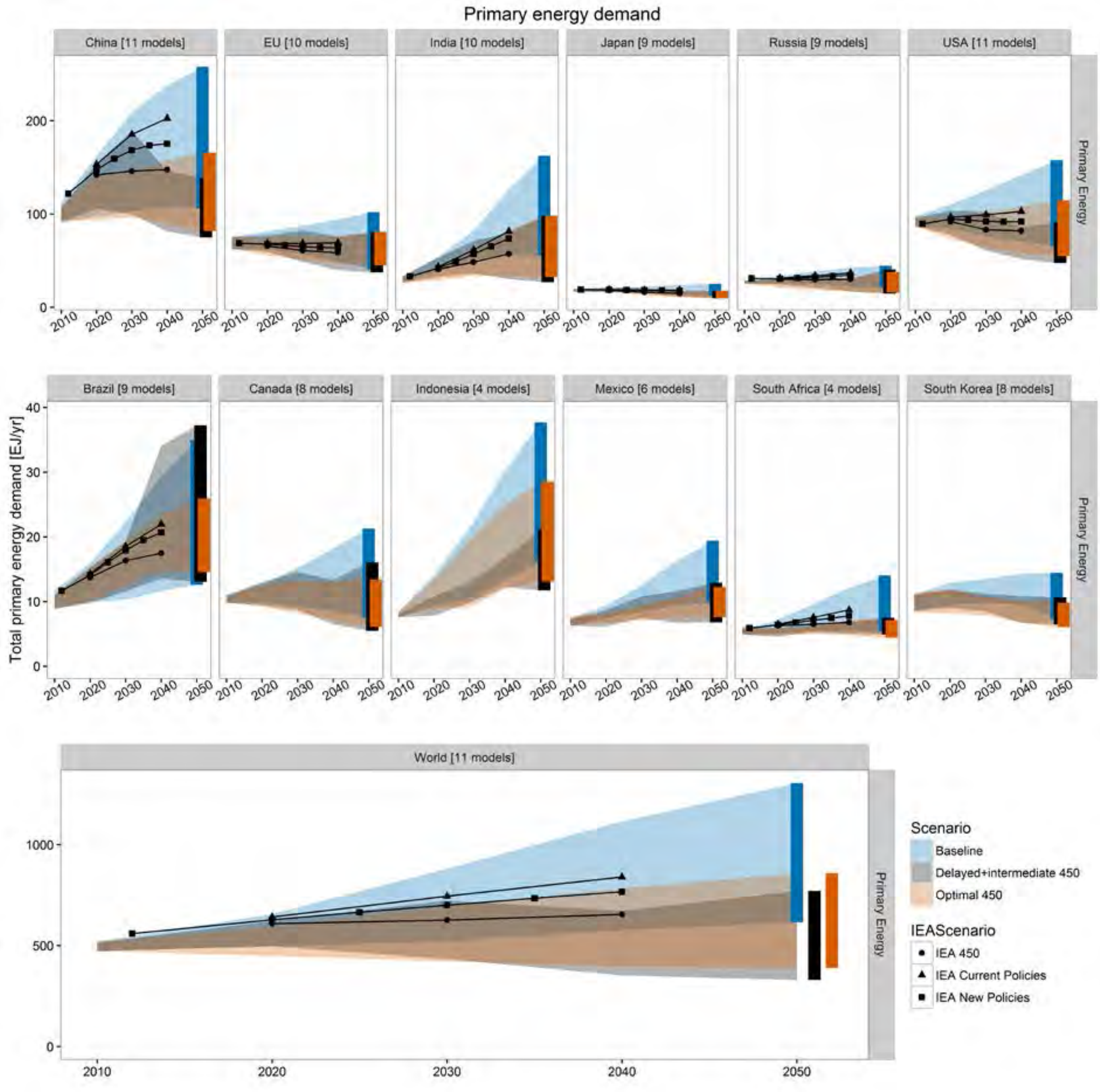


Figure 2: Total primary energy demand (EJ/year) in baseline, delayed + intermediate 450 ppm, and optimal 450 ppm scenarios. IEA World Energy Outlook scenarios (450 ppm, current policies, new policies) are also plotted for reference. The number of models per country reporting this variable is indicated. Coloured vertical bars show the 2050 scenario ranges.

Energy Intensity

Primary and final energy intensity decrease strongly in all countries and all scenarios, including the baseline scenario, but especially in developing countries and the Russian Federation (Figure 3).

Comparison with the national model results

The projected trends in energy intensity are generally in line with national scenario projections. For Brazil, the pathways as well as the absolute values are very similar to the projections by the national modelling team. The Indian team noted that the projected trend of declining energy intensity agrees with their results of decoupling of energy use and GDP growth, although rates of decoupling might differ. Veysey et al. (2015) expect some improvement in energy intensity in Mexico between 2010 and 2020, and substantially more improvement towards 2050. This trend is most pronounced in the delayed + intermediate 450 scenarios shown in Figure 3.

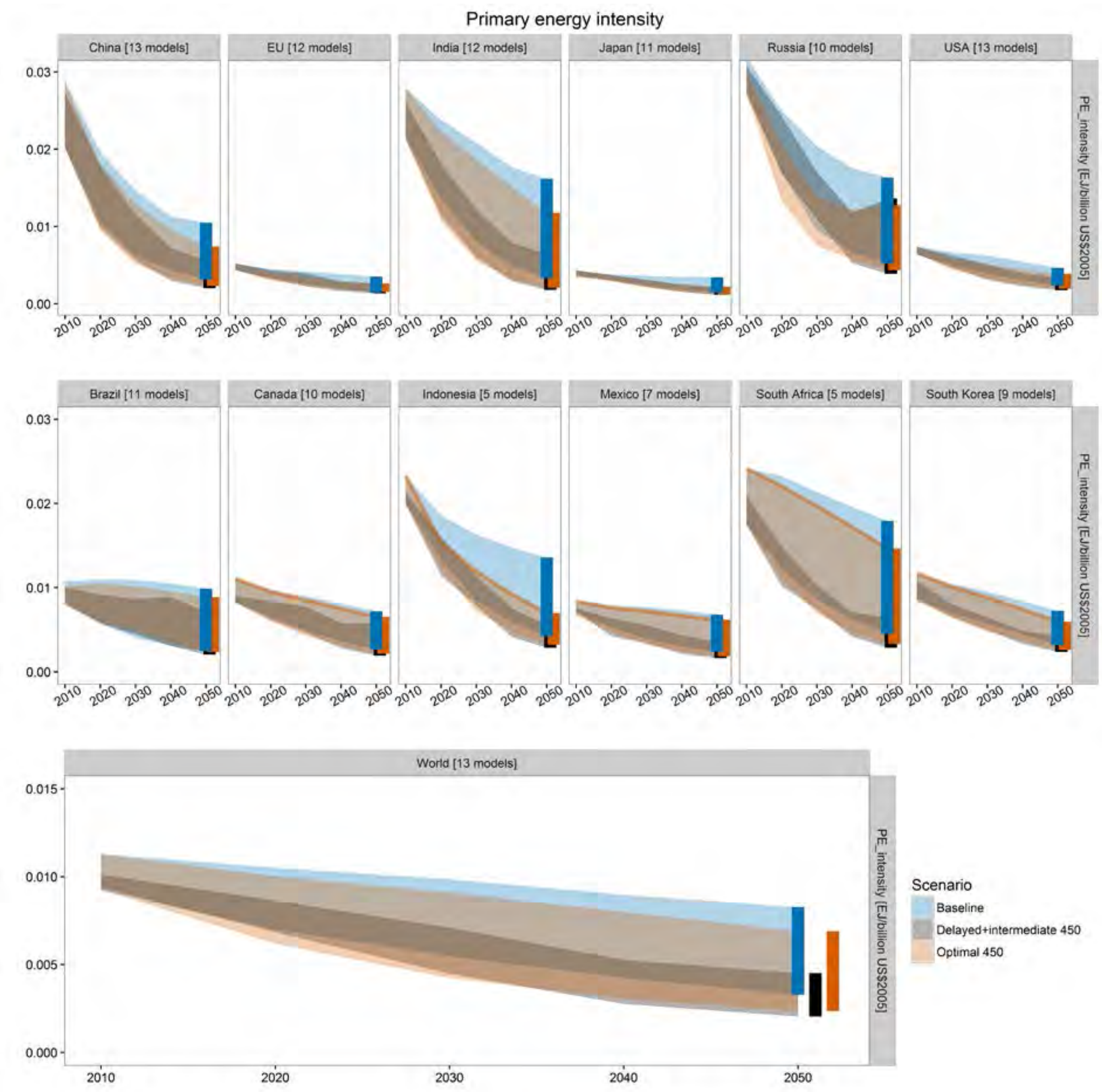


Figure 3: Primary energy intensity (EJ/billion US$2005) in baseline, delayed + intermediate 450 ppm, and optimal 450 ppm scenarios. The number of models per country reporting the variables used to calculate energy intensity is indicated.

Greenhouse Gas Emissions

Figure 4 gives projected total CO_2 emissions, while Figure 5 presents projected CO_2 emissions per capita. Worldwide, a strong emission increase can be observed in the baseline scenarios, mostly driven by the trend in low-income countries. In contrast, total CO_2 emissions decrease rapidly for the mitigation scenarios in all countries, and even turn negative in Brazil, as a result of land-use management. Some differences can be observed across the different regions in the reduction rates – reflecting assumptions on mitigation potential. The Figure also shows quite substantial differences across the models for the various regions. The IEA emissions projections are at the lower end of the global model range, because they exclude land use change emissions.

