



## Limiting Global Warming to 2°C

Policy findings from Durban Platform  
scenario analyses

# LIMITS

LOW  
CLIMATE  
**I**MPACT  
SCENARIOS  
AND THE  
**I**MPPLICATIONS  
OF REQUIRED  
**T**IGHT  
EMISSION  
CONTROL  
**S**TRATEGIES

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## LOW CLIMATE IMPACT SCENARIOS AND THE IMPLICATIONS OF REQUIRED TIGHT EMISSION CONTROL STRATEGIES

Limiting Global Warming to 2°C

### **Policy findings from Durban Platform scenario analyses**

#### **Authors (2014)**

Massimo Tavoni (FEEM)  
Elmar Kriegler (PIK)  
Keywan Riahi (IIASA)  
Detlef P. van Vuuren (UU/PBL)  
Nils Petermann (PIK)  
Jessica Jewell (IIASA)  
Sara Herreras Martinez (UU)  
Shilpa Rao (IIASA)  
Mariësse van Sluisveld (UU)  
Alex Bowen (LSE)  
Aleh Cherp (CEU)  
Katherine Calvin (PNNL-JGCRI)  
Giacomo Marangoni (FEEM)  
David McCollum (IIASA)  
Bob van der Zwaan (ECN)  
Tom Kober (ECN)  
Hilke Rosler (ECN)  
The LIMITS Consortium

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Mariaester Cassinelli (FEEM)

For more information on LIMITS please visit  
<http://www.feem-project.net/limits>

To access the LIMITS scenario database please visit  
<https://secure.iiasa.ac.at/web-apps/ene/LIMITSDB>



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## LIMITS Consortium

Project coordinator: Fondazione Eni Enrico Mattei (FEEM), Italy



International Institute for Applied Systems Analysis (IIASA), Austria



Potsdam Institute for Climate Impact Research (PIK), Germany



Utrecht University (UU), Netherlands



London School of Economics and Political Science (LSE), United Kingdom



Energy Research Centre of the Netherlands (ECN), Netherlands



EU Joint Research Centre – Institute for Environment and Sustainability (IES), Italy



Central European University, Hungary



National Development and Reform Commission, Energy Research Institute (ERI), China



Indian Institute of Management (IIM), India



### Associated Research Organisations:

Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI), USA



National Institute for Environmental Studies (NIES), Japan



## Introduction

### The Durban Platform and the 2°C target

Countries worldwide agreed, as part of the Cancun declaration in 2010, to focus international climate policy on stringent greenhouse gas emission reductions with the aim to limit global warming to less than 2°C above preindustrial levels. Subsequently, the Durban Platform for Enhanced Action was established in 2011 as a new track for negotiating an international climate treaty that is to enter into force in 2020. The Durban Platform negotiations recognize that in order to move toward the 2°C target, the discussion of mitigation targets can no longer be restricted to Annex I countries whose share of annual global greenhouse gas emissions has declined to less than a half over the past decade. It thus provides an opportunity for discussing post-2020 emission reduction commitments beyond the traditional divide of developed versus developing countries, although the key elements of the United Nations Framework Convention on Climate Change, such as the notion of differentiated responsibilities and capabilities, remain central to the negotiations. If successful, the Durban Platform could achieve the first global climate policy regime that covers all major emitters and could open up a pathway to stringent mitigation efforts in line with the 2°C target.

Over the past few years, the LIMITS project has been looking into various aspects of formulating international climate policies in the context of the 2°C target. These aspects included the required level of transformation, feasibility considerations in different regions, economic costs, co-benefits of climate change mitigation, and financial and distributional issues. In this report, we present a number of key outcomes of the LIMITS project. These include the following key findings:

- Achieving the 2°C target requires a limit on cumulative greenhouse gas emissions at the global level.
- The challenges of strict mitigation pathways differ between regions.
- Global carbon pricing can minimize the costs of mitigation, but to avoid disproportionate economic impacts on some regions, burden sharing is critical.

These findings are discussed in detail in the main sections of this report.

#### Basic overview of LIMITS

**Duration:** October 2011 to September 2014

**Funding:** 3,462,863 EUR from the EU Seventh Framework Programme (grant agreement no 282846)

**Project coordinator:** Massimo Tavoni, Fondazione Eni Enrico Mattei (FEEM), Italy

**Work package leaders:** Massimo Tavoni (FEEM), Keywan Riahi (IIASA), Elmar Kriegler (PIK), Detlef P. van Vuuren (UU)

**Project manager:** Mariaester Cassinelli (FEEM)

**Scientific Advisory Panel:** Alessandro Lanza (Luiss University, Euro-Mediterranean Center on Climate Change), Raymond Kopp (Resources for the Future), Bert Metz (European Climate Foundation), Hans Holger Rogner (IIASA, Royal Institute of Technology KTH)

<sup>1</sup> The findings, opinions, interpretations and recommendations in this report are entirely those of the authors

### **The LIMITS model comparison project**

The LIMITS project explores the dimensions of the mitigation challenge at the global and regional level and assesses policy options for achieving the 2°C target and the associated energy technology investments. LIMITS is funded by the European Union and stands for Low Climate Impact Scenarios and the Implications of Required Tight Emission Control Strategies.<sup>1</sup>

The LIMITS project assesses a series of critical questions which are especially relevant for climate policy making:

- What is the economic and technical feasibility of attaining stringent climate policies?
- What are the investment requirements to implement the necessary energy system transformations and how can countries foster the needed investments?
- What is the role of policies in promoting mitigation, recognizing the diversity of regional and national interests?

LIMITS used results from multiple state-of-the-art integrated assessment models to gain insights into these questions. LIMITS is a 3-year research project that started in October 2011 with ten partners from Europe, China, India, and collaborators from the US and Japan. The project brings together experts in several different domains which include integrated assessment modelling, energy system analysis, finance, economic development, land use and agriculture.

### **The integrated assessment models participating in LIMITS**

Integrated assessment models (IAMs) are tools designed to investigate the implications of achieving climate and other objectives in an integrated and rigorous framework, accounting for major interactions among energy, land-use, economic and climate systems. These models are used to generate global long-term scenarios for a number of regions or countries that can help inform climate and energy policy decisions about potential medium-term courses of actions that could help to achieve long-term climate objectives. Scenarios from IAMs provide important input to scientific reviews such as the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environment Programme (UNEP) Emissions Gap Report. In order to obtain robust conclusions from the various models with their different assumptions and design characteristics, IAM teams have engaged in model inter-comparison projects based on common scenarios and study protocols. The models involved in the LIMITS model comparison project are listed below. To obtain information on the likelihood of LIMITS scenarios to limit global warming to 2°C above preindustrial levels, all emissions projections have been run through the coupled gas cycle climate model MAGICC that has been widely used for projections of future climate change.

<sup>1</sup> *The findings, opinions, interpretations and recommendations in this report are entirely those of the authors*

Model name	Institute	Model category	Representation of anticipation
AIM-Enduse/CGE	NIES	Partial/general equilibrium	Recursive dynamic
GCAM	JGCRI	Partial equilibrium	Recursive dynamic
IMAGE/TIMER	UU/PBL <sup>2</sup>	Partial equilibrium	Recursive dynamic
MESSAGE-MACRO	IIASA	General equilibrium	Perfect foresight
REMIND	PIK	General equilibrium	Perfect foresight
TIAM-ECN	ECN	Partial equilibrium	Perfect foresight
WITCH	FEEM	General equilibrium	Perfect foresight

### The LIMITS scenarios

The models participating in LIMITS calculated the implications of scenarios focusing on the potential outcomes of the Durban platform negotiations. These scenarios used a range of assumptions about the stringency and timing of emissions reduction and about burden sharing regimes. The LIMITS results focus on 10 regional aggregates and on a set of major economies.

In this report, we focus on the following scenarios assessed in LIMITS:

Scenario name	Near-term policy (before transition)	Transition starting around	Long-term target (after transition)	Likelihood of staying below 2°C	Additional policies
<b>Baseline scenarios</b>					
No policies	None			0%	None
Reference	Reference policies			Minimal	None
Energy independence	None			0%	Energy independence
Oil independence	None			0%	Oil independence
Air Pollution	None			0%	Fixed, Current and Stringent air pollution controls
<b>Durban scenarios without burden sharing</b>					
2°C 450 ppm	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	None
2°C 500 ppm	Reference policies	2020	500 ppm CO <sub>2</sub> e	around 50%	None
<b>Durban scenarios with burden sharing</b>					
2°C 450 ppm PC	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	Per capita
2°C 450 ppm EE	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	Equal effort
<b>Durban failure scenario</b>					
2°C 2030 500 ppm	Reference policies	2030	500 ppm CO <sub>2</sub> e	around 50%	None
<b>Combined energy independence-climate scenarios</b>					
2°C 450 ppm Energy independence	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	Energy independence
2°C 450 ppm Oil independence	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	Oil independence
<b>Combined air pollution-climate scenarios</b>					
2°C 450 ppm Air Pollution	Reference policies	2020	450 ppm CO <sub>2</sub> e	around 2/3	Fixed, Current and Stringent air pollution controls

<sup>2</sup> The contribution of PBL Netherlands Environmental Assessment Agency in providing the IMAGE model infrastructure and cooperating with Utrecht University in model application is kindly acknowledged.

The no policies scenario addresses the future energy system and emission developments in the absence of climate policy. The reference scenario is based on formulated 2020 national energy and climate targets reflecting the unconditional Copenhagen pledges. The scenario is extended after 2020 by assuming a similar national effort in the subsequent decades. The Durban Platform 2°C scenarios differ in the likelihood of achieving the 2°C target. The scenarios that achieve atmospheric greenhouse gas concentrations of around 450 ppm CO<sub>2</sub> equivalent (CO<sub>2</sub>e) by the year 2100 correspond to a roughly two-thirds likelihood of staying below 2°C, whereas the scenario leading to 500 ppm CO<sub>2</sub>e correspond to a roughly even chance of staying below 2°C. Two of the 2°C scenarios include burden sharing regimes between regions that are the topic of Section 3 of this report. In the Durban failure scenario, stringent global climate policy action starts only after 2030 instead of 2020 as called for in the Durban Platform negotiations.

## Findings from the LIMITS project

### Key Findings on limiting global warming to 2°C

In this report, we present central findings from the LIMITS project. Specifically, Section 1 deals with the possible emission pathways that could achieve the 2°C target; Section 2 discusses the challenges at the regional level of transitioning the global energy system from its current path to a 2°C pathway; Section 3 focuses on how to address the distributional issues associated with a global climate policy regime.

In summary, the key findings from these sections are:

**Achieving the 2°C target requires a limit on cumulative greenhouse gas emissions at the global level.** Different global emission pathways can be compatible with the 2°C target, meaning that there is some flexibility in the timing of emission reductions. However, cumulative global emissions over the 21st century must be kept within a tight budget. The technical and economic challenges of transitioning to a pathway that can achieve the necessary long-term emission reductions are exacerbated if the transition is delayed. In Section 1 of this report, we provide an overview of the global mitigation challenge that a transition from current policies to a 2°C pathway entails.

