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SPECIAL ISSUE

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The LIMITS study on Durban Platform scenarios

Abstract

This paper provides a novel and comprehensive model-based assessment of possible outcomes of the Durban Platform negotiations with a focus on emissions reduction requirements, the consistency with the 2°C target and global economic impacts. The Durban Platform scenarios investigated in the LIMITS study—all assuming the implementation of comprehensive global emission reductions after 2020, but assuming different 2020 emission reduction levels as well as different long-term concentration targets—exhibit a probability of exceeding the 2°C limit of 20-41% when reaching 450 (450-480) ppm CO₂e, and 35-59% when reaching 500 (480-520) ppm CO₂e in 2100. Forcing and temperature show a peak and decline pattern for both targets. Consistency of the resulting temperature trajectory with the 2°C target is a societal choice, and may be based on the maximum exceedance probability at the time of the peak and the long run exceedance probability, e.g. in the year 2100. The challenges of implementing a long term target after a period of fragmented near-term climate policy can be significant as reflected in steep reductions of emissions intensity and transitional and long term economic impacts. In particular, the challenges of adopting the target are significantly higher in 2030 than in 2020, both in terms of required emissions intensity decline rates and economic impacts. We conclude that an agreement on comprehensive emissions reductions to be implemented from 2020 onwards has particular significance for meeting long term climate policy objectives.

Keywords: Climate Change, Climate Policy, 2 Degrees C target, Durban Platform, Integrated Assessment

1. Introduction

Climate change is a major challenge faced by human society (IPCC 2007; Stern 2007; World Bank 2012). While there is increasing recognition of this challenge around the world, there is also an increasing reluctance about enacting global climate policies in the near to medium term. This reflects the fact that international climate negotiations have made only slow progress, and a global climate treaty mandating comprehensive greenhouse gas emissions reductions has remained, so far, illusive. Although a series of climate policy measures were adopted in several world regions (UNEP 2012), global emissions have been rising over the last decade with only a small downturn in 2008-9 in the wake of the financial crisis (EDGAR 2011). National and international policy agendas are currently overwhelmed with economic crisis and other significant world developments. This has led to climate policy slipping down the global policy agenda, casting further doubt on the prospects of near-term success in enabling globally significant emissions reductions.

This paper provides an overview of 2°C scenarios that account for the fragmented nature of current mitigation efforts. They were tailored to represent a range of plausible outcomes of the on-going Durban Platform negotiations on a Post-2020 climate architecture. We use a set of seven energy-economy and integrated assessment models to perform an original assessment of possible Durban Platform outcomes, which elucidate the relation between near

term mitigation actions and the long term target of limiting warming to 2°C. The scenarios were produced in the context of the LIMITS project on the implementation of stringent stabilization pathways in major economies (<http://www.feem-project.net/limits/>). Durban Platform scenarios have so far not been investigated in a model intercomparison study. The value of such model intercomparisons consists in a thorough assessment of the robustness of results across models.

This article focuses on a high level assessment of the global economic and climate outcomes of the Durban Platform scenarios. Key questions are: What climate outcome can be achieved with stringent climate targets imposed from 2020 onwards?

What are the implications for emissions reduction requirements in various sectors and global economic costs? What significance does the stringency of near term action until 2020 have for implementing the 2°C pathways? And what happens if the Durban Platform negotiations fail, in which case it may be unlikely that renewed attempts can establish a global treaty before 2030?

The paper is structured as follows. Section 2 reviews the current status of the climate negotiations, and its implications for the 2°C target. Section 3 introduces and motivates the scenario setup of the study and summarizes the participating models. Section 4 describes the emissions pathways that emerge in the Durban Platform scenarios, and Section 5 the cumulative emissions and climate outcomes across models. Section 6 focuses on the economic impacts both in the shorter and longer term. Section 7 discusses the implications of our results and draws conclusions.