Per capita CO_2 emissions are projected to decline in all countries under mitigation scenarios. Global average CO_2 emissions reach about 0.3 – 2 tCO_2/capita by 2050 under delayed 450 scenarios, with intermediate 450 scenarios falling within that range. Developing countries generally remain below the global average, although the upper end of the ranges for China, Indonesia and South Africa are slightly above the global average for the delayed 450 scenario category. Most OECD countries show per capita emissions ranges similar to or higher than the global average.

Figure 6 shows that total greenhouse gas emissions in 2030 need to decrease significantly below the baseline in all countries to remain on a 2°C pathway, as in the delayed and especially optimal 450 scenarios.

Comparison with the national model results

Indian national scenarios project per capita emissions that remain below the global average, which is also projected by the global models included in this study (0.2 – 1.4 tCO_2/capita by 2050 under delayed 450 scenarios). Herreras Martínez et al. (2015) report the results of the MESSAGE-Brazil model with projected CO_2 emissions for Brazil of 1633 $MtCO_2$ by 2050 under their reference scenario, and 212 $MtCO_2$ under a 450 ppm scenario. These numbers agree with the results from the global models in MILES, considering that the projections by Herreras Martínez et al. (2015) do not include land use emissions, while the projections shown in Figure 4 do. Global model emission projections for the European Union are in line with regional scenarios developed for the EU.

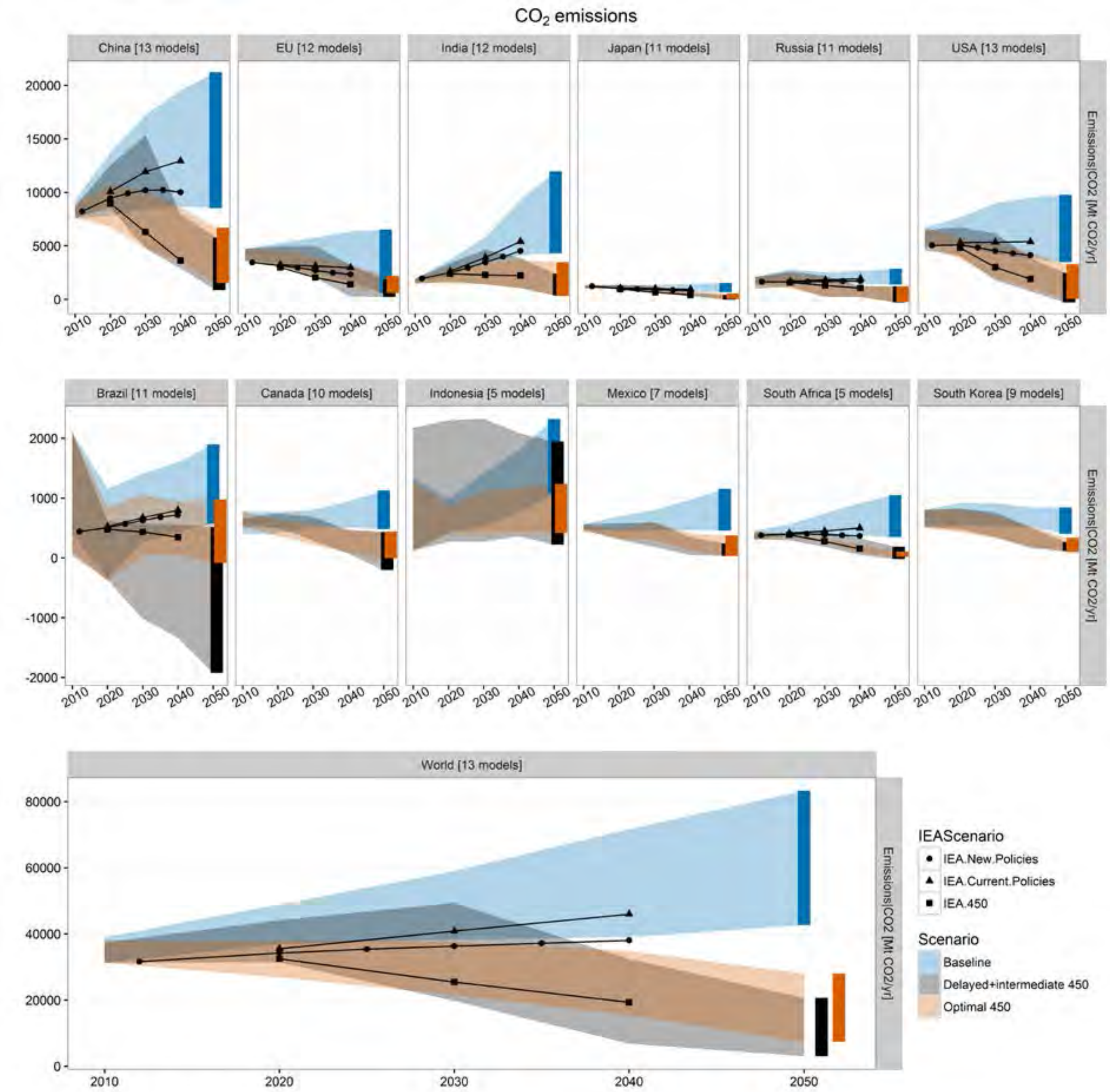


Figure 4: Total CO_2 emissions (Mt CO_2/year) in baseline, delayed + intermediate 450 ppm, and optimal 450 ppm scenarios. IEA World Energy Outlook scenarios (450 ppm, current policies, new policies) are also plotted for reference (note that these projections exclude emissions from land use change, whereas the global models include land use CO_2 emissions). The number of models per country reporting this variable is indicated.

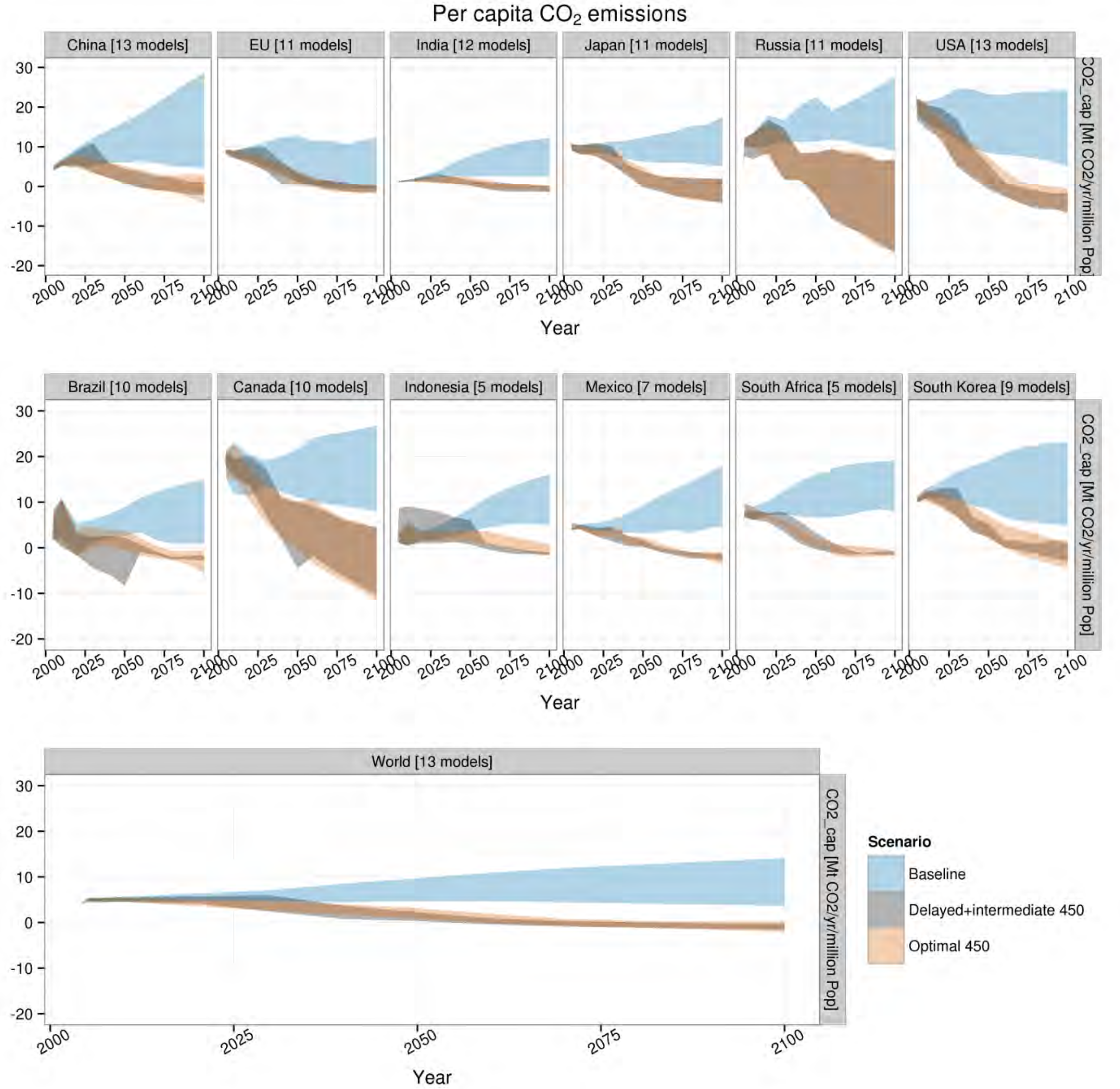


Figure 5: Per capita CO_2 emissions (tCO_2/capita) in baseline, delayed + intermediate 450 ppm, and optimal 450 ppm scenarios. The number of models per country reporting the variables used to calculate per capita emissions is indicated.