**The challenges of strict mitigation pathways differ between regions.** Important factors are the differences between national policies in the near term, the regional baseline emissions in the long term, regional economic capabilities, and the availability of mitigation options. In Section 2 of this report, we discuss these regional factors and potential regional mitigation patterns.

**Global carbon pricing can minimize the costs of mitigation, but to avoid disproportionate economic impacts on some regions, burden sharing is critical.** It is possible to pursue both efficiency and equity goals by harmonizing international carbon pricing mechanisms while allocating emission allowances based on equity principles. The mitigation burden of disadvantaged regions can also be addressed through dedicated financial support for the required low-carbon investments. Examples for burden sharing approaches and a discussion of regional implications are provided in Section 3.

# 1. Global emission pathways to 2°C

The Durban Platform reinforces the goal of international climate policy to limit global warming to 2°C. In this section, we look at some of the main considerations for achieving a transition from current trends to possible pathways that could meet the 2°C target.

## 1.1 Meeting the 2°C target requires a break with current emission trends

### 1.1.1 Cumulative CO<sub>2</sub> emissions must be limited

A key question for policy-making is what the 2°C target implies for global greenhouse gas (GHG) emissions. Although emission pathways of various shapes could be consistent with the 2°C target, it should be noted that there is a direct relationship between cumulative CO<sub>2</sub> emissions and the probability of staying below 2°C. Due to the fact that CO<sub>2</sub> dominates the total amount of GHG emissions and due to its long lifetime in the atmosphere, meeting the 2°C target implies a strict budget for total CO<sub>2</sub> emissions, limiting the amount of cumulative emissions over the century. To keep global warming below 2°C with a more than two-thirds likelihood, the LIMITS models suggest that cumulative CO<sub>2</sub> emissions over the period 2011-2100 need to be constrained to about 670-1100 GtCO<sub>2</sub> – while non-CO<sub>2</sub> greenhouse gases need to be seriously constrained as well. This would result in atmospheric GHG concentrations of about 450 ppm CO<sub>2</sub>e in 2100. A somewhat more lenient emissions budget (1000-1570 GtCO<sub>2</sub>) resulting in 500 ppm CO<sub>2</sub>e in 2100 would give an even chance of keeping global warming below 2°C.

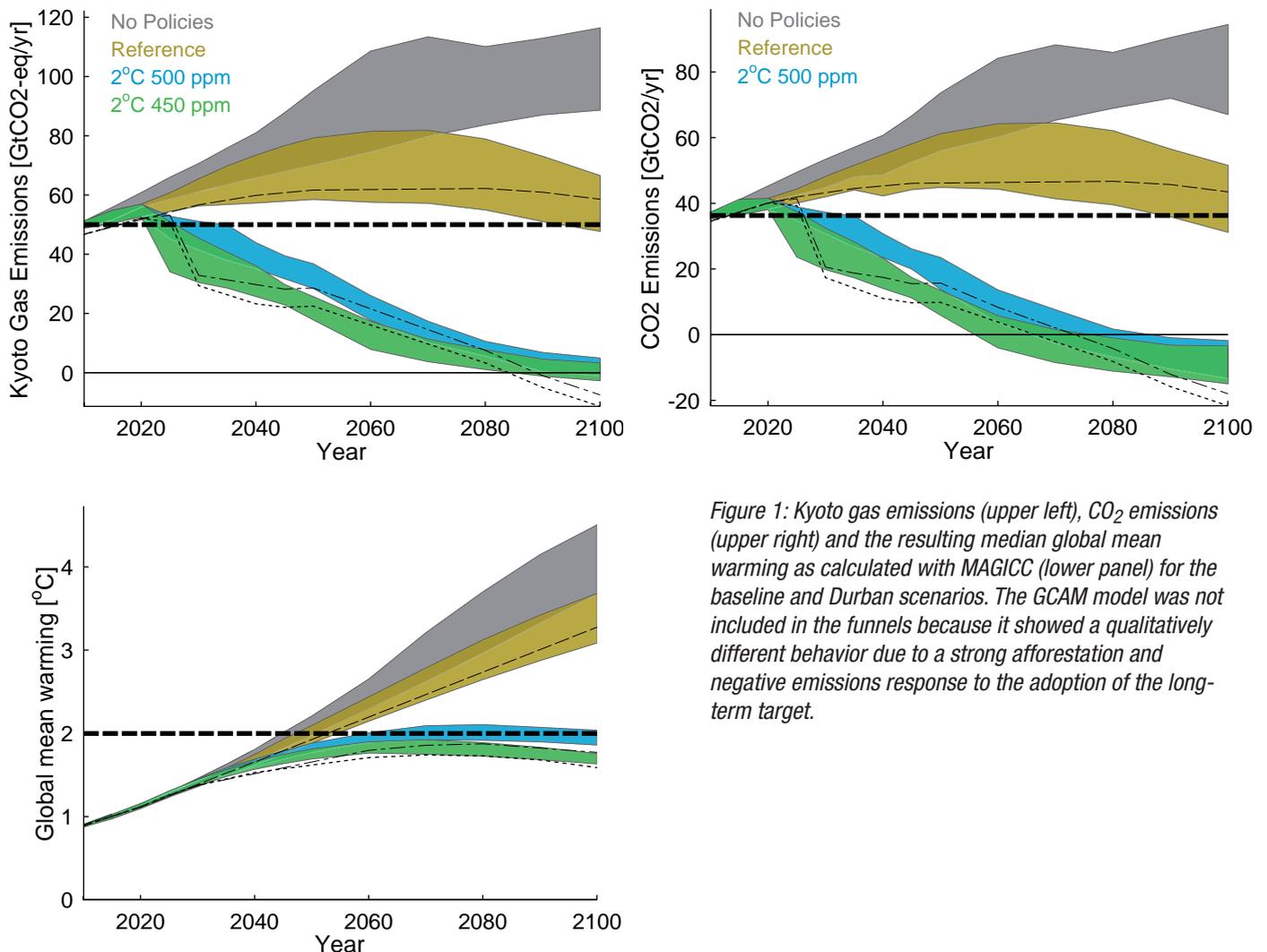


Figure 1: Kyoto gas emissions (upper left), CO<sub>2</sub> emissions (upper right) and the resulting median global mean warming as calculated with MAGICC (lower panel) for the baseline and Durban scenarios. The GCAM model was not included in the funnels because it showed a qualitatively different behavior due to a strong afforestation and negative emissions response to the adoption of the long-term target.

The findings of this section are largely based on Kriegler et al. (2013), van der Zwaan et al. (2013), and Marangoni et al. (2014).

### 1.1.2 The current fragmented policies do not lead toward a 2°C pathway

Global emissions would exceed the 2°C emissions budget within a few decades if they continued on the pathway set by current national energy and climate policies. The current levels of policy ambition are represented by the pledges made by several countries at the Copenhagen Conference of Parties to the UNFCCC. Even if all pledges are fulfilled, the resulting emission reductions would be insufficient for an optimal pathway towards limiting global warming to 2°C. This has been emphasized several times by the UNEP Emissions Gap Reports and reiterated by the model calculations of the LIMITS project. An important finding in LIMITS is that if the Copenhagen Pledges are followed up by similar emissions intensity improvements throughout the century, this would likely lead to warming of more than 3°C by 2100 (see Figure 1). After 2100, warming would further continue. To reach a pathway that can achieve the 2°C target, a break with the current upward trend in emissions is needed well before the emissions budget associated with 2°C is exhausted.

## 1.2 Transitioning to a 2°C pathway poses technical and economic challenges

### 1.2.1 The challenge of transitional costs depends on timing

A cost-efficient path toward the 2°C target would involve a peak and subsequent decline of global GHG emissions as early as possible. If the international community uses the Durban Platform to put in place efficient mitigation policies based on global carbon pricing, the costs of meeting the 2°C target need not be prohibitive. According to the LIMITS models, the net present value losses of consumption or economic output – compared to a no-policy baseline and using a 5% discount rate – are 0.6%-5.3% for meeting the 2°C target with high likelihood (450 ppm CO<sub>2</sub>e). Models estimate 25-45% lower costs for only an even chance of meeting the target (500 ppm CO<sub>2</sub>e). Such costs are eclipsed by the expected multiplication of global per-capita consumption and economic output over the 21st century. However, during the two decades following the onset of a global policy regime, transitioning from current trends to a 2°C pathway can strongly impact consumption, as consumption growth must be reduced in favour of investment in the transition. This transitional impact on consumption is more severe if the emissions budget is tighter and if stringent climate policies are delayed for longer, as subsequent emission reductions would have to be steeper and – in the case of delay - a stronger lock-in of energy systems and infrastructure into high emissions intensity would complicate the transition. The LIMITS study suggests that if the Durban Platform negotiations failed and the transition to a 2°C pathway was delayed from 2020 to 2030, the reduction of global consumption growth in the transition period would be significantly exacerbated. Figure 2 shows that based on the model results for the 2°C 500 ppm scenario, successful Durban Platform negotiations would lead to a reduction by 1-5 percentage points (of 80-95% consumption growth in the baseline) during 2020-2040, whereas a failure of the negotiations and delay of the transition until 2030 would lead to considerably higher reduction by 3-9 percentage points (of 70-80% growth) during 2030-2050.

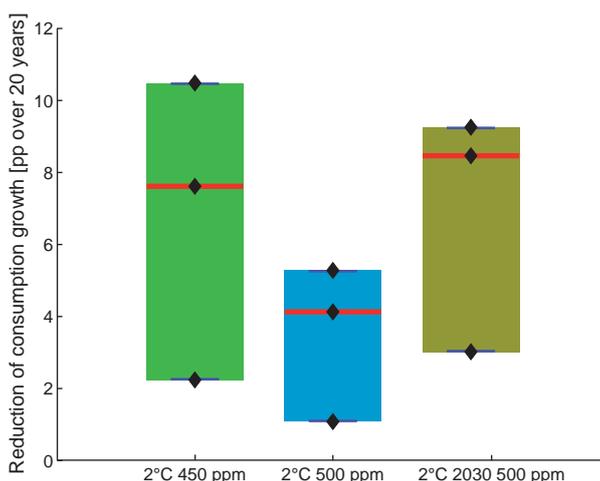


Figure 2: Reduction of consumption growth over the two decades following target adoption (2020–2040) for the Durban scenarios and 2030–2050 for the Durban failure scenario) with respect to the consumption growth in the no policy baseline (in percentage points) as projected by the general equilibrium models in the study. Individual model results are shown by black diamonds.

### **1.2.2 Low-carbon technologies must be deployed at a rapid pace**

The LIMITS models looked into the characteristics of 2°C scenarios. An important finding is that in order to achieve the 2°C target with a high likelihood, global CO<sub>2</sub> emissions must be reduced to zero by the third quarter of the century. This requires a rapid deployment of low-carbon technologies. The faster this deployment can be achieved, the fewer excess emissions are generated, reducing the need for compensation through negative emissions later in the century. If stringent climate policies are implemented shortly after 2020, the deployment of low-carbon energy technologies will most likely reach the highest rates between 2030 and 2050.