2. Climate negotiations, the 2°C target, and the analysis of long term mitigation targets

The failure of the Copenhagen Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) to reach an international climate agreement in 2009 sparked a backlash on multi-lateral climate action. The ensuing COPs in Cancun, Durban and Doha in the years 2010, 2011, and 2012, respectively, have tried to put the process back on track. The proposal of limiting global warming to 2°C above preindustrial levels was recognized as a guiding principle for the long-term objective of the UNFCCC to “avoid dangerous interference with the climate system” (UNFCCC 1992). It was initially laid down in the Copenhagen Accord (UNFCCC, 2009), but while the Accord was agreed upon by 141 countries by the end of 2012 including all major emitters, it was never adopted as a legally binding agreement under the UNFCCC. Elements of the Accord were brought under the roof of the UNFCCC in Cancun in 2010 (UNFCCC, 2010). This included the recognition of the 2°C target¹ as well as the Copenhagen pledges on 2020 emissions reduction targets made by 16 Annex I countries (UNFCCC Technical paper

¹ Decision 1/CP.16 “1.4 further recognizes that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity; also recognizes the need to consider, in the context of the first review, as referred to in paragraph 138 below, strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5 °C;” (UNFCCC, 2010).

2012). Several Non-Annex I countries also submitted Copenhagen pledges which – under the name of nationally appropriate mitigation actions (NAMAs) – are of voluntary nature.²

The Durban conference in 2011 established the Durban Platform for Enhanced Action as a new track for negotiating an international climate treaty. The track aims to establish an international climate treaty to enter into force in 2020 (UNFCCC 2011). It was reinforced by the Doha climate conference in 2012, which established a second commitment period of the Kyoto protocol until 2020 to be superseded by such a global climate treaty after 2020. Doha also closed down the concurrent long-term action track based on the Bali Action Roadmap that was originally set up to deliver a climate treaty at the Copenhagen conference. These developments will allow international negotiators to focus their efforts on the Durban Platform. Nevertheless, it is highly uncertain at this point if the Durban Platform will fare better than the Bali roadmap. A few key parameters like the recognition of the 2°C target, the inclusion of emerging economies in the discussion of legally binding targets, and a stronger focus on regional and national climate action have changed, but skepticism about the feasibility of a global climate treaty in the near to medium term remains. There is a perceived disconnect between the international recognition of the 2°C target, the modest nature of existing emissions reduction pledges until 2020 and the uncertainty about global cooperative action thereafter. This has invigorated the debate about the viability of adopting the 2°C target as a long term goal for climate mitigation. Several studies have claimed that the 2°C target is close to becoming out of reach (IEA 2011; Stocker 2012). Other studies have pointed to the gap between current ambition levels for the year 2020 and cost-effective mitigation pathways that are consistent with the 2°C targets (UNEP 2011; UNEP 2012, Höhne et al., 2012; Rogelj et al., 2012). Such studies need to be put into context of their notion of achievability and their assumptions about the 2°C target. There is no direct translation of the 2°C target into an emissions pathway. First, temperature responds with a time lag to the cumulative amount of greenhouse gases in the atmosphere, implying that different emissions profiles with comparable cumulative amounts of emissions can reach similar temperatures in the long run. Second, the amount of cumulative greenhouse gas emissions consistent with the 2°C target depends on assumptions about carbon cycle and climate response (Meinshausen et al. 2009) which are, inter alia, a function of the availability of negative emissions technologies in the long term (Van Vuuren and Riahi 2011).

Global coupled energy-economy-land use-climate models, so called integrated assessment models (Weyant et al. 1996), are used to assess the socio-economic implications of 2°C pathways. Such models have been deployed extensively in intercomparison projects to explore climate targets in the range of 450 to 550 ppm CO₂ equivalent (CO₂e) concentration of GHGs in the atmosphere (Clarke et al. 2009; Edenhofer et al. 2010; Luderer et al. 2012; Calvin et al. 2012; Kriegler et al. 2014c). Since a mitigation target of 450 ppm CO₂e (or equivalently a radiative forcing level³ of 2.6 W/m²), is found to be consistent with a likely (probability > 67%) achievement of the 2°C target (Meinshausen et al. 2011; Rogelj et al. 2013), those studies are relevant for assessing the implications of adopting the 2°C target. They show that under highly idealized assumptions about climate policy, including immediate and full cooperation of all regions and sectors in reducing emissions, full technology availability including negative emissions technologies, and no significant global market distortions pushing up the cost of climate policy implementation,

² Many pledges by Annex I and Non-Annex I countries are conditional on reciprocal action of others. See http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php for details.

³ An aggregate atmospheric greenhouse gas concentration is specified in terms of the CO₂ equivalent concentration that would lead to the same radiative forcing as the full collection of greenhouse gases. Thus, CO₂ equivalent concentration and radiative forcing are equivalent metrics.

mitigation pathways consistent with 2°C can be pursued at aggregated economic costs of a few percent of economic output and consumption, respectively.