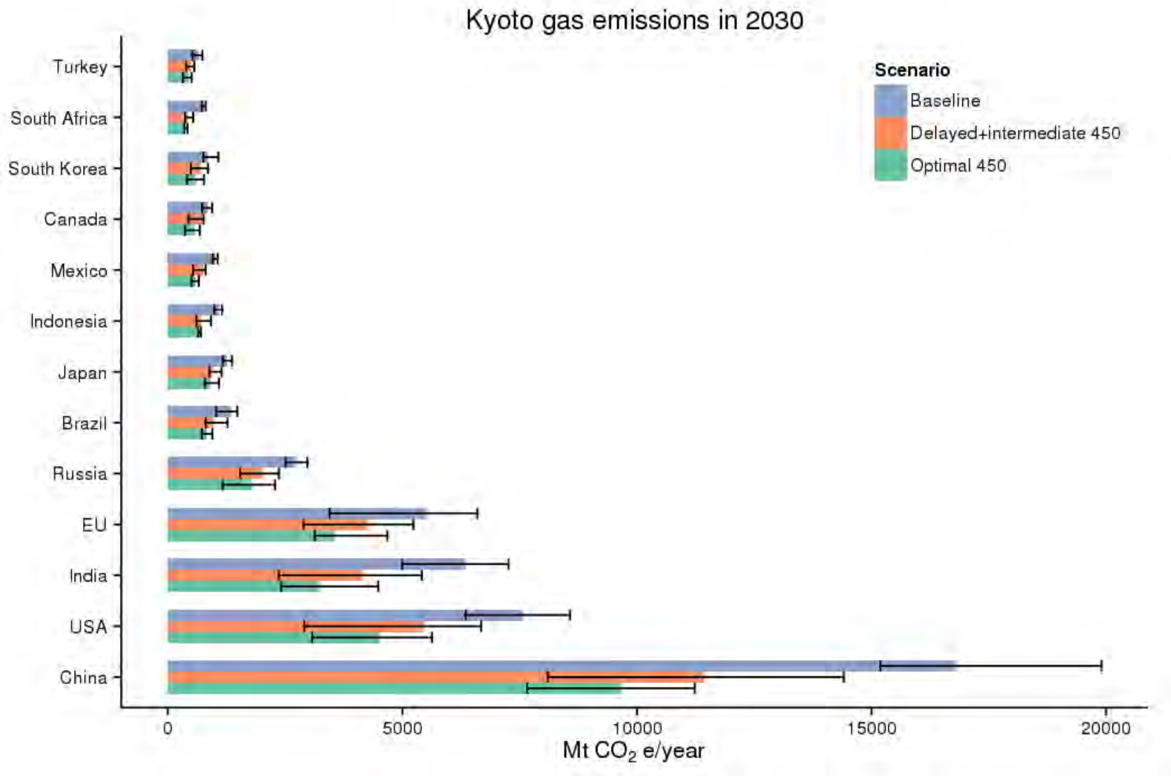


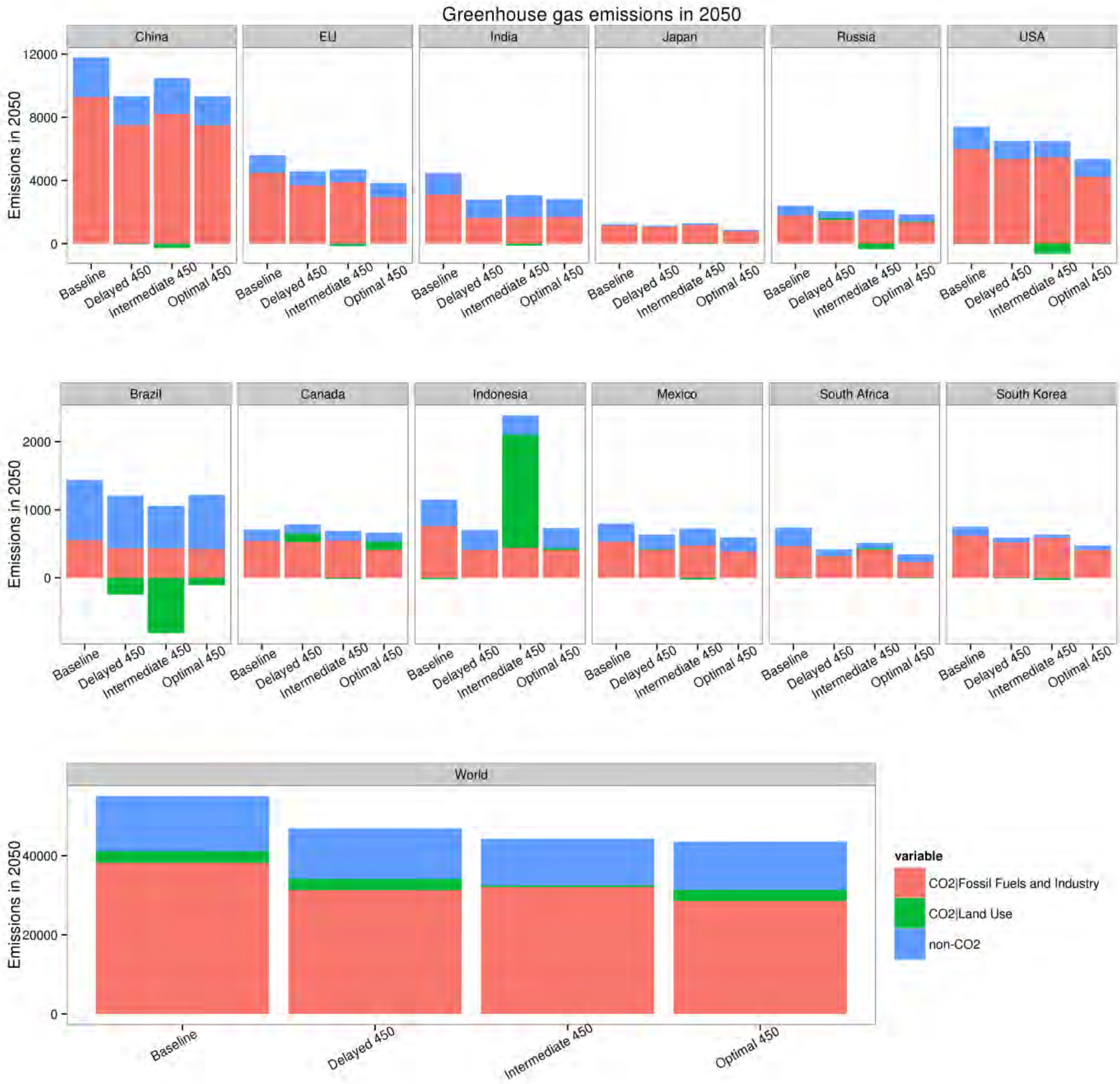
Figure 6: Kyoto gas emissions (MtCO$_2$e) in 2030 for Baseline, Delayed + intermediate 450, and Optimal 450 scenarios. Filled bars show the median value across models, error bars show the 10th to 90th percentile range.

Emissions: CO_2 Energy, CO_2 Land Use, Non-CO_2

Figure 7 shows the projected greenhouse gas emissions in 2050 in terms of CO_2 emissions from fossil fuels and industry, CO_2 emissions from land use, and non-CO_2 emissions. The emissions in each of these categories decline in the mitigation scenarios with respect to the baseline projections, with land use emissions even turning negative in some cases (Brazil, USA). CO_2 emissions from fossil fuels and industry represent the majority of global total emissions in the baseline, while the mitigation scenarios result in about equal shares of non-CO_2 emissions and CO_2 emissions from fossil fuels and industry globally. There are, however, regional differences. In China, for example, CO_2 emissions from fossil fuels and industry remain the major contributor to total emissions, while in Indonesia, land use emissions represent the largest share.

Looking at the change between 2010 and 2050 (lower part of Figure 7), globally, all emission categories show values lower than one in the mitigation scenarios, i.e. all emission sources decrease between 2010 and 2050. Please note that there are three emissions categories so the reference value for comparison with 2010 levels is three and not one. The Delayed 450 scenario shows larger reductions in all emission categories than the Optimal 450 scenario, because the Delayed 450 scenario requires faster and deeper emission reductions in the long

term than the Optimal 450 scenario.
Note that the intermediate 450 scenario category is not directly comparable to the other scenario categories, because it is mostly based on one model run, whereas the other scenario categories show the median of a larger number of runs.