The LIMITS models suggest that decarbonization can be achieved most rapidly in the electricity sector. In fact, a 2°C pathway would likely lead to carbon-neutrality by around mid-century and negative emissions thereafter in this sector (see section 1.2.3 for a brief look at negative emission options). While the models disagree on the exact mix of low-carbon technologies, all models show a strong growth of solar and wind electricity generation capacity. Between 2030 and 2050, the deployment of either solar and wind power exceeds the addition of coal power capacity between 2000 and 2010 (see Figure 3). The addition of capacities to generate power from bioenergy, nuclear power and fossil fuels with carbon capture and storage depends on the region and model. Overall, the deployment rates of low-carbon electricity generation would need to exceed the rates of conventional capacity additions in the recent past. This poses industrial, infrastructural, financial, and socio-political challenges not yet experienced in the energy sector at this scale.

A substantial portion of decarbonization is achieved through energy demand reductions through energy efficiency, conservation, and structural changes. Until 2050, energy savings are at least as important as renewable energy deployment in most regions and models. In the transport sector, where low-carbon alternatives are limited, energy savings generally contribute more to emissions reduction than fuel switching throughout the century.

A challenge for sufficiently rapid low-carbon energy deployment is the possible lock-in of carbon-intensive infrastructure. As long as policies are not stringent enough to prevent the addition of further long-lived carbon-intensive power plants and infrastructure, the sunk costs of such investments make it more costly to switch to low-carbon alternatives and may cause delays in emission reductions. Until a global climate policy agreement has been reached that provides a clear signal for low-carbon investments, it is the role of national policies to diminish carbon lock-in. In those developing countries where energy policies offer only a weak, if any, signal for low-carbon investment in the near term, international assistance may be warranted to help incentivize such investments and thus prevent problematic carbon lock-in.

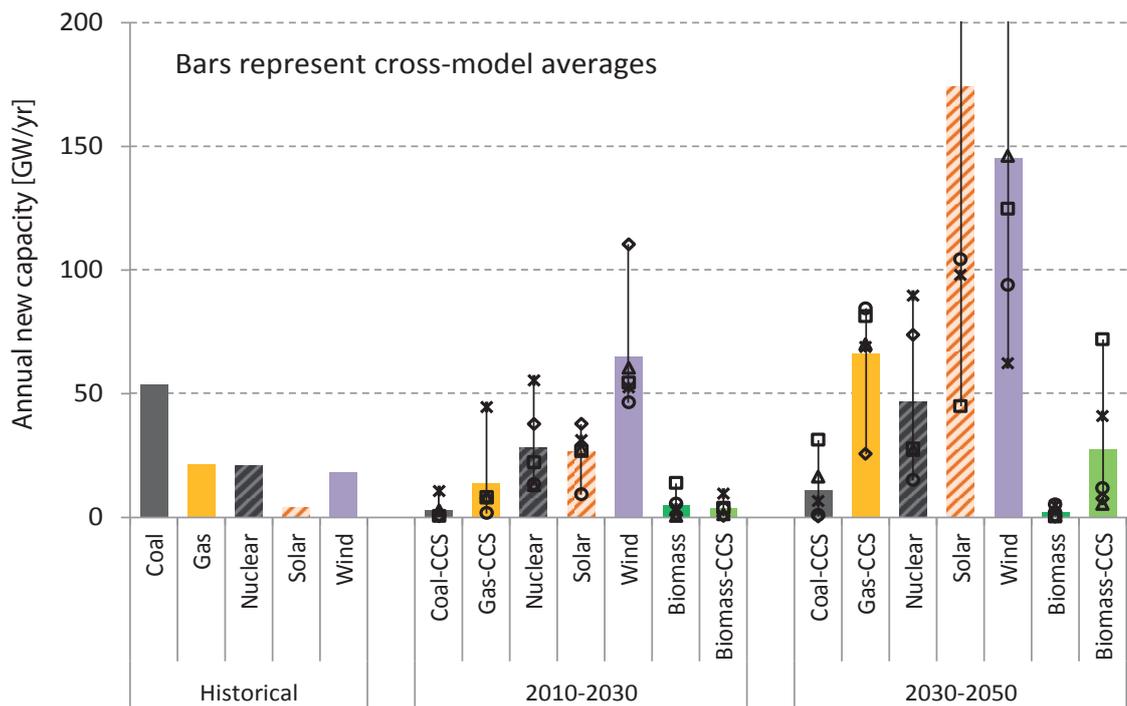


Figure 3: Average annual capacity additions (history and short- to medium-term future) for various fossil-based and low-carbon energy technologies in the 2°C 450 ppm scenario. Historical data correspond to 2000-2010, except for nuclear energy (1980-1990). For solar and wind, the data points from one model fall outside the scale of the figure: 400 and 300 GW/yr for solar and wind respectively.

### 1.2.3 Technological breakthroughs are needed for full decarbonization

Although the deployment of already existing technologies may go a long way toward decarbonization, technical challenges related to upscaling renewables, developing carbon-capture and storage (CCS), and achieving high energy efficiency levels call for further technological breakthroughs. In particular, research and development (R&D) is needed in order to develop carbon-free alternatives in sectors which are difficult to decarbonize, such as the transportation sector with its strong reliance on liquid fuels.

Limiting end-of-century CO<sub>2e</sub> concentrations to levels consistent with a 2°C target – around 450 ppm or 500 ppm – requires that global CO<sub>2</sub> emissions are reduced to zero by the third quarter of the century. To compensate for remaining CO<sub>2</sub> emissions in the sectors that are most difficult to decarbonize and for some of the other greenhouse gases that may be impossible to fully eliminate, it may be necessary to achieve negative emissions where possible. Thus, the deployment of negative emissions technologies is a key contributor to 2°C emission pathways in the LIMITS scenarios. Conceivable techniques to achieve negative emissions may include afforestation or direct air capture among other options. In the LIMITS models, a central option for generating the needed volume of negative emissions is the combination of biomass combustion with carbon capture and storage (BECCS), which places the carbon that plants remove from the atmosphere into geological reservoirs. The LIMITS models estimated cumulative carbon dioxide removal from the atmosphere by use of BECCS in the range of 400 to 850 GtCO<sub>2</sub> over the period 2011-2100 (see Figure 4). The feasibility of achieving large volumes of negative emissions is uncertain and would require considerable R&D efforts. For instance, a condition for the large-scale deployment of BECCS would be an improvement in the land management sustainability of large-scale bioenergy use and the development of reliable CCS systems to effectively store carbon underground.

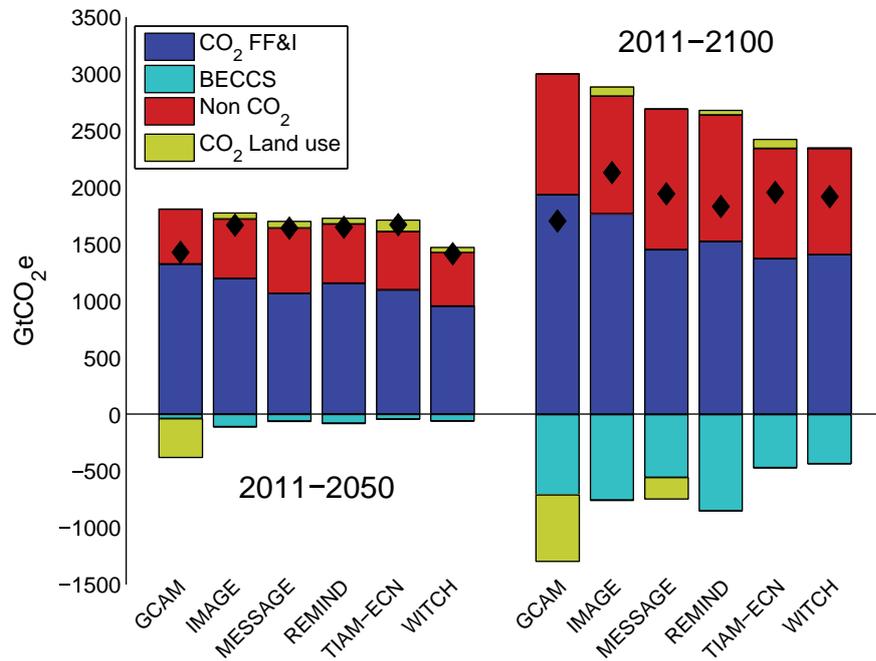


Figure 4: Cumulative global Kyoto gas emissions over the periods 2011-2050 and 2011-2100 broken down into individual sectors. The black diamonds show net total cumulative emissions.

It is important that R&D investments in breakthroughs for low-carbon fuels and negative emission technologies are made in the near future, so that the relevant options are available once the emissions budget is depleted and carbon-free energy is needed throughout the economy. In the area of energy efficiency improvements, on the other hand, where continuous incremental improvements can be expected, R&D investments may benefit from a more gradual and sustained rise. A LIMITS study based on the WITCH model finds that the R&D investments in low-carbon energy and energy efficiency advancements needed for a 2°C pathway are at the order of US\$50 billion per year until 2050. This would be approximately 4-5 times the annual average public investments in clean energy in IEA member states over the last two decades.

## 2. Regional mitigation pathways

In the previous section, we have shown that, although challenging, it is still possible to achieve the 2°C target if emissions are reduced rapidly in the decades after 2020. Given that climate policies require national and regional action, the most important challenge of the Durban Platform is to ensure that stringent climate policies are implemented in large GHG-emitting countries and regions shortly after 2020.

### 2.1 National near-term climate policies are an important early step

#### 2.1.1 Near-term policies can provide important impetus for long-term action

Despite their limitations, current near-term policies of limited geographical scope can provide very important bridges towards more comprehensive efforts. Although their contribution to the needed emission reductions may be relatively small, national near-term policies until 2020 can play a significant role by preparing economies for stronger action beyond 2020. Near-term emission reductions from national policies may bring the emissions trend closer to the required long-term trend, thus limiting the carbon lock-in and easing the transition to a pathway toward 2°C. Figure 5 compares the emission pathways associated with national policies in the reference case with no-policy pathways and 2°C pathways. In those regions where the reference case shows significantly lower near-term emissions than the no-policy case – above all in the EU – near-term policies are a significant early step toward more stringent policies that could achieve the 2°C target.