While such idealized implementation scenarios are very useful as an analytical benchmark, they obviously will not materialize in this form. In the real world, institutional, societal and political constraints will be key determinants of available emission reductions both in the short and long-term. In this context, it is useful to consider the gap between projected emissions reductions from existing pledges in 2020 and emissions reductions in idealized 450 ppm implementation scenarios (UNEP, 2011, 2012). Recent IAM studies have explored the impact of delayed action (compared to idealized implementation) on 450 ppm mitigation pathways (Luderer et al., 2013, 2014; Rogelj et al. 2012 & 2013; Jakob et al. 2012; Riahi et al. 2014, van Vliet et al., 2012). They found that such a stabilization level can still be reached by the end of 2100, albeit at the expense of greater forcing overshoot, greater dependence on the availability of negative emissions, and greater institutional challenges after adopting the long term target. These findings highlight the need for an in-depth investigation of the implementability of 2°C mitigation pathways taking into account the existing policy situation.

3. Methods

Scenario design

The LIMITS study investigates plausible outcomes of the Durban Platform (DP) negotiations that can be broadly consistent with the objective of keeping global mean warming below 2°C since preindustrial levels. To exploit the potential range of 2°C emissions pathways, it explores two ambitious mitigation targets that a global climate treaty established in the Durban negotiations might aim for, i.e. reaching atmospheric greenhouse gas (GHG) concentrations at roughly 450 and 500 ppm CO₂e in 2100. Overshoot of these forcing targets before 2100 is allowed. The choice of climate target should be understood as a proxy for the stringency of the global cap on future emissions that is implied by a potential climate treaty. It is not implied that those targets have to be adopted literally in a Durban Platform agreement. A comparison of the 450 and 500 ppm concentration targets in terms of their mitigation requirement has not yet been undertaken with a multi-model ensemble.

Since the Durban Agreement calls for the implementation of the international climate treaty by 2020, the DP scenarios assumed that a globally uniform carbon price is fully established in the first model year following 2020⁴. For the period until 2020, it was assumed that individual regions follow domestic climate and technology policies that include emissions reduction targets for the year 2020 as laid down in the Copenhagen pledges. Two variants of the fragmented action until 2020 were considered and implemented as fragmented climate mitigation scenarios, a more lenient reference policy (RefPol until 2020) reflecting unconditional Copenhagen Pledges or the stringency of current policies, and a strengthened version (StrPol until 2020) based on conditional Copenhagen Pledges. Not all regions are assumed to take action before 2020. Further information on the two variants can be found in the Supplementary Online Material (SOM).

⁴ This is the year 2025 in AIM-Enduse, GCAM, IMAGE, REMIND and WITCH (representing the period 2022.5-2027.5), and the year 2030 in MESSAGE (representing 2021-2030) and TIAM-ECN (representing 2025-2035).

The four DP scenarios (RefPol-450, StrPol-450, RefPol-500, StrPol-500) constitute the combinations of the lenient and strengthened fragmented action scenarios until 2020 with the long term targets of 450 or 500 ppm CO₂e implemented thereafter (cf. Table 1). To incorporate the possibility of a further delay of international climate negotiations, a scenario with lenient fragmented action until 2030, followed by the adoption of the 500 ppm climate target (RefPol2030-500) was also included. The study also considered extrapolations of the fragmented action scenarios over the entire 21st century at the level of ambition reflected in the 2020 targets, scenarios RefPol and StrPol. The RefPol was directly adopted from the AMPERE study on staged accession scenarios (Kriegler et al., 2014b), while the StrPol scenario was developed as a strengthened variant of RefPol specifically for this study. A detailed description of the lenient and strengthened reference policy scenarios can be found in the Supplementary Online Material (SOM). Finally, the study included a baseline run without climate policy as a common reference case for all climate policy scenarios and the benchmarking cases of immediate global cooperation to reach the 450 and 500 ppm climate targets for analytical purposes.