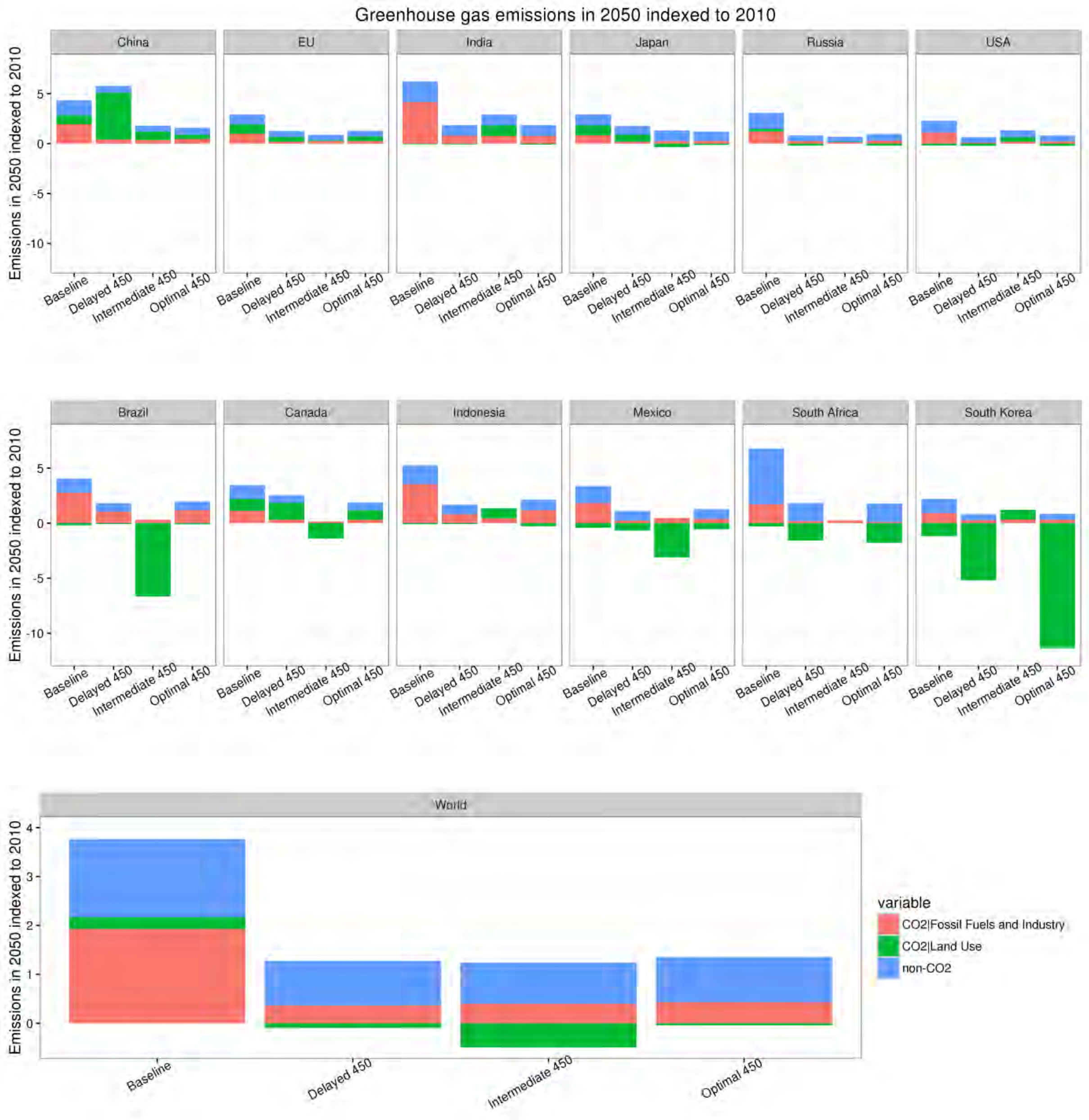


Figure 7: CO_2 emissions from energy supply and from land use, and non-CO_2 emissions in 2050 (upper graph: $MtCO_2eq$/year; lower graph: indexed to 2010) in baseline, delayed 450, intermediate 450 and optimal 450 scenarios.

Regional cumulative emissions

The scenarios can be used to calculate cumulative CO_2 emissions over a given period. These cumulative CO_2 emissions can be interpreted as regional emission constraints consistent with global climate policy targets assuming cost-efficient implementation across the regions. Note that the cumulative emissions linked to e.g. a <2°C temperature outcome need to be constantly updated to account for revised estimates of past, current and future emissions as well as developments in climate science. The regional cumulative emissions are presented in Figure 8 (median of all models). The difference in cumulative emissions between the baseline and the mitigation scenarios is especially pronounced in China and India.

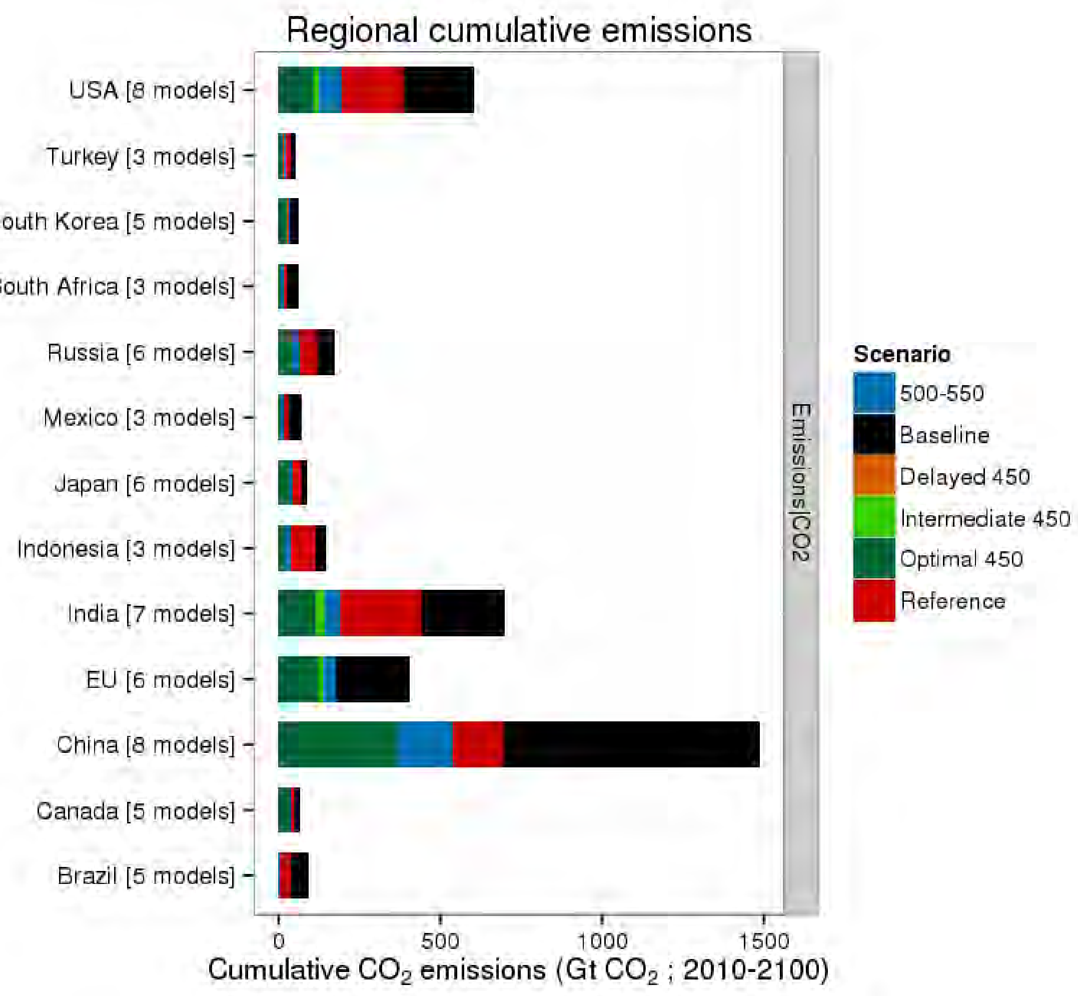


Figure 8: Cumulative CO_2 emissions (Gt CO_2) between 2010 and 2100 per country / region and scenario, based on the median of the model ensemble. The number of models per country is indicated. The coloured areas are indicative of the emission reductions going from one scenario category to another. For instance, the black area indicates the additional emissions in the baseline scenario compared to the current policy (reference) scenarios. The red area shows the additional emissions between current policies and 550 ppm CO_2.

Peak Year

Figure 9 presents the peak year in CO_2 emissions per region. Under the optimal 450 scenarios, most countries' CO_2 emissions peak before 2025 (except for India, which peaks around 2030). Under delayed 450 scenarios, this peak generally shifts to later in the century by construction, although not by much. The peak year is even later in 500-550 ppm scenarios, especially in India and Indonesia.

Comparison with the national model results

National scenarios for the European Union indicate that emissions have already peaked, which is not the case for some of the global model scenario results. For Brazil, the peak year of CO_2 emissions in the reference scenario is projected to be around 2060 (albeit with a large model spread), which is slightly later than found by Herreras Martínez et al. (2015), whose reference scenario shows a peak between 2045 and 2050. Peaking occurs considerably earlier in mitigation scenarios for Brazil, around 2015 under delayed 450 scenarios. The 450 ppm scenario by Herreras Martínez et al. (2015) peaks in 2020.