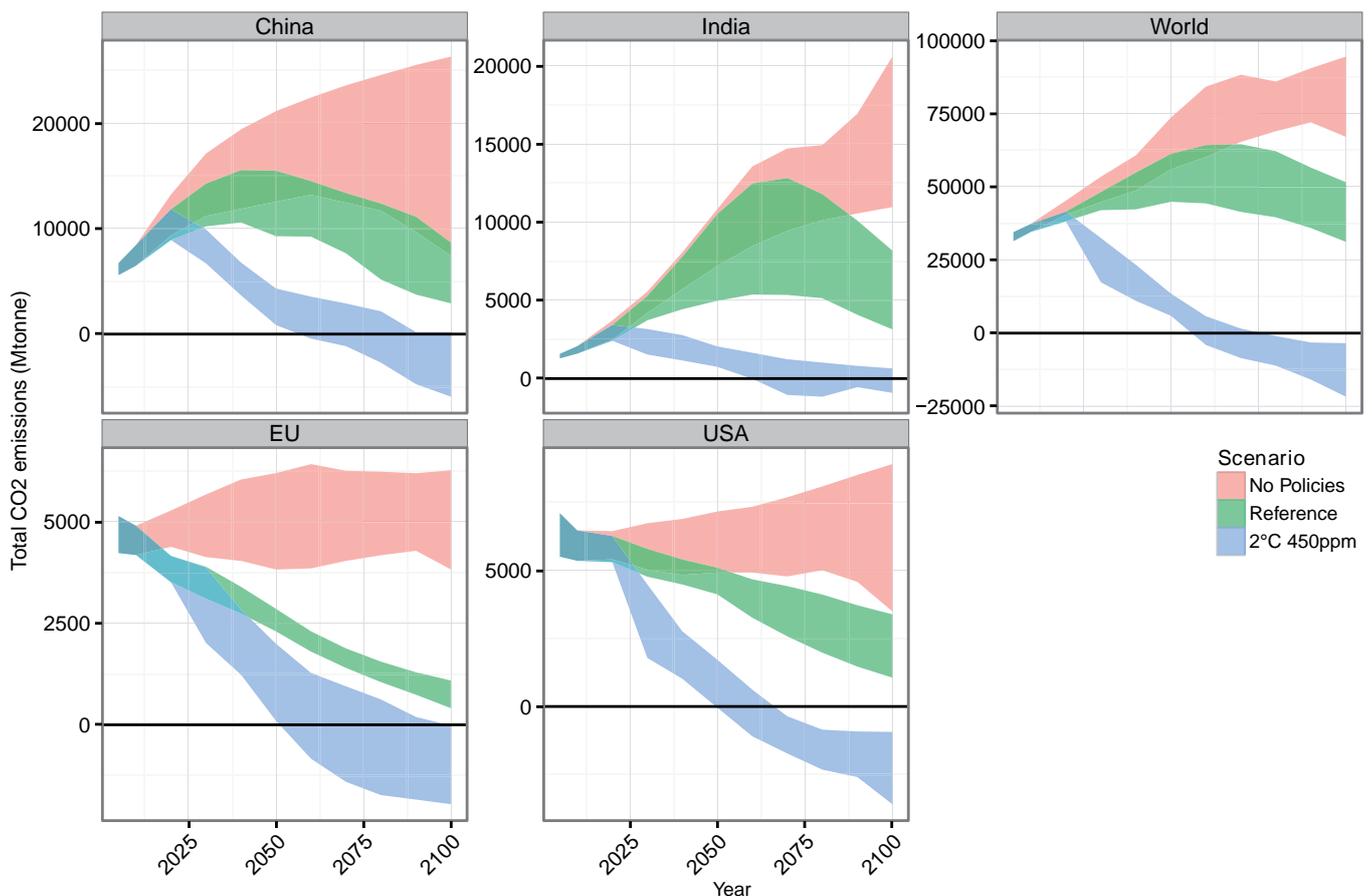


Figure 5: Regional CO<sub>2</sub> emission paths in scenarios with no policies, with reference policies reflecting the Copenhagen Pledges and their extension, and under a global climate policy agreement implemented after 2020.

If countries fulfil their Copenhagen Pledges, the emissions intensity of the world economy will improve faster than the historical trend: by about 2% to 3% per year based on the LIMITS models compared to 1% per year in 2005-2010. For a cost-efficient pathway toward the 2°C target, global average emissions intensity improvements have to progress further: to about about 5% or more per year over the 2020s. The size of the gap between near-term emission trends and what is required in the medium term can be reduced by effective near-term climate policies.

### 2.1.2 The 2°C target calls for actions by all world regions within the coming decade

Without explicit mitigation policies, models project emissions to increase until very late in the century in essentially all regions. This result is based on the expectation of continued economic growth and availability of fossil fuels. The reference policies scenario would lead to earlier peak years in several major economies depending on the stringency of the commitments, but in other regions emissions would continue to grow well into the second half of the century (see Figure 6). If, on the other hand, the Durban Platform results in a global climate agreement to meet the 2°C target, emissions would have to peak and decline much sooner. The results show that for atmospheric GHG concentrations of 450 ppm CO<sub>2</sub>e, such a pathway requires emission reductions in the early 2020s in all world regions, in sharp contrast to the dispersed picture resulting from the no policies and reference cases. A pathway to 500 ppm CO<sub>2</sub>e, would give the option of some leeway for an emissions break by the 2030s in a few regions with the greatest economic difficulties to cut back emissions. It should be be noted that Figure 6 only shows where emission reductions are achieved: the costs of these reductions may be shared via flexible instruments.

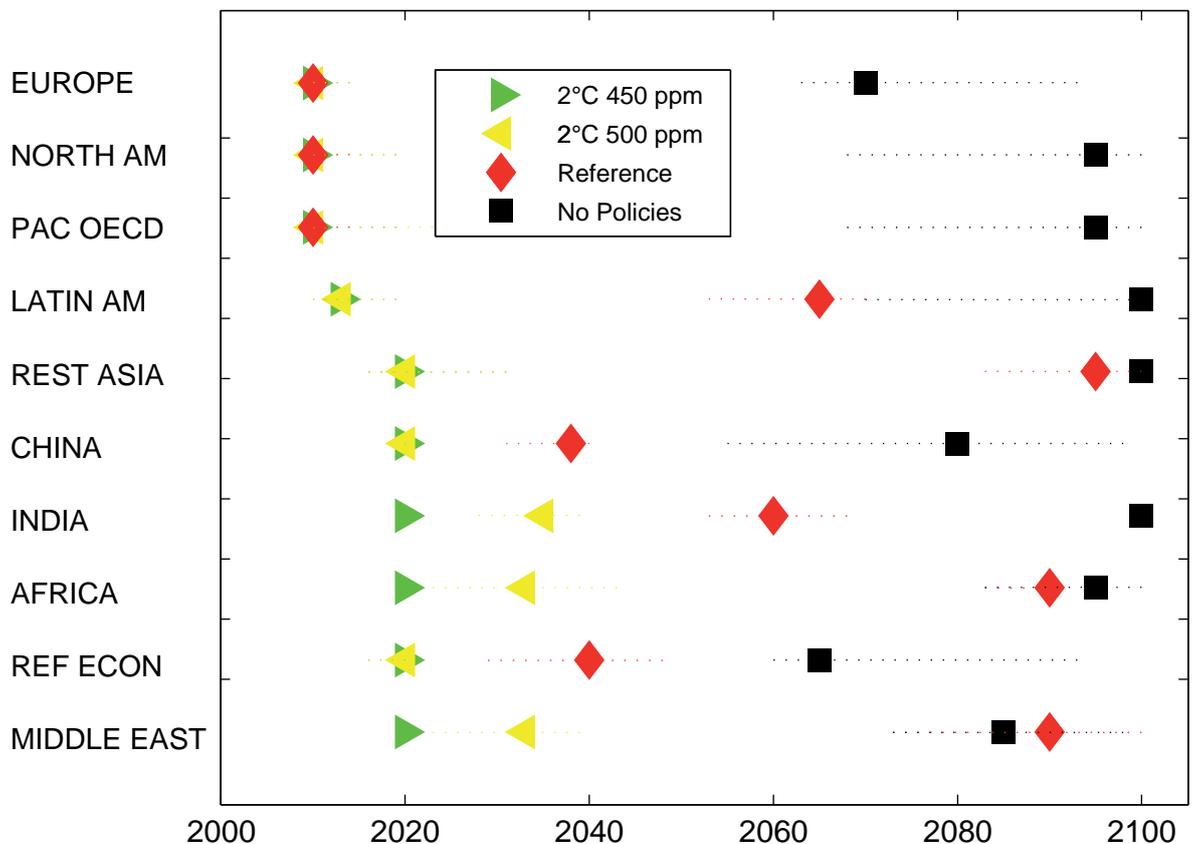


Figure 6: Peak year of regional emissions (Kyoto gases, median across models indicated by markers, model range by dotted lines). “2100” denotes an increasing emissions trajectory throughout the 21st century until the end of the time horizon of the models. Model time step is typically 5 to 10 years. “PAC OECD” stands for Pacific OECD countries, “REF ECON” for the reforming economies in Eastern Europe (outside the EU) and the former Soviet Union.

### 2.1.3 A limit of 2°C would require a significant reduction of carbon budgets in all major economies

Figure 7 provides estimates of regional cumulative emission budgets from 2010 to 2100 as well as the historical contribution to emissions of the major economies. It indicates that in the No Policies and Reference scenarios, the emissions of major economies like China or OECD countries would by themselves exhaust the entire global carbon budget compatible with 2°C. This attests to the crucial importance of a comprehensive climate agreement if the 2°C target is to be met. A limit of 2°C would require a significant reduction of carbon budgets in all major economies. The regional budgets for 2°C scenarios shown in Figure 7 assume a cost-efficient distribution of global mitigation efforts. However, there is considerable uncertainty about the cost-effective regional split of emission budgets as it depends on, inter alia, baseline emissions, regional mitigation potentials, and terms of trade effects, all of which can vary substantially across models and regions.