Scenario class		Scenario Name	Scenario Type	Near-term Target / Fragmented Action	Fragmented Action until	Long-term Target
No policy baseline		Base	Baseline	None	N/A	None
Fragmented action		RefPol	Reference	Lenient	2100	None
		StrPol	Reference	Strengthened	2100	None
Immediate action		450	Benchmark	None	N/A	450 ppm
		500	Benchmark	None	N/A	500 ppm
Delayed action	DP scenarios	RefPol-450	Climate Policy	Lenient	2020	450 ppm
		StrPol-450	Climate Policy	Strengthened	2020	450 ppm
		RefPol-500	Climate Policy	Lenient	2020	500 ppm
		StrPol-500	Climate Policy	Strengthened	2020	500 ppm
		RefPol2030-500	Climate Policy	Lenient	2030	500 ppm

Table 1: Overview of scenarios considered in this article. Additional scenarios of different burden sharing regimes were investigated by the companion study of Tavoni et al. (this issue).

Implementation of the long term climate target

The 450 and 500 ppm CO₂e targets were defined in terms of limits on the combined radiative forcing from all anthropogenic radiative agents assessed in the IPCC 4th assessment report, except nitrate aerosols, mineral dust aerosols, and land use albedo changes (this forcing has been called AN3A forcing; Kriegler et al., 2014c; the three agents that are excluded are more speculative and often treated exogenously in the models). The AN3A forcing target levels were set to 2.8 W/m² in 2100 for the 450 ppm target, and to 3.2 W/m² in 2100 for the 500 ppm target

(taking into account that the excluded forcing agents are estimated to have net negative forcing in the range -0.2 - -0.4 W/m² in the RCP2.6 in 2100). Both targets allow overshoot before 2100. The more stringent target has a similar level of stringency as the RCP2.6 (Representative Concentration Pathway; Van Vuuren et al. 2011).

The adoption of a climate target induces a price on the emissions controlled under the target. Full where (region) and what (sector) flexibility of emissions reduction was assumed ensuring the selection of the cheapest globally available mitigation option at the margin. In the LIMITS study, models only priced Kyoto emissions under the target, while the non-Kyoto forcers remained uncontrolled. However, those models that include them endogenously by source, can account for the effect of mitigation strategies on non-Kyoto emissions. The models used their endogenous atmospheric chemistry and forcing representation to establish consistency with the AN3A forcing target.

Probabilistic climate projections

The climate outcome of the emissions scenarios from the LIMITS models were calculated with the carbon-cycle/climate model MAGICC in probabilistic mode (Meinshausen et al. 2009). This approach differs from previous model comparisons which used the endogenous climate information from the integrated assessment models where available. The LIMITS approach has the advantage of providing a unified treatment of carbon cycle and climate system uncertainty and offers the possibility to generate climate information for model scenarios that do not provide it endogenously (Schaeffer et al., 2014).

For each IAM emission scenario, MAGICC was run 600 times, each time with different set of carbon-cycle, atmospheric-chemistry, forcing and climate-system parameters. Carbon-cycle parameters were drawn from 9 sets of parameters that enable the model to emulate the responses of nine different carbon-cycle models. These sets were randomly combined with the 600 sets of other model parameters, selected from a much larger set by constraints that let the model reproduce several climate variables as observed over the past century (with uncertainty ranges) and produces an overall (posterior) distribution of climate sensitivity consistent with IPCC AR4's meta-analysis: median sensitivity of 3°C global-mean temperature increase for a doubling of CO₂ and 74% likelihood of sensitivity between 2 and 4.5°C (Meinshausen et al., 2009; Rogelj et al. 2012). The overall distribution of outcomes provides a "best-estimate" (median) of climate projections and a broad carbon-cycle/climate-system uncertainty range. It allows to derive a probability of limiting global warming to 2°C for each emissions scenario investigated in this study, if the 600 variations of model parameters are interpreted as a random draw from a prior distribution of climate system uncertainty.

Initial emissions in 2010 were harmonized for the MAGICC6 runs. Emissions from TIAM-ECN and WITCH were supplemented with Non-Kyoto emissions derived from projections of the other models. In general, the endogenous forcing and temperature outcomes of the models will differ somewhat from MAGICC6 results due to the probabilistic approach and differences in representations of the carbon cycle and climate system. This implies that emissions scenarios can lead to a small spread in anthropogenic forcing around the 450 and 500 ppm CO₂e target levels in the DP scenarios (Figure 1c, S1c and Table 3). In this paper, we will only show the harmonized forcing outcomes as derived with MAGICC6.