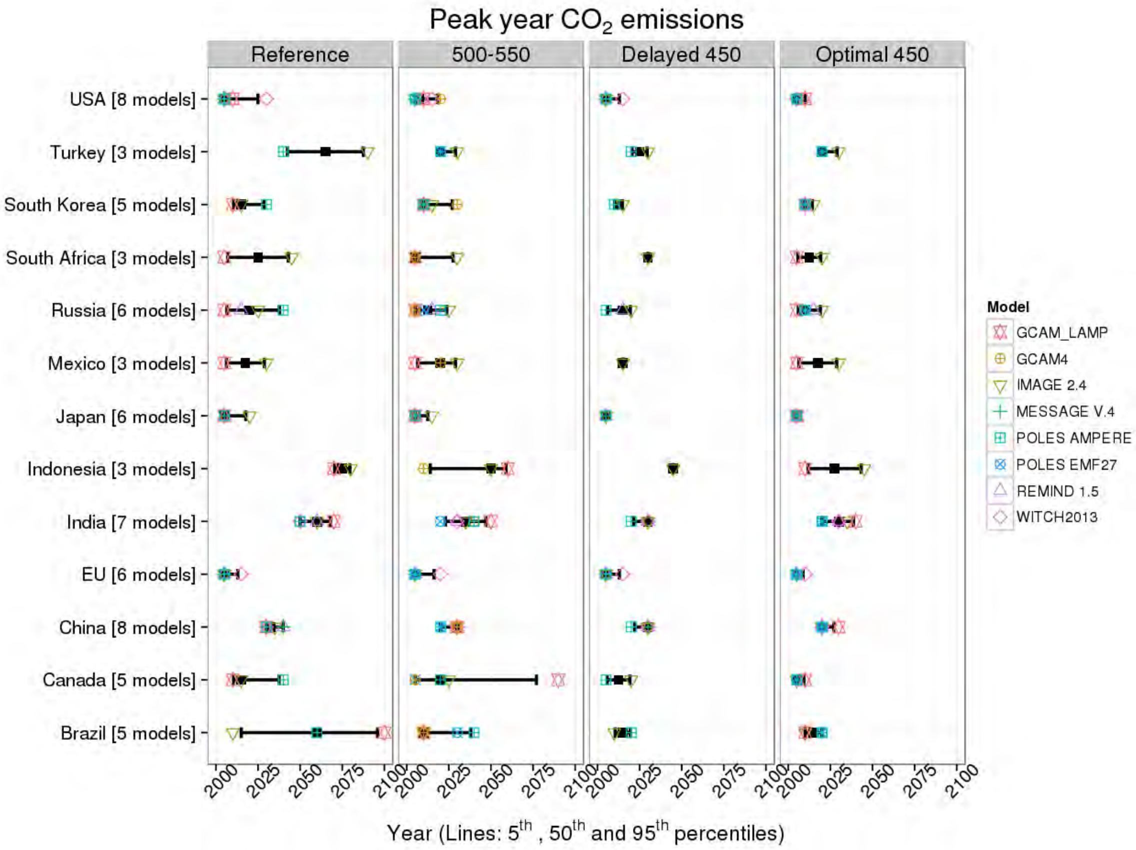


Figure 9: Peak year of CO_2 emissions per country, in reference, 500-550 ppm, delayed 450 and optimal 450 scenarios. Models are plotted individually (coloured shapes), lines show the 5th, 50th and 95th percentiles of the range of model results.

Low-carbon energy technology as a function of cumulative emissions

All countries show increasing deployment of low-carbon primary energy sources with respect to carbon-intensive energy sources as stringency in mitigation increases, i.e. lower cumulative emission scenarios, as shown in Figure 10. Low-carbon primary energy sources are all primary energy sources except coal, gas and oil without carbon capture and storage (CCS). For developed countries, this generally means a substantial increase on 2010 levels. Some developing countries, such as Brazil, India and Indonesia, on the other hand, show 2010 shares of low-carbon primary energy sources that are already close to the range reached in mitigation scenarios (over 25% of total primary energy supply in these cases).

Figure 11 shows that the share of low-carbon energy sources in electricity generation increases substantially in mitigation scenarios, compared to baseline scenarios. In 2030, the global average share of low-carbon energy sources is roughly twice as high in mitigation scenarios as the share in baseline scenarios.

Comparison with the national model results

Mexico is projected to reach about a 65% – 100% share of low-carbon energy sources in the mitigation scenarios, which is confirmed by Veysey et al. (2015). They conclude that all models included in their study find a significant decarbonisation necessary to reach Mexico's greenhouse gas emission reduction target, with 'clean sources[3]' reaching a share of 80% to 100% of electricity generation by 2050.

The Brazilian national modelling team created their own intermediate 450 scenario for comparison, in which they defined low-carbon sources in the same way as was used to produce Figure 11 (i.e. fossil fuels with CCS, nuclear, biomass with and without CCS, and non-biomass renewables). They find high shares of low-carbon sources in electricity generation, going from 79% in 2010 to 100% in 2050, mainly due to growth of non-biomass renewables (solar photovoltaic, solar CSP, distributed solar, wind, wind offshore, hydropower and ethanol). The global models project similar shares, reaching about 80%–100% by 2050.

[3] Defined as in Mexico's Electricity Industry Law: non-biomass renewables, biomass, nuclear, and CCS technologies (Veysey et al., 2015).

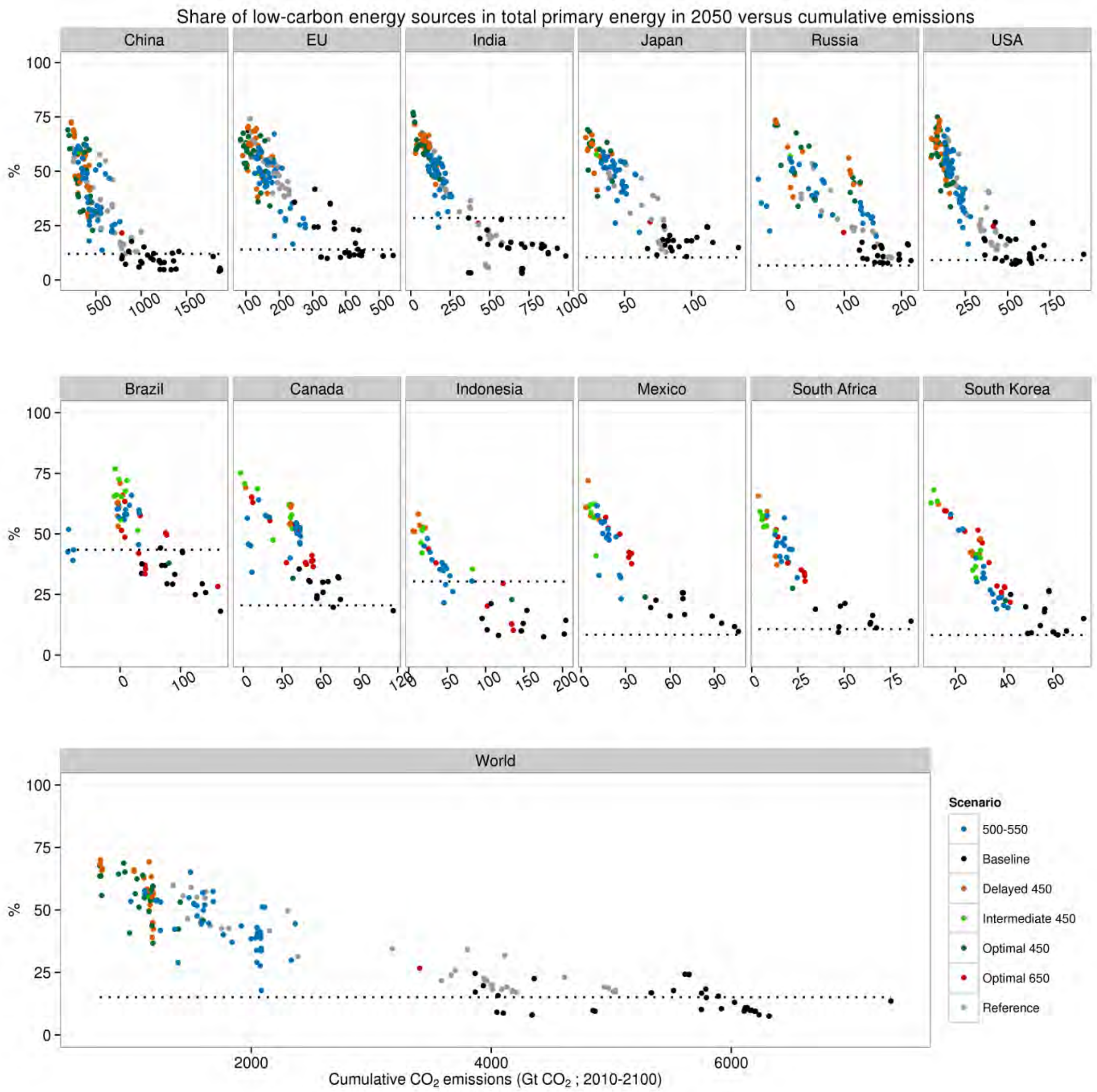


Figure 10: Share (%) of low-carbon primary energy sources (all sources except coal, gas and oil without carbon capture and storage, CCS) in total primary energy supply in 2050, versus cumulative CO_2 emissions (Gt CO_2) between 2010 and 2100. The scenario categories are shown as colour. 2010 values are indicated by black dotted lines.