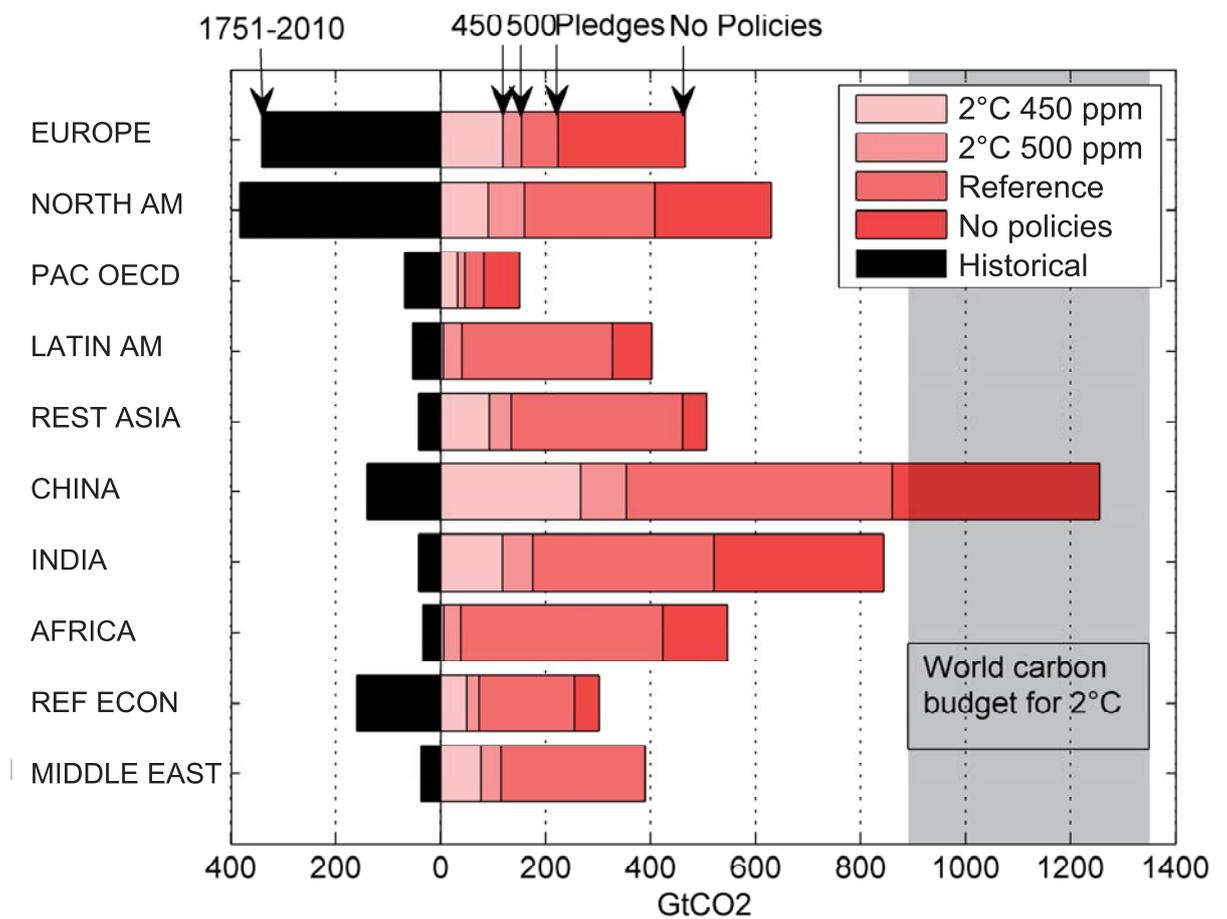


Figure 7. Regional carbon budgets, as cumulative CO<sub>2</sub> emissions for the period 2010-2100. All numbers are median values across models. Historical emissions are for the period 1751-2010. The shaded area shows the World carbon budget range for 2°C policies (450 ppm or 500 ppm) based on the model medians. "PAC OECD" stands for Pacific OECD countries, "REF ECON" for the reforming economies in Eastern Europe (outside the EU) and the former Soviet Union.

As discussed in Section 1.2.3, keeping cumulative global emissions within a 2°C carbon budget likely requires negative CO<sub>2</sub> emissions in the second half of the century. The potential for negative emissions varies by region (see Figure 5), depending on trends in emission drivers, technological capabilities, and the availability of carbon storage sites.

## **2.2 The potential for mitigation options differs among regions**

### ***2.2.1 Regional characteristics imply different mitigation patterns***

Many factors determine regional mitigation pathways, such as the differences in energy resource endowments, existing infrastructure, technological capabilities, and energy demand trends, as well as differences in national energy and climate policies. Progress toward a global climate policy regime may harmonize regional policies somewhat, but the other factors would remain.

Several deployment patterns can be extracted from the LIMITS models for four major economies (China, India, the European Union, and the United States) under the constraints of a 2°C scenario. In all regions, the electricity sector has the strongest abatement potential. Here, carbon neutrality can be achieved by mid-century with a variety of technology options. Figure 8 shows more specific regional deployment patterns in the electricity sector, both in the reference case and under 2°C constraints. Several observations can be made from the data shown in Figure 8 and from other LIMITS data:

- Although the configurations differ across models, in nearly all regions, the share of non-biomass renewable energy in electricity production increases two- to three-fold. The expansion of renewable energy is most dramatic in China, which becomes the largest user of non-biomass renewable energy by the late 2020s, overtaking the United States.
- Models differ in the relevance they assign to nuclear power. On average, nuclear energy use increases only moderately in all regions except China, where nuclear power grows most strongly in response to climate policy.
- After 2030, the use of CCS is important in all regions as a decarbonization strategy for the remaining fossil fuel use and as an option for negative emissions through BECCS. In India and other emerging economies, CCS plays an important role in allowing continued use of coal in order to satisfy growing energy needs. BECCS is expected to find application predominantly in the USA, China and the EU due to the combination of technological capabilities and access to biomass feedstock.

Among end-use sectors, significant mitigation potential may be found in the industry sector, particularly in emerging regions like China and India. In economically more advanced regions with higher motorization rates, such as the EU and US, abatement in the transportation sector becomes increasingly important, especially once other mitigation options have been exploited. According to most LIMITS models, abatement in the buildings sector is not as strong as in the industry and transportation sectors, although the high and increasing share of electricity use in buildings means that a decarbonized electricity sector can minimize buildings-related emissions. Overall, energy efficiency in end-use sectors is an important abatement strategy in all regions. The reduction of emissions from land-use does not play a major role in China, India, the US, and Europe, but holds significant mitigation potential in Latin America, Africa, and some regions of Asia. The reduction of non-CO<sub>2</sub> emissions can be considered a complementary response strategy that may contribute 10-20% to overall abatement.

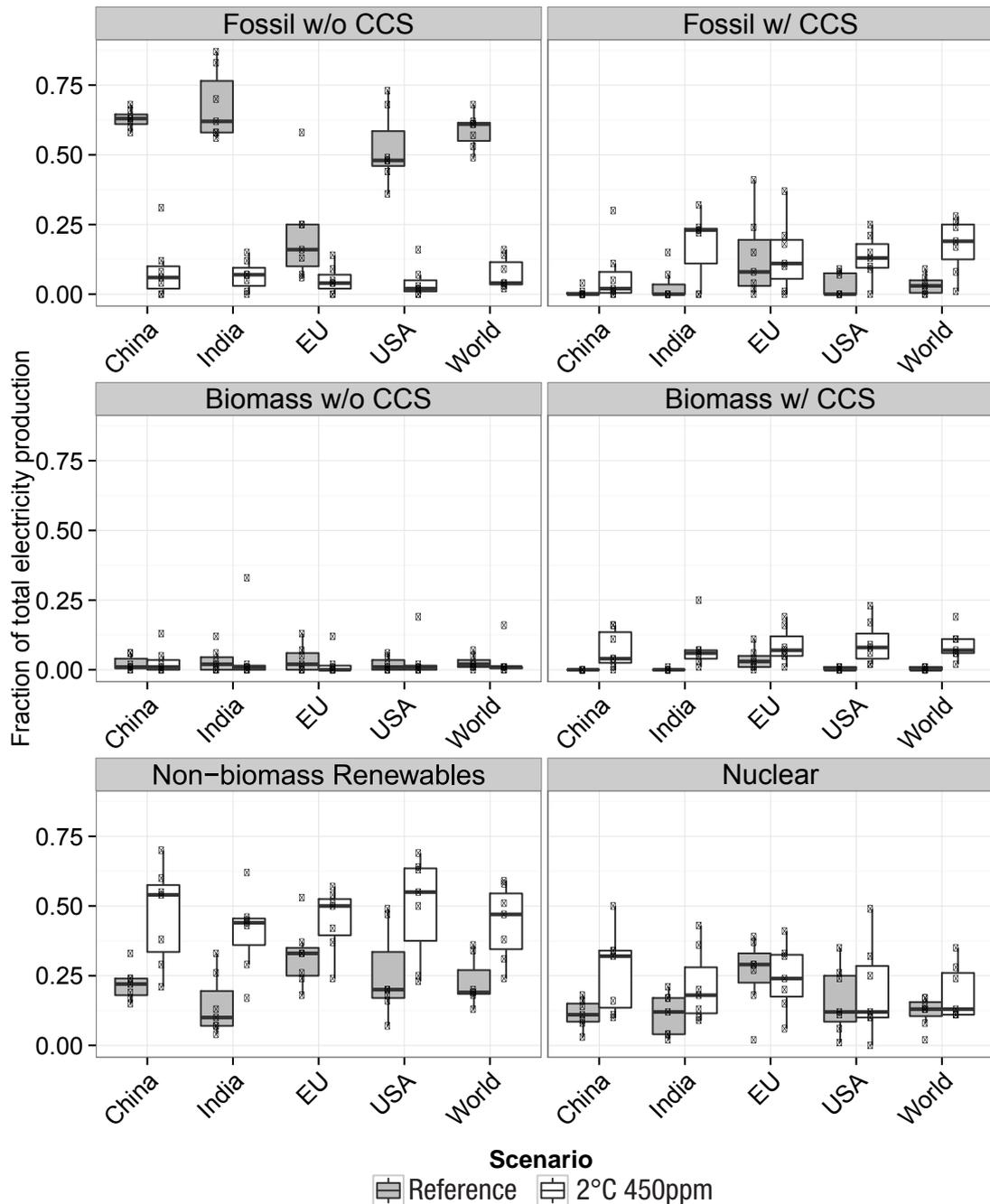


Figure 8: Fraction of electricity production for major and upcoming regions in 2050 in the Reference and 2°C 450 ppm scenarios. Non-biomass renewables consist of photovoltaics, concentrated solar power, onshore and offshore wind, and hydropower. CCS stands for carbon capture and storage.

### 2.2.2 China, India and Brazil may play important roles in achieving the 2°C target

Figure 7 showed the very significant role of non-Annex I regions (Asian countries, Latin America, Africa, and the Middle East) with regards to global emission reductions – simply based on the size of their expected future emissions in the absence of climate policy. In order to obtain further insight into the emission reductions in some of these regions, LIMITS partners compared the results from global models with those based on national models. These studies confirmed that the results from global and national models are largely consistent: Reducing emissions to a level that could keep a global temperature rise by 2100 under 2°C was not only found technologically feasible at the global level but also at the level of specific regions and countries. However, the studies also confirmed the large gap between current plans and the level of ambition that would be needed to follow a 2°C pathway.

**India:** Both the global and regional models in the Indian study showed that coal will remain the mainstay of the Indian energy system under the no-policy scenario even by the end of the century. Coal is the most important domestic resource and is available at rather low costs. Future coal use, however, is expected to be much cleaner than now. Results from all modelling teams indicate that Indian CO<sub>2</sub> emissions will not peak until 2100 under the no-policy scenario. To achieve peaking of Indian emissions by 2030, a minimum carbon tax of US\$150 per tonne would need to be imposed. To achieve an emissions peak by 2020, an immediate minimum carbon tax of US\$200 per ton CO<sub>2</sub>e is needed, along with expedited phasing-out of at least a third of coal-based energy infrastructure in the next ten years. The high level of investments in India also implies that ensuring the right infrastructure plays a key role here. For transport, this requires an integrated mobility plan with low-carbon transport at its core.

**China:** The study on China looked into a very stringent emission reduction strategy with emissions peaking in 2025 and declining by 70% until 2050. Such stringent policies could build upon the experience already obtained through current Chinese policies. For instance, China is already implementing caps on energy demand, together with targets for non-fossil fuel energy by 2020. China is also making significant progress in the implementation of provincial emission trading schemes.