Participating models

A total of seven energy-economy and integrated assessment models participated in the LIMITS study: AIM-Enduse, GCAM, IMAGE, MESSAGE, REMIND, TIAM-ECN, WITCH (cf. Table 2). Further technical details and references on these models are provided in the SOM. The models represent the global energy system with various levels of sectoral and regional detail. All models covered the time period until 2100 with the exception of AIM-Enduse (to 2050).

The participating models also differ regarding their methodological approaches: the partial equilibrium (PE) models GCAM, IMAGE and TIAM-ECN calculate cost-minimal energy supply to meet a price-elastic energy (service) demand. The inter-temporal general equilibrium (GE) models MESSAGE, REMIND and WITCH embed the energy sector into the larger context of the economy. Moreover, the models differ in their representation of GHG emissions and their sources, energy demand and supply sectors, population and GDP baselines, and assumptions about techno-economic parameters (cf. SOM). These are key factors influencing the results analysed in this study. The differences reflect different choices of modellers on how to best approach the analysis of mitigation pathways, and the structural uncertainties regarding the underlying mechanisms. This diversity in model structure and assumptions allows to explore the associated range of uncertainties.

Model name	Model category	Anticipation/ Foresight	Land use change emissions	GHG and aerosol emissions	Negative emissions technologies
AIM-Enduse	Partial Equilibrium	Recursive dynamic	Endogenous	full basket of greenhouse gases, precursors and aerosols	BECCS (for electricity, hydrogen production),
GCAM	Partial Equilibrium	Recursive dynamic	Endogenous	full basket of greenhouse gases, precursors and aerosols	BECCS (for electricity, biofuel, biogas, hydrogen production), Afforestation
IMAGE/TIMER	Partial Equilibrium	Recursive dynamic	Endogenous	full basket of greenhouse gases, precursors and aerosols	BECCS (for electricity, biofuels and hydrogen production)
MESSAGE-MACRO	General equilibrium	Perfect foresight	Endogenous	full basket of greenhouse gases, precursors and aerosols	BECCS (for electricity, biofuel, biogas, hydrogen production), Afforestation
REMIND	General equilibrium	Perfect foresight	Endogenous	full basket of greenhouse gases, precursors and aerosols	BECCS (for electricity, biofuels and hydrogen production)
TIAM-ECN	Partial Equilibrium	Perfect foresight	Endogenous	CO ₂ , CH ₄ , N ₂ O. No F-Gases represented	BECCS (for electricity, biofuel, biogas, hydrogen production)
WITCH	General equilibrium	Perfect foresight	Endogenous	CO ₂ , CH ₄ , N ₂ O, fluorinated gases and SO ₂ aerosols	BECCS (for electricity production)

Table 2: Key characteristics of models participating in the LIMITS model-comparison study

4. Implications of the Durban Platform Scenarios for emissions pathways

Reaching atmospheric greenhouse gas concentrations in the range of 450 to 550 ppm CO₂ equivalent (CO₂e) requires a massive reduction of GHG emissions until 2100 (Clarke et al. 2009; Edenhofer et al. 2010; van Vuuren et al., 2011; Kriegler et al., 2014c). The LIMITS study adds to this an investigation of Durban Platform emissions scenarios that achieve 450 and 500 ppm CO₂e targets after a period of fragmented action until 2020 (Figure 1, see Figure S1 for the StrPol-450/550 scenarios). After 2020, the emissions in the DP scenarios fall quickly below the reference policy scenario, and the gap widens significantly over time (Figure 1a&b; S1a&b). Both fragmented action scenarios lead to a peaking of global emissions during 2040-70 and a return to slightly above (RefPol) or below (StrPol) 2010 emissions levels by the end of the century. This implies an increase of anthropogenic climate forcing to 4.4-6.2 W/m² in 2100 (Figure 1c & S1c), corresponding to 640-890 ppm CO₂e. Our results confirm the findings of other studies that a continuation of the current level of ambition as suggested by existing emissions reduction commitments is insufficient to achieve ambitious climate mitigation targets (Luderer et al. 2014; Blanford et al. 2014, Kriegler et al., 2014b).