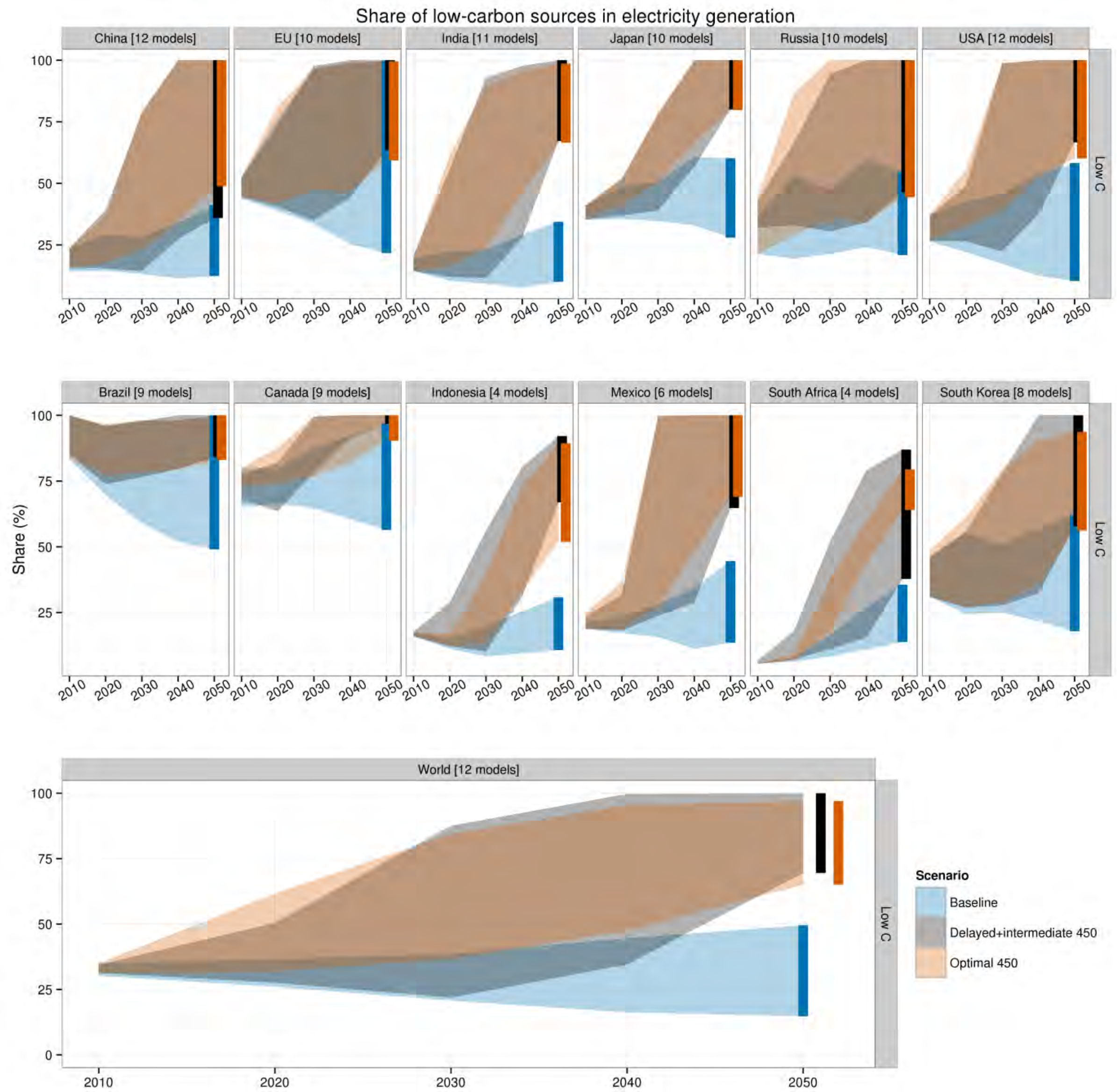


Figure 11: Share (%) of low-carbon energy sources in electricity generation (all sources except oil, gas and oil without carbon capture and storage, CCS). The number of models per country is indicated.

Policy Costs

By 2030, the median policy costs under optimal 450 scenarios are higher than those under delayed 450 scenarios for the world and for the region of China (Figure 12). However, the delayed 450 scenarios result in higher policy costs by 2050, compared to the optimal 450 scenarios. This can be explained by the steeper emission reductions needed in the longer term in the delayed 450 scenarios To some extent, these policy costs may be compensated by avoided impacts of climate change, though economic modelling is beyond the scope of this paper.

Note that the regions are covered by less models than for other variables shown above, because models report different policy cost variables; here, consumption loss is shown.

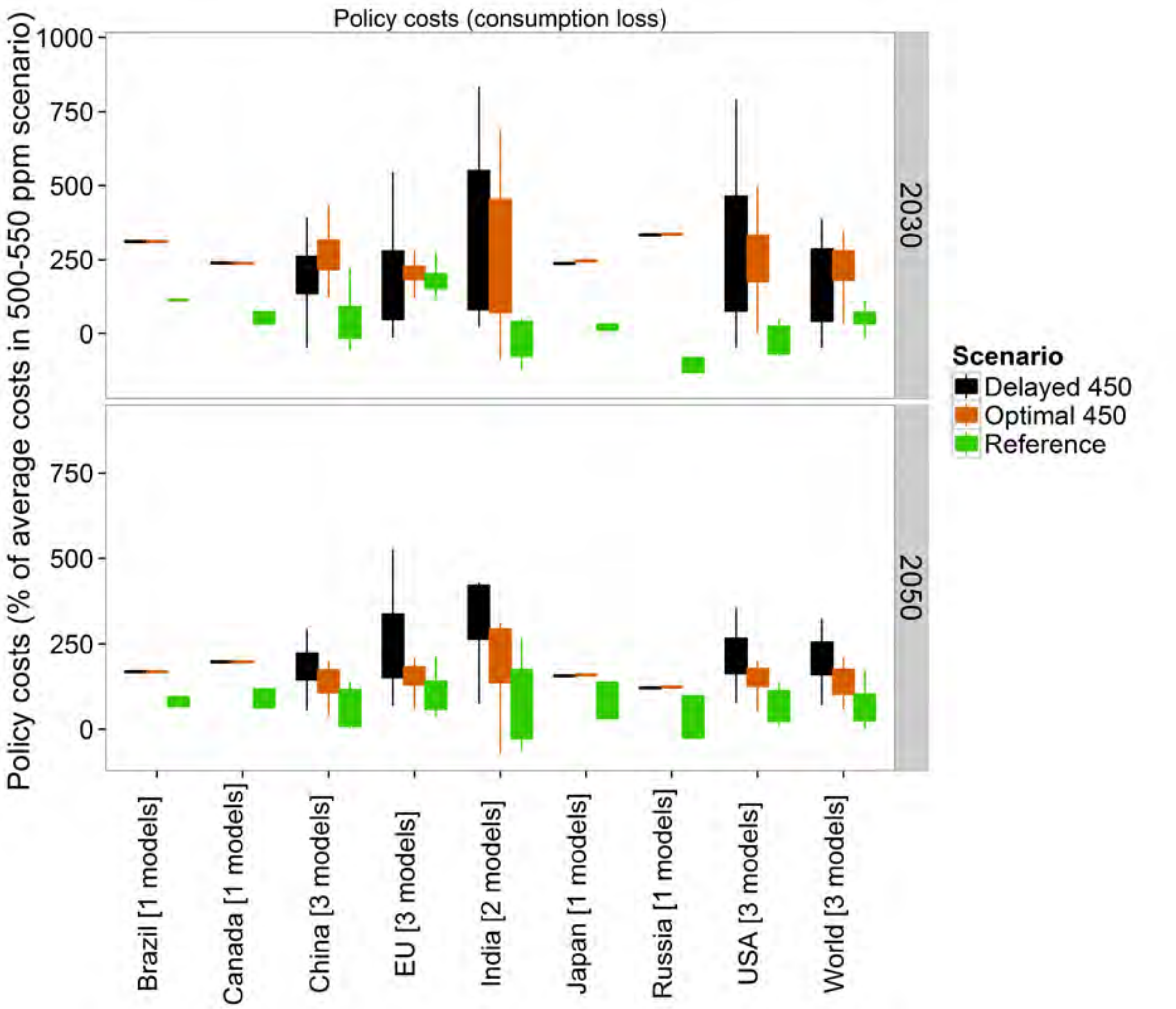


Figure 12: Policy costs (consumption loss), expressed as % of average costs in the 500-550 ppm scenarios of the same model, by 2030 and 2050, per country and scenario category. The number of models per country reporting this cost variable is indicated. Categories include the reference scenario (current climate policies), the cost-optimal implementation of a 450 ppm target and the delayed implementation of a 450 ppm target (see methods).

How do assumptions on the availability of different technologies influence these results?

Implications of Technology Availability Assumptions

The two modelling inter-comparison projects AMPERE and EMF27 have explored the implications of different technology assumptions on scenario results. Figure

13 shows the different primary energy mixes for five different technology assumptions as indicated in Table 5.

Table 5: Scenario categories used to evaluate technology availability implications (all scenario categories are variants of the AMPERE2-450-xxx-OPT scenario, thus assume an optimal 450 ppm pathway).

Scenario category	Description
FullTech	The default assumption of each model.
LowEI	Assuming lower energy intensity of the economy, which can be interpreted as a higher efficiency of end-use technologies, that are not explicitly represented in some of the models, or a less materialistic evolution of the economy with a strong focus on the service sector, or a combination of both.
noCCS	Assuming that carbon capture and storage will not be used (due to technology failures or as a political decision).
Conv	A conventional world, with only limited biomass use (100 EJ globally is available) and the share of variable power technologies (wind + solar) does not exceed 20% of electricity generation.
EERE	A world of high efficiency and with focus on renewable energies. This combines the assumption of LowEI and noCCS and additionally assumes a global phase-out of nuclear power after the end of the economic lifetime of all standing and currently planned nuclear reactors.