**Brazil:** There is general agreement between the global and the regional models regarding the projected emission trends. Under current policies, energy-related CO<sub>2</sub> emissions are projected to increase 1.5-3.0% per year in Brazil and the whole Latin American region. In the 2°C 450 ppm scenario, CO<sub>2</sub> emission reductions in Brazil of 55%-87% below the Reference scenario are achieved by 2050. The implementation of CCS in combination with fossil fuels and bioenergy, as well as hydro, biomass and wind energy are identified as the most promising low-carbon options for the region, if technical, economic, environmental and social challenges can be overcome. Brazil is the first country in Latin America to adopt a national voluntary climate change mitigation goal by law. However, the assessment of the effectiveness of this goal is difficult due to the law's vague targets.

Further initiatives also exist in other countries. While at least half of global energy investments still flow into conventional fossil fuel energy infrastructure, a growing share of investment goes to renewable energy and energy efficiency –largely as a result of policy support. Such policies are not limited to industrialized countries. For instance, more than 40% of renewable energy investments in 2012 and 2013 were located in developing countries.<sup>3</sup> Most of this investment occurred in the large emerging economies of China, India, and Brazil, with a significant share of the capital sourced domestically.

<sup>3</sup> Frankfurt School – UNEP Centre / BNEF (2014), *Global Trends in Renewable Energy Investment 2014*, Frankfurt, Germany.

### 3. Sharing the mitigation burden among regions

#### 3.1 Global carbon pricing is efficient but poses distributional challenges

##### 3.1.1 Wide geographical policy coverage can help to keep stringent mitigation affordable

In the current fragmented climate policy landscape, mitigation efforts and carbon prices differ among the regions that have implemented such measures and are absent in others. This is not efficient and does in the long run risk disproportionately high mitigation costs for some regions and carbon leakage to other regions. To keep global emissions within the limited 2°C budget, it is crucial that all affordable mitigation opportunities are exploited, which can best be achieved by involving all countries and by equalizing the marginal mitigation costs through globally harmonized carbon pricing. A globally harmonized carbon price – established through either a harmonized carbon tax, an international emissions trading scheme, or a combination of such approaches – provides an incentive to exploit mitigation opportunities around the world with a marginal cost up to the carbon price. Without such a mechanism, affordable opportunities in some places would be left untapped while more expensive opportunities in other places would have to fill the gap.

##### 3.1.2 Developing countries will require the largest increase in low-carbon investment

The generally higher capital cost of low-carbon technologies will most likely increase the amount of total energy investment needed over the coming decades beyond the increase that is to be expected in the absence of climate policies. The upward pressure of clean energy and energy efficiency investments on overall energy sector investments is likely to more than outweigh the combined effect of disinvestments into fossil-based energy technologies and lower energy demand due to efficiency and conservation. By comparing the investments in the fragmented reference policy scenario that represents a continuation of current policies with the investments in a 2°C scenario, we can identify how large a “clean energy investment gap” needs to be filled so that sufficient investment flows into the decarbonization of the economy.

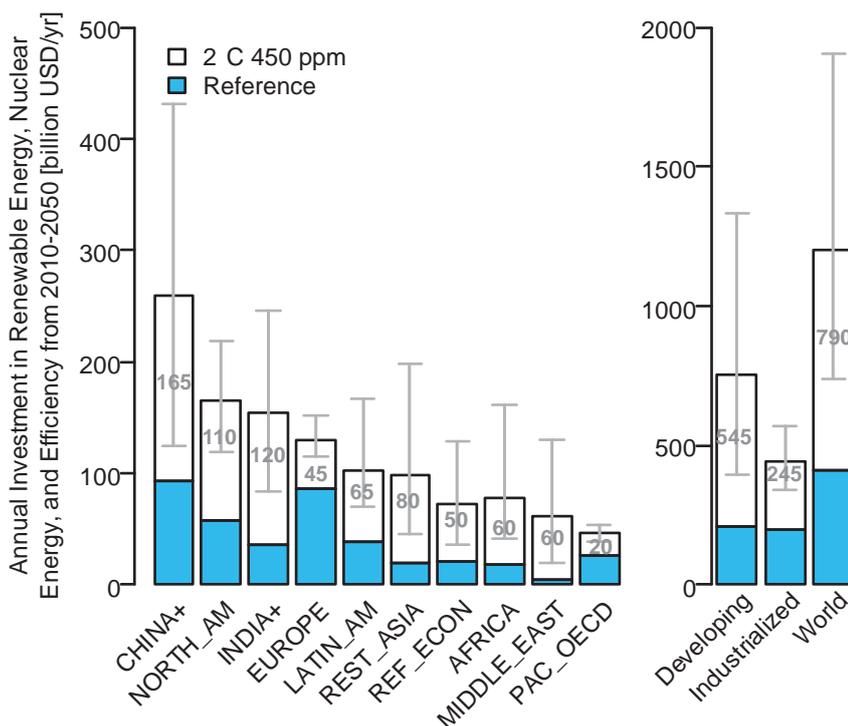


Figure 9: Clean-energy investment requirements in the Reference and 2°C 450 ppm scenarios. Investments include renewables and nuclear on the supply side and energy efficiency on the demand side. The difference between the scenarios (the white bars) represents a region’s “clean energy investment gap”; also indicated by the numbers in gray. The bars show the average across models, whereas the uncertainty bands depict the range of model results for the gap. Due to rounding, regional numbers may not sum exactly to developing, industrialized, and world totals. CHINA+ and INDIA+ can in some models include smaller economies neighbouring China and India. REF\_ECON stands for the reforming economies in Eastern Europe (outside the EU) and the former Soviet Union. PAC\_OECD stands for the Pacific OECD countries, primarily Japan, Australia, and New Zealand.

The findings of this section are largely based on Tavoni et al. (2013), McCollum et al. (2013), and Bowen et al. (2014).

Three observations can be gleaned from the suite of LIMITS models used to analyse the changing energy investments portfolio under climate policy:

- Energy demand grows fastest in developing countries and surpasses demand in industrialized countries between 2010 and 2050. Nevertheless, only about half of the clean energy and energy efficiency investment happens in developing countries in the reference case. Under stringent global climate policies, on the other hand, almost two-thirds of clean energy and energy efficiency investments occur in developing countries. The clean energy investment gap is thus largest in developing countries: about US\$550 billion per year between 2010 and 2050. Filling this gap would boost developing country clean energy investment from about US\$200 billion to about US\$750 billion per year (Figure 9).
- Climate policy shifts energy investment from upstream investments in fossil fuel extraction and refinement further downstream to low-carbon electricity generation, transmission, distribution, and storage, as well as to investment into energy efficiency. Energy efficiency investments constitute a significant share of global clean energy investment in the stringent climate policy case, and the largest portion of this occurs in developing countries.
- Stringent climate policies contribute to a dampening of energy investments in fossil fuel exporting countries, which remain around today's level despite worldwide increases in energy investments.

In addition to clean energy investment, stringent climate policies boost the demand for R&D efforts related to mitigation options. Based on a single-model study, clean energy and energy efficiency R&D should increase by the order of US\$50 billion per year.

The aggregate regional incremental clean energy investment need is well within the range of past regional variations in investment volumes. In some regions, the incremental clean energy investment needs are lower than the current fossil fuel subsidies, and although other regions face a larger clean energy investment gap, the global shortfall is still of the same order of magnitude as current fossil fuel subsidies. The challenge of financing the transition to a 2°C path should thus not be insurmountable. It does, however, require credible and robust policy that gives investors sufficient confidence by signalling a commitment to mitigating climate change as well as an enabling institutional, financial, technical, and legal environment, especially in developing countries. A combination of policy mechanisms could be needed to attract the necessary investment capital, but the exact policy choices may depend on local and national circumstances. An essential component of effective global climate policy that could achieve a 2°C goal, however, is carbon pricing. The LIMITS models suggest that in theory, the revenue from carbon pricing in a 2°C scenario could provide sufficient cash to cover all investment needed for the energy transition. However, this depends on how countries choose to use the carbon pricing revenue and on the distributional arrangement among countries in a global climate policy regime.

### ***3.1.3 The economic impacts of mitigation efforts differ between regions***

Even though a globally harmonized carbon price equalizes the marginal mitigation costs around the world, it affects some economies more than others. Much low-cost mitigation potential exists in developing countries, which generally have higher carbon-intensities relative to economic output and have rapidly rising baseline emissions. Even though exploiting this potential improves the cost-efficiency of global mitigation, it places much of the mitigation burden on developing countries and results in high costs relative to the size of their economies. For Africa, India, or China, the cost resulting from a globally uniform carbon price as a share of economic output may be about 2-3 times that for the OECD countries.

Similarly, countries that rely on fossil fuel exports for much of their economic wealth bear disproportionate economic costs from global mitigation efforts due to reduced demand and depressed prices for their fossil fuel resources. The economic impact on those countries, including the fossil fuel exporters of the Middle East and of the former Soviet Union, is likely even higher than for most developing countries.