In contrast to the reference policy scenario, the DP scenarios peak in 2020 and lead to a complete or near-complete phase out of global emissions by 2100. The GCAM model even shows a substantial amount of negative greenhouse gas emissions due to large scale deployment of bioenergy with CCS (BECCS) by the end of the century. The time profile of the DP scenarios is characterized by a trend break in emissions growth at the time of adoption of the target in 2020. It is strongest in the WITCH model due to an immediate response of energy demand and the GCAM model due to rapid large scale afforestation after 2020 (see Calvin et al. 2014b, for further discussion). Figure 2 investigates the magnitude of the trend break by comparing the decline in emissions intensity of GDP (including all Kyoto gases) in the three periods 2010-2020 (before adoption of the target), 2020-2030 (directly after the adoption), and 2030-2040. There are noticeable differences between the emissions intensity decline rates in the decades before and after the adoption of the target. It can be seen that the magnitude of the decline rates is influenced both by the stringency of the short term policy (RefPol vs StrPol) and the stringency of the long term target (450 vs. 550) that is adopted. While the choice of the long term target exerts the larger influence, the choice of near term policy plays also a role. The less stringent the near term policy until 2020, the larger the “jump” from lower emissions intensity decline rates before 2020 to as a result slightly higher decline rates that are implied after target adoption. Figure 2 compares the decline rates over the period 2010-2040 to the range of decline rates observed in the immediate action scenarios for 2020-30 (shaded areas for 450 and 500 ppm CO₂e, respectively). It can be seen that the fact of delayed target adoption pushes up required emissions intensity decline rates for the time after 2020; the more stringent the target the stronger. This is due to the fact that excess emissions in an early period need to be compensated later on to still reach the targets, leading to higher emissions reductions rates particularly in the 2020-50 period, and lower 2100 emissions levels in the DP scenarios compared to the immediate action cases. This supports one of the findings in Riahi et al. (2014) who have studied the impact of delaying target adoption until 2030 rather than 2020. The LIMITS study has included only one such scenario (RefPol2030-500), and this shows the largest increase in emissions intensity decline rates at the time of target adoption. However, it should also be noted that what we call immediate action (as of 2015) here would have been perceived as a delay scenario back in 2000 when the Kyoto Protocol entered into force. Thus, there is also a significant trend break between the annual average reduction in GHG emissions intensity over the recent past (2005-2010; around 1% per year as shown by the dashed line) and the emissions intensity decline rates that the models project for what we now call immediate action. Finally, the trend break is even larger when considering CO₂ emissions from fossil fuel combustion and industry rather than the full

basket of Kyoto gases, since the carbon intensity of global output has risen by approx. 1% per year over 2005-2010 (Figure S2).