For this analysis, we have selected the REMIND model for illustration, which studied several variants of the AMPERE2-450-xxx-OPT scenario for the 6 regions shown in Figure 13. REMIND was the only model able to provide all scenarios for all 6 regions.

These different assumptions result in very strong differences in the deployment of different technologies, with generally more deployment of the unrestricted options, if one or several options are unavailable. Therefore, the extremes observed in technology-restricted scenarios tend to be higher than in the default scenario (FullTech). Moreover, the difference across scenarios is more important than variability across regions. The results imply a large deployment of CCS for India and Japan, which might raise feasibility problems. Furthermore, the high use of biomass for some regions is improbable unless regions can import biomass.

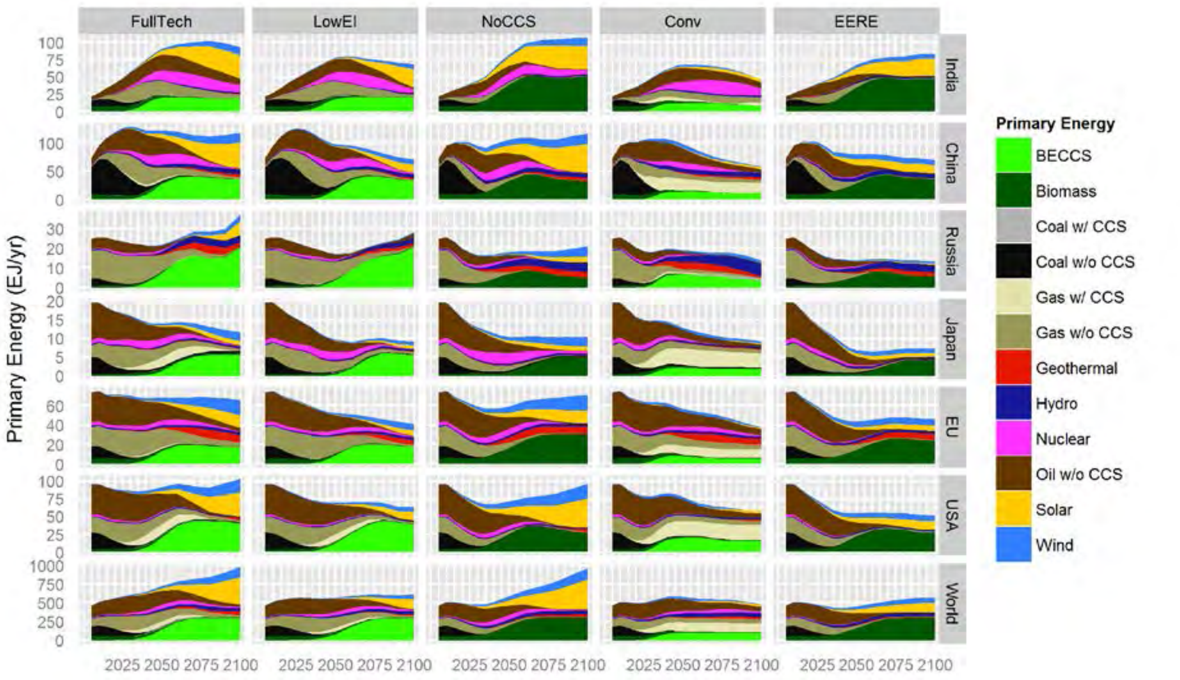


Figure 13: Primary energy mixes for 4 major economies + world under different assumptions on technology availability in the REMIND model.

What are important co-benefits at the national / regional level of the different policies?

Co-benefits

Energy Security and Energy Independence Co-benefits of Mitigation

Climate policies (both existing pledges[4] (see e.g. Den Elzen et al., 2015, Roelfsema et al., 2014) and 450 stabilization scenarios) globally lead to lower energy trade (Cherp et al., 2013, Jewell et al., 2014, Jewell et al., 2013), but both the uncertainty and the reduction in net-energy imports (or conversely reduction in net-exports) from the baseline varies between countries and over time. There are three types of national dynamics with respect to net-energy trade. Firstly, energy importers generally experience a decrease in net-energy imports in climate stabilization scenarios compared to the baseline development while, secondly, energy exporters experience a loss of energy export revenues from climate stabilization policies (Figure 14). However, the differences between the baseline and the climate stabilization scenario are relatively small, except for the Middle East and North Africa (MENA) region. The results for Canada are

[4] The **Pledges** scenario is the so-called "Stringent Policy" scenario from the LIMITS exercise (Kriegler et al., 2014b).

influenced by one model showing a strong decrease in exports. Regional analyses for Europe and the 2030 framework study show that energy imports decrease with increasing ambition of climate policies, confirming the trends shown in Figure 14.

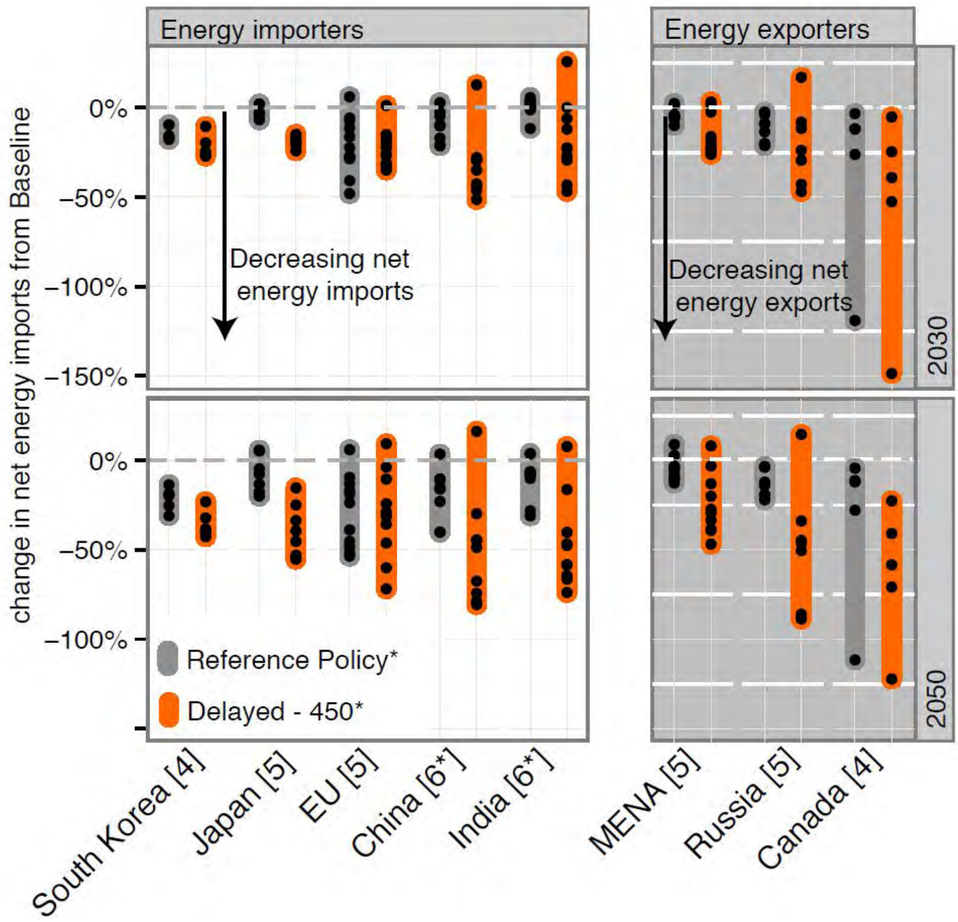


*Figure 14: Change in net-energy imports (left) and net-energy exports (right) for major energy importers and exporters. The number for each country represents the number of models. *Note: Reference Policy includes LIMITS-RefPol and AMPERE3-RefPol. Delayed-450 includes LIMITS-RefPol-450 and AMPERE3-450. Models include IMAGE, MESSAGE, REMIND, TIAM-ECN, WITCH, DNE and POLES. For China and India, we excluded one model which diverges from the trend of all the other models. In both cases, all but one model depict them as energy importers.*

Thirdly, there are countries that in the baseline experience changes in their net-energy trade (Table 6). For these countries, climate policies would likely not have the biggest impact on their net-energy trade in the short term, but rather the relative cost of extraction technologies and resource base development between different regions. This dynamic is most pronounced in the USA, which becomes a net energy exporter (primarily of coal) in most models between 2025 and 2060; climate stabilization does not reverse this trend but delays it and prevents the USA from developing significant energy export revenues in the latter half of the century. For Mexico, as the country's oil reserves are depleted, the country becomes a net energy importer around 2030, followed by growing energy imports. Climate stabilization curbs the growth of energy imports. Finally, Brazil is characterized by very low energy imports today, which grow but plateau around 2030 before becoming a net energy exporter around 2050.

Table 6: Countries with shifting net-energy dependence in the Baseline

	Baseline	**Reference Policy**	**Delayed-450**
USA	Becomes a net energy exporter in most models (5 out of 7) between 2025 and 2060.	Similar to Baseline but the shift is delayed and coal exports are lower.	Similar to Baseline but loses most energy exports post 2050.
Mexico	Oil reserves are depleted, and becomes energy importer ~2030 followed by growing imports.	Similar to Baseline	Similar to Baseline but lower imports.
Brazil	Very low energy imports today. In Baseline, modest growth in energy imports which plateau ~2030.	Similar to Baseline	Similar to Baseline

Air Pollution Co-benefits of Mitigation

Achieving a 450 ppm stabilization scenario implies a fundamental transformation of the global energy system. Such a transformation will not only result in the required greenhouse gas emissions reductions, but will also affect the abundance of air pollutants in the atmosphere. Greenhouse gas emissions, in particular CO_2, are reduced to a large degree by phasing out unabated fossil-fuel energy production, like coal, and replacing them with less carbon intensive alternatives like renewables or biomass energy. Because air pollutants are co-emitted with CO_2 during the combustion processes, changes in the energy system can result in less or more air pollutants emissions.