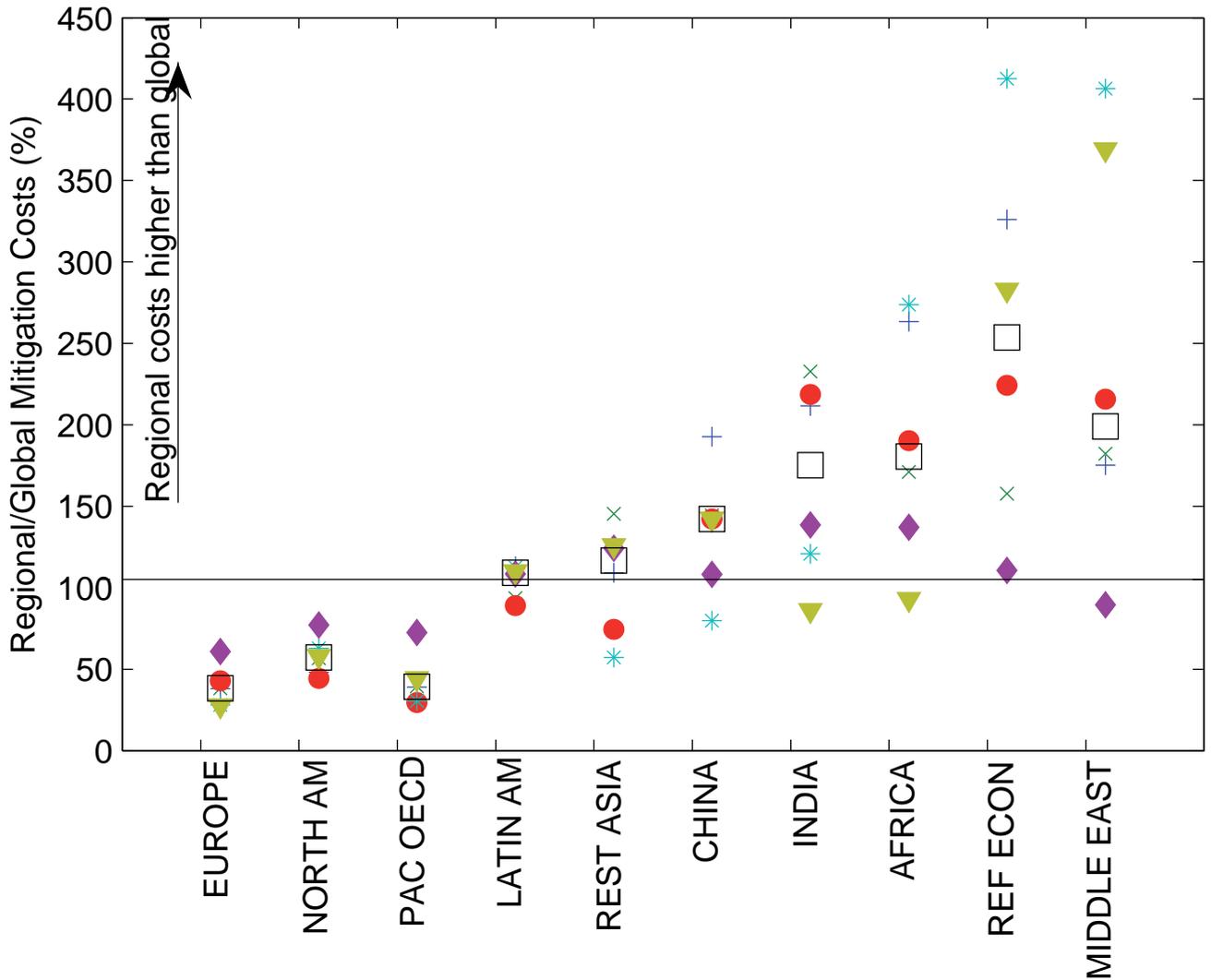


Figure 10: The distribution of regional policy costs relative to the global average under a harmonized global carbon price in the 2°C 450 ppm scenario. Costs are actualized in net present value from 2020 to 2100 using a 5% discount rate.

These uneven economic impacts pose a critical challenge: All significant emitters must participate for a global mitigation regime to achieve the 2°C target, but there are strong economic disincentives to participation for many of the countries with large mitigation potentials. To overcome this conundrum, a burden sharing arrangement would have to be found that allows all major emitters to participate in globally harmonized carbon pricing without exposing themselves to disproportionate economic impacts.

## **3.2 Regional differences call for burden sharing**

### ***3.2.1 Burden sharing can decouple where mitigation is pursued from who bears the cost***

It looks like a conflict between efficiency and equity: a globally uniform carbon price as an efficient mitigation solution would lead to uneven regional economic impacts. However, in theory at least, this conflict can be solved. The question of where emissions are reduced can be decoupled from the question of who bears the cost, thus separating the issues of efficiency and equity. A globally harmonized carbon price does not preclude burden sharing through financial flows between countries based on direct assistance, carbon markets, or other mechanisms.

A multitude of burden sharing options are conceivable, including attempts to take into account historical responsibility, technical and economic capabilities, population, lost revenue, or other factors. Since participation by at least all major emitters is critical for meeting the 2°C target, a successful burden sharing approach would have to be acceptable to countries with diverse economic and political conditions. Burden sharing at a global scale would have to involve arrangements that go beyond bilateral assistance and could, for instance, involve financial assistance mechanisms based on multilateral funds – such as the Green Climate Fund established by the UNFCCC in 2011, for which industrialized countries pledged to provide the yearly sum of US\$100 billion by 2020. Such funds could help developing countries finance mitigation and adaptation measures. Another prominent option is burden sharing through global emissions trading, in which financial flows are based on the supply of and demand for allowances instead of a donor-recipient relationship.

### ***3.2.2 Assistance with financing can reduce investment challenges for poor countries***

Climate finance through the Green Climate Fund or other mechanisms may in the coming decades channel substantial financial resources to developing countries with the purpose of supporting mitigation and adaptation investment. If historical experience is a guide, emerging economies with stronger financial markets may be able to relatively easily finance the incremental cost of low-carbon energy supply through domestic savings as long as the necessary capital can be mobilized in the face of competing demands for capital. On the other hand, financial assistance from developed nations can be critical for unlocking mitigation potential in poorer countries with underdeveloped financial markets, particularly in Africa.

In stringent climate mitigation scenarios, poorer developing countries have particularly high incremental energy investment needs relative to the size of their economies. These countries are less able to finance incremental investments through increases in domestic savings. The financial resources agreed on by industrialized countries at the UNFCCC summit in Copenhagen may help to cover these incremental investment needs, depending on whether their annual volume increases with the increasing needs after the year 2020. However, it must be noted that covering the incremental investment costs does not amount to covering the full cost of climate change mitigation in developing countries. The LIMITS results suggest that the full mitigation costs are likely to be substantially larger than incremental aggregate investment needs and are not necessarily incurred in the sectors in which most of the additional investment takes place. The international community has not yet agreed on how to determine the full incremental costs that are to be covered by the Green Climate Fund, but if the full GDP impact of mitigation policies is taken as the basis, the costs are higher than if only the incremental investment costs are accounted for. If the international community intends to share the full economic burden of mitigation – and possibly also the burden of adaptation – emissions trading schemes as discussed below may provide an instrument for doing so.

### **3.2.3 International emissions trading can be designed for burden sharing based on equity principles**

Emissions trading schemes can be designed for burden sharing while keeping intact the efficiency of harmonized carbon pricing. The valuable emission allowances in an emissions trading scheme can be distributed according to equity principles or other considerations that help address the concerns of countries that would otherwise bear disproportionate mitigation costs. In a global allowance market, the allowance price would be the same across countries independent of how the allowances are distributed.

To illustrate the possible implications of burden sharing through emissions trading, LIMITS has examined two examples of possible approaches. These are by no means the only perceivable ways to share the mitigation burden, but they allow us to assess important regional and institutional effects of burden sharing based on two distinct principles:

- **Equal per-capita emission rights** based on egalitarian equity principles can be achieved by allocating emission allowances based on countries' populations. While this approach can be seen as fair from the perspective of recognizing the equal value of each human, it does not take into account that the regional cost of mitigation does not necessarily relate to the size of the regional population. Since an immediate per-capita allocation would lead to vast imbalances in the regional supply and demand for allowances, the per-capita approach assessed by LIMITS assumes that the allocation of allowances starts from the status quo and converges to an equal per-capita allocation by 2050 while the global amount of allowances is reduced in line with the 2°C target.
- **Equalized mitigation efforts** can be the goal of attempts to allocate allowances such that each region's costs relative to GDP equal the global average. This approach accounts for regional differences in the burden of mitigation and economic capacity but does not specifically favor regions with lower per-capita emissions.

In the per-capita scheme, permits are sold mostly by countries with rapidly growing populations and low per-capita emissions; primarily India and African countries. In the equal effort scheme, most non-OECD countries are among the sellers. In both schemes, the OECD countries are buyers, whereas oil-producing countries in the Middle East and possibly China are among the buyers in the per-capita scheme but are sellers in the equal effort scheme. A robust result of the LIMITS analysis is that while the per-capita scheme reduces disparities in regional mitigation effort, even after allowance trading it still shows higher mitigation costs for developing countries, particularly China and oil-producing countries. By offering China and the Middle East a greater amount of allowances compared to the per-capita approach, the equal effort approach may be more politically feasible. However, it would be very challenging to determine what allocation of allowances would indeed satisfy the principle of equal effort. The equal effort scenario assessed in LIMITS thus represents a highly stylized case of burden sharing that nonetheless provides insights into the implications of a burden sharing regime in which all parties have negotiated for allowance shares that do not leave them with a disproportionate mitigation burden.

For many regions in the developing world, both the per-capita and the equal effort scheme would provide annual financial flows from carbon trade that are at least on the same order of magnitude as the total incremental investment requirements for the transition to a 2°C pathway (see Figure 11). While this could greatly facilitate clean energy investments in developing countries, ensuring the efficient use of such substantial financial resources poses an institutional challenge.

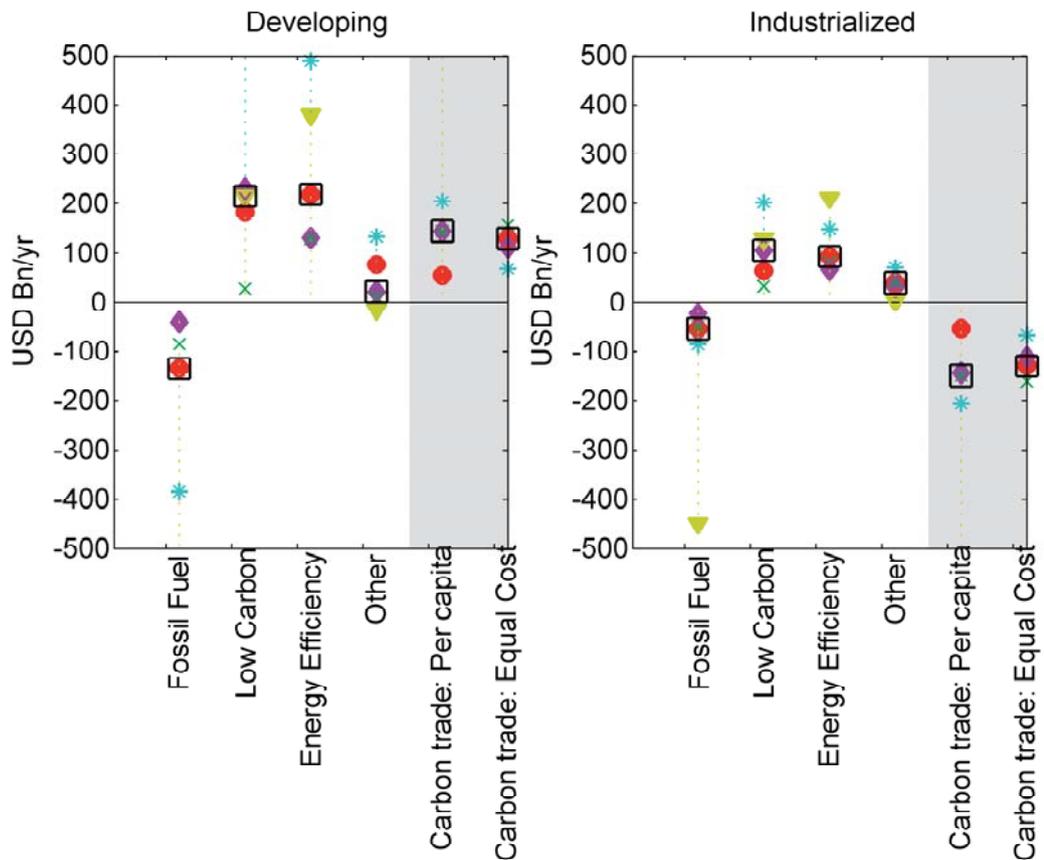


Figure 11: Additional annual investment for different sectors in developing and industrialized countries in the 2°C 450 ppm scenario relative to the Reference scenario. Different markers show results from different models. The amounts shown are USD billion/yr (average over the period 2010-2050; no discounting). The two shaded columns on the right side of each box report trade of CO<sub>2</sub> permits (positive values indicate selling) for the two burden sharing regimes discussed in subsection 3.2.3.