Figure 15 shows that, across the board, sulphur dioxide emissions are strongly reduced as a positive side-effect of greenhouse gas emission mitigation. This is the case for both developing and developed countries. The main reason for this reduction is that unabated coal combustion is a dominant source of sulphur dioxide emissions, and this source of energy production needs to be rapidly replaced by less carbon-intensive alternatives in order to achieve a 450 stabilization scenario.

Significant reductions can also be found for emissions of black carbon (soot). However, because black carbon can be emitted during the combustion of fossil fuels as well as from much less carbon-intensive energy sources, like biomass (Bond et al., 2013), the effect can vary regionally. While, generally, black carbon emissions are reduced together with emissions of greenhouse gases in 450 scenarios, some estimates show increasing black carbon emissions in countries that strongly rely on bioenergy to achieve their greenhouse gas targets. In the latter cases, more complementary policies are required to specifically reduce air pollution from black carbon.

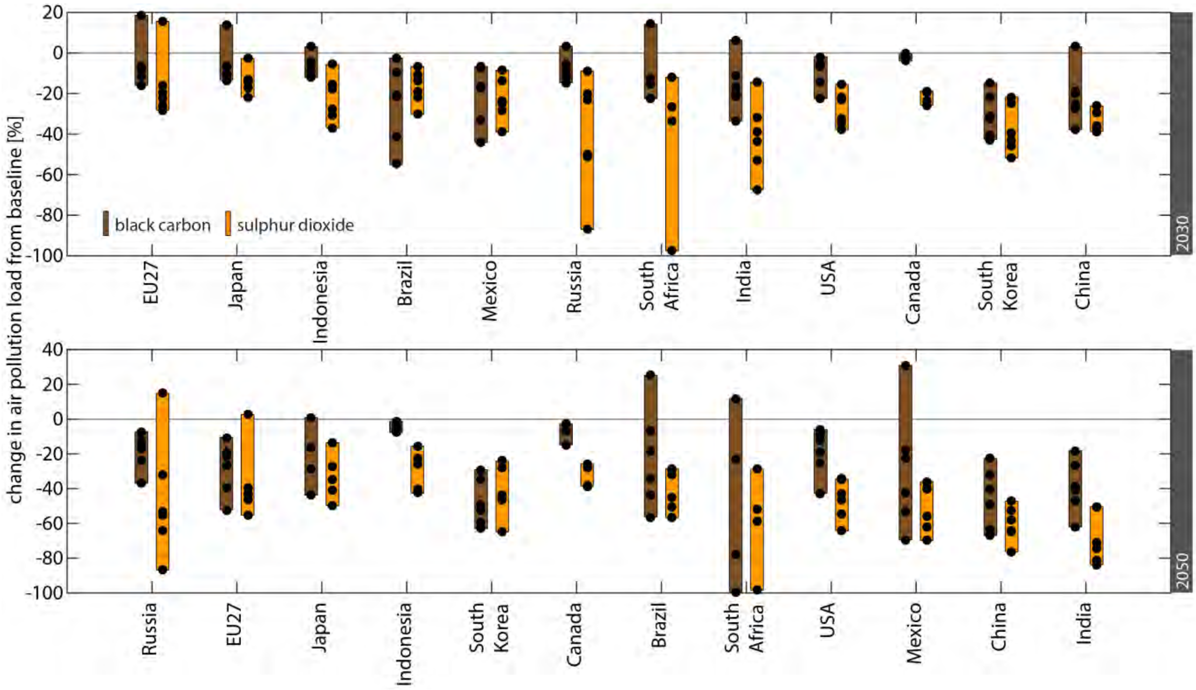


*Figure 15: Changes in black carbon (brown) and sulphur dioxide (orange) emissions when moving from a baseline in absence of targeted new climate policies to a pathway in line with stabilizing atmospheric CO_2-equivalent concentrations at 450 ppm. Data is provided for 2030 (top) and 2050 (bottom). Dots show single model results, bars the full range. *Note: The LIMITS-Base (LIMITS1) scenario is taken as the baseline scenarios. LIMITS-RefPol-450 (LIMITS6) is taken as the 450 scenario. Models include IMAGE, MESSAGE, REMIND, GCAM, AIM, and WITCH. In case models did not report data at the national level, the reductions in air pollutants from the encompassing region were downscaled based on the shares found in the IMAGE model. Both the baseline and the 450 scenario assume a successful implementation of current air pollution legislation policies (CLE).*

Conclusions

In this paper, we have looked into the regional results of a set of global models in order to derive policy-relevant indicators at the national level and to compare the insights of the global models with insights of national modelling teams.

General conclusions

- **The mitigation scenarios require major emission reductions in all countries. These can only be achieved by a considerable change in the energy supply of these countries.** Primary energy demand decreases strongly in the mitigation scenarios, compared to the baseline scenario, especially in developing countries. The 450 scenarios show a reduction in all countries of roughly 30-40% compared to the baseline. There are regional differences, with e.g. South Africa showing a stronger reduction in primary energy demand under mitigation scenarios.
- **Per capita CO_2 emissions are projected to decline in all countries under mitigation scenarios. Global average CO_2 emissions reach about 0.3 – 2 tCO_2/capita under delayed 450 scenarios.** Total CO_2 emissions decrease in most countries under the mitigation scenarios, and even turn negative in Brazil (due to land use, acting as a sink). In terms of per capita emissions, developing countries generally remain below the global average, although the upper end of the ranges for China, Indonesia and South Africa are slightly above the global average. Most OECD countries show per capita emissions ranges similar to or higher than the global average. CO_2 emissions from fossil fuels and industry represent the majority of global total emissions in the baseline, while the mitigation scenarios result in about equal shares of non-CO_2 emissions and CO_2 emissions from fossil fuels and industry globally. There are, however, regional differences in the mitigation scenarios. In China, for example, CO_2 emissions from fossil fuels and industry remain the major contributor to total emissions, while in Indonesia, land use emissions represent the lion's share. The difference in cumulative emissions between the baseline and the mitigation scenarios is especially pronounced in China and India (assuming cost-efficient implementation across regions).
- **Under the optimal 450 scenarios, most countries' CO_2 emissions peak before 2025 (except for India) and a phase-out of CO_2 emission occurs around 2060.** Under delayed and intermediate 450 scenarios (taking into account 2020 pledges and introducing optimal policies between 2020 and 2025), this peak generally shifts to later in the century, although not by much. The peak year is even later in 500-550 ppm scenarios, especially in India and Indonesia.
- **All countries show increasing shares of low-carbon primary energy sources with lower cumulative emissions.** For developed countries,

this generally means a substantial increase on 2010 levels. Some developing countries, such as Brazil, India and Indonesia, on the other hand, show 2010 shares of low-carbon primary energy sources that are already close to the range reached in mitigation scenarios (over 25% of total primary energy supply in these cases).

- **There is a cost advantage to starting mitigation early.** Delayed 450 scenarios show lower median policy costs in the short term in some regions (China and the world), but higher policy costs in the long term in all regions, compared to the optimal 450 scenarios.

Comparison with national projections

- **In general the projections seem to be in line with those used at the national level, although the latter show somewhat higher growth rates in Brazil and India**.
- Primary energy intensity decreases strongly in all countries and all scenarios, including the baseline scenario, but especially in developing countries and the Russian Federation.

Co-benefits

- **Energy importing countries generally experience a decrease in net-energy imports in climate stabilization scenarios compared to the baseline development, while energy exporters experience a loss of energy export revenues from climate stabilization policies.** Countries that experience changes in net energy trade in the baseline, most notably the USA, are likely more affected by relative costs of extraction technologies and resource base developments than by climate policies.
- **Across the board, sulphur dioxide emissions are strongly reduced as a positive side-effect of greenhouse gas emission mitigation**. This is the case for both developing and developed countries. Significant reductions of black carbon emissions can also be found, albeit with regional differences. Countries that strongly rely on bioenergy to reach mitigation targets, for example, see increasing black carbon emissions, thus requiring additional policies to reduce air pollution from black carbon.

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The MILES project

The MILES project (Modelling and Informing Low Emission Strategies) is an international cooperation project between 19 research teams from emerging countries like China, India and Brazil and research teams in developed countries from Europe, the US and Japan. Key objectives of the project are: 1) to explore different country-level strategies consistent with the 2°C target, 2) to increase understanding of differences between strategies in different parts of the world, and 3) to enhance in all participating countries the capacity to perform analysis of mitigation strategies. This is implemented by sharing experience on i) scenario definition to ensure the necessary level of detail in the definition of the low-carbon strategies for informing national and international policy discussions on decarbonisation, ii) model development to ensure the improvement of national modelling capacities permitting the elaboration of modelling frameworks able to represent a broad coverage of sectors, activities and GHG, and enable the representation of socio-economic implications of policy choices; iii) comparative and diagnostic model analysis to better understand the influence of model structure on model results and iv) policy analysis of model results to identify those trajectories that are relevant for the purpose of defining strategies and policies that are both consistent with climate and development objectives.

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