### 3.2.4 Global burden sharing poses a major institutional challenge

If global burden sharing is to address much of the distributional impacts of global climate policy, the traded carbon allowances or financial and technical assistance would have to reach a very substantial value. Ensuring the smooth operation of such substantial burden sharing mechanisms and preventing misuse of the associated financial flows poses a major institutional challenge.

In both the per-capita and the effort equal effort scheme, the annual value of traded emission allowances may run into hundreds of billions of dollars by 2030 (Figure 12). The total value of these allowances is a function of the traded volumes and the allowance price. Although the overall amount of emissions is ratcheted down through the climate policy regime, the discrepancy between the allocated regional allowances and the regional mitigation opportunities is likely to remain strong, thus sustaining the demand for traded allowances. The allowance price increases over time due to the increase in marginal abatement cost. Thus, the overall value of the international carbon trade is likely to further increase until 2050 and may grow to surpass the value of the international energy trade. Models differ on whether the per-capita or the equal effort approach would result in greater values traded in the international carbon market, but on average the value of traded emissions until 2050 is higher in the per-capita scheme.

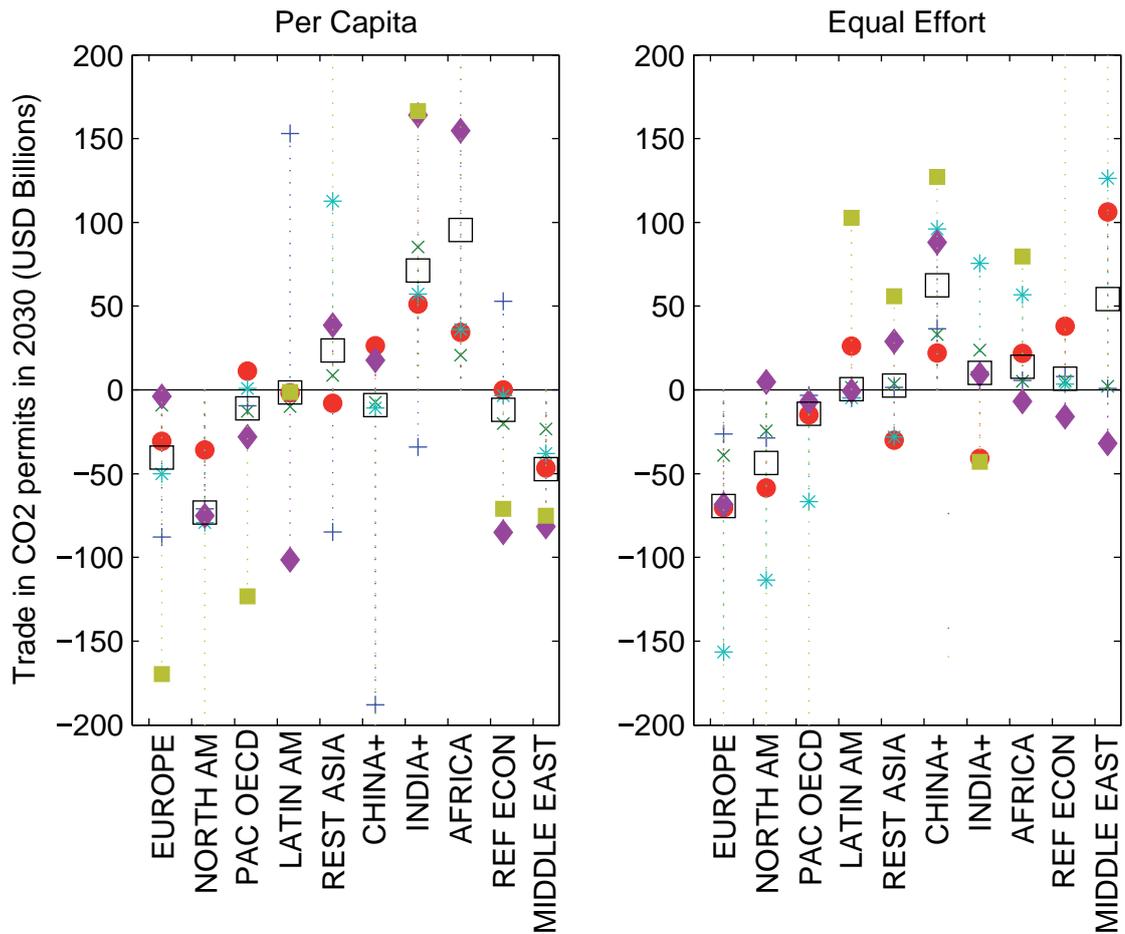


Figure 12: Regional trade flows of GHG emission permits in 2030 for the per-capita and equal effort burden sharing schemes (positive = selling, negative = buying). Different markers show results from different models.

The emergence of emission allowances as a major revenue source for countries with excess allowances could have profound economic and social repercussions – such as Dutch disease and corruption – and would require the existence of strong property rights and institutions. The stability of the international carbon market requires strong global institutions, whereas the domestic use of carbon market revenue is a matter of national institutions. The level of carbon pricing needed to achieve the 2°C target may generate revenue that amounts to several percent of gross world product over the decades after its introduction. Even under very stringent climate policies, carbon pricing revenue would lie well within the bounds of revenue that governments are used to handling, given that in 2010, governments revenues amounted to 36% of GDP in industrialized and 27% of GDP in developing countries. Implementing such carbon pricing is politically challenging, as it would most likely meet resistance by affected interest groups. However, it does not have to increase the overall burden on the private sector if tax rates elsewhere in the economy are reduced in turn – which could potentially reduce the institutional challenge of tax evasion in other sectors and increase productivity by reducing fiscal disincentives to the efficient allocation of factors of production.

## LIMITS publications

### LIMITS SPECIAL ISSUE on Durban Platform scenarios

Climate Change Economics, November 2013, Vol. 04/Issue 04:

E. Kriegler, M. Tavoni, T. Aboumahboub, G. Luderer, K. Calvin, G. De Maere, V. Krey, K. Riahi, H. Rosler, M. Schaeffer, D. van Vuuren: **What does the 2°C target imply for a global climate agreement in 2020? The LIMITS study on Durban Platform scenarios.** DOI: 10.1142/S2010007813400083.

M. Tavoni, E. Kriegler, T. Aboumahboub, K. Calvin, G. De Maere, J. Jewell, T. Kober, P. Lucas, G. Luderer, D. McCollum, G. Marangoni, K. Riahi, D. van Vuuren: **The distribution of the major economies' effort in the Durban platform scenarios.** DOI: 10.1142/S2010007813400095.

D. McCollum, Y. Nagai, K. Riahi, G. Marangoni, K. Calvin, R. Pietzcker, J. van Vliet, B. van der Zwaan: **Energy investments under climate policy: a comparison of global models.** DOI: 10.1142/S2010007813400101.

J. Jewell, A. Cherp, V. Vinichenko, N. Bauer, T. Kober, D. McCollum, D. van Vuuren, B. van der Zwaan: **Energy security of China, India, the E.U. and the U.S. under long-term scenarios: Results from six IAMs.** DOI: 10.1142/S2010007813400113.

M. van Sluisveld, D. Gernaat, S. Ashina, K. Calvin, A. Garg, M. Isaac, P. Lucas, I. Mouratiadou, S. Otto, S. Rao, P. Shukla, J. van Vliet, D. van Vuuren: **A multi-model analysis of post-2020 mitigation efforts of five major economies.** DOI: 10.1142/S2010007813400125.

B. van der Zwaan, H. Rösler, T. Kober, T. Aboumahboub, K. Calvin, D. Gernaat, G. Marangoni and D. McCollum: **A Cross-Model Comparison of Global Long-Term Technology Diffusion under a 2°C Climate Change Control Target.** DOI: 10.1142/S2010007813400137.

K. Calvin, M. Wise, D. Klein, D. McCollum, M. Tavoni, B. van der Zwaan, D. van Vuuren: **A multi-model analysis of the regional and sectoral roles of bioenergy in near- and long-term CO2 emissions reduction.** DOI: 10.1142/S2010007813400149.

Climate Change Economics, February 2014, Vol. 05/Issue 01:

T. Kober, B. van der Zwaan, H. Rösler: **Emission Certificate Trade and Costs under Regional Burden-Sharing Regimes for a 2°C Climate Change Control Target.** DOI: 10.1142/S2010007814400016.

T. Aboumahboub, G. Luderer, E. Kriegler, M. Leimbach, N. Bauer, M. Pehl, L. Baumstark: **On the regional distribution of climate mitigation costs: the impact of delayed cooperative action.** DOI: 10.1142/S2010007814400028.

G. Marangoni, M. Tavoni: **The clean energy R&D strategy for 2°C.** DOI: 10.1142/S201000781440003X.

I. Staub-Kaminski, A. Zimmer, M. Jakob, R. Marschinski: **Climate Policy in Practice: A Typology of Obstacles and Implications for Integrated Assessment Modeling.** DOI: 10.1142/S2010007814400041.

A. Bowen, E. Campiglio, M. Tavoni: **A macroeconomic perspective on climate change mitigation: Meeting the financing challenge**. DOI: 10.1142/S2010007814400053.

### Reports

A. Garg, P.R. Shukla, B. Kankal, 2014: **India Report: Alternate development pathways for India: aligning Copenhagen climate change commitments with national energy security and economic development**. Indian Institute of Management.

### Further Peer Reviewed Publications

F. Humpenöder, A. Popp, J.P. Dietrich, D. Klein, H. Lotze-Campen, M. Bonsch, B. L. Bodirsky, I. Weindl, M. Stevanovic, C. Müller, 2014: **Investigating afforestation and bioenergy CCS as climate change mitigation strategies**, Vol. 9/Issue 6, Pages 064029, Environmental Research Letters. DOI:10.1088/1748-9326/9/6/064029.

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G.C.K. Leung, A. Cherp, J. Jewell, Y. Wei. 2014. **Securitization of Energy Supply Chains in China**. Applied Energy 123 (June): 316–26. DOI: 10.1016/j.apenergy.2013.12.016.

K. Jiang, H. Chenmin et al.: **China's Emission Scenario toward global 2 degree target**, 2012, Pages 16-19, Energy of China.

K. Jiang, X. Zhuang, R. Miao and H. Chenmin: **China's Role in Attaining the Global 2 Target**, Volume 13, Supplement 01, 2013, Climate Policy. DOI: 10.1080/14693062.2012.746070.

### Working Papers

E.Campiglio: **Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy**, Working Paper 11.06.2014, London School of Economics and political science.

F.Sferra and M. Tavoni: **Endogenous Participation in a Partial Climate Agreement with Open Entry: A Numerical Assessment**, Nota di Lavoro 60.2013, Fondazione Eni Enrico Mattei.