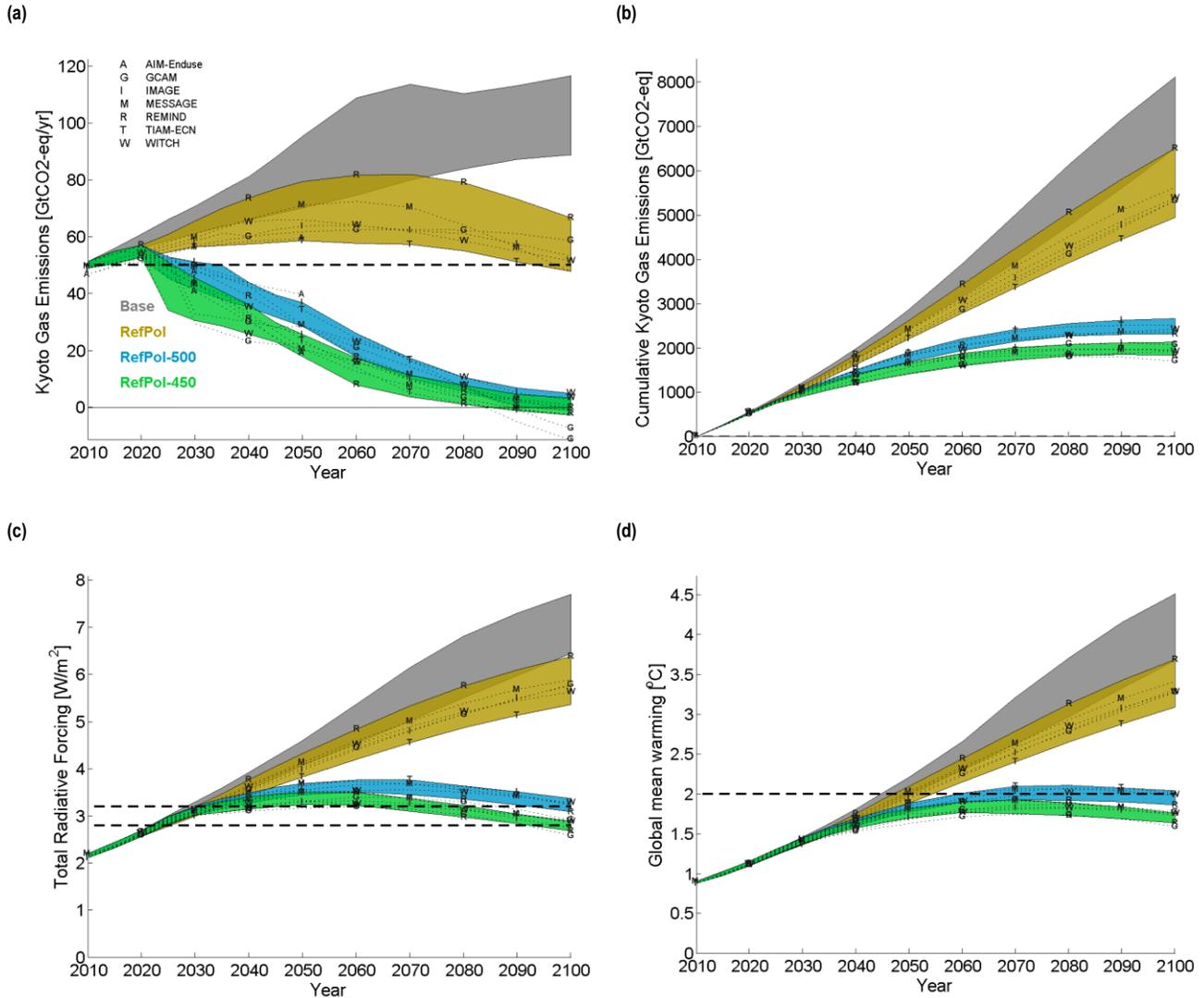


Figure 1: Kyoto gas emissions over the period 2010-2100 per year (Panel a) and in cumulative terms (Panel b) for a subset of LIMITS scenarios (see Figure S1 for corresponding StrPol scenarios). The resulting median radiative forcing and global mean warming as calculated with MAGICC are shown in Panel c & d. The AIM and GCAM models were not included in the funnels because AIM projected emissions only out to 2050 and GCAM showed a qualitatively different behavior due to a strong afforestation and negative emissions response to the adoption of the long term target.

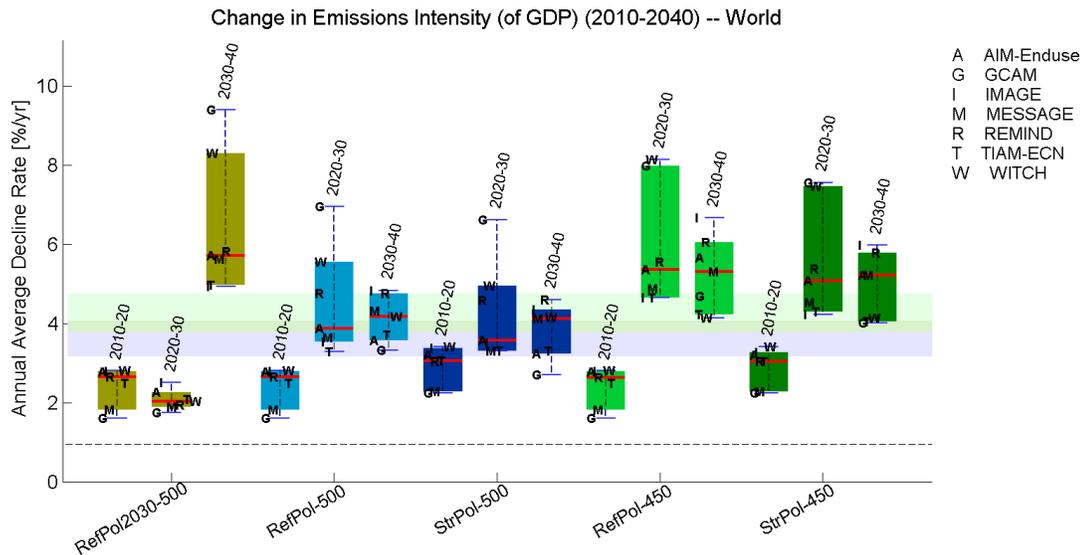


Figure 2: Annual average emissions intensity decline rate (of Kyoto gases per unit of GDP) for the periods 2010-20 (left bars), 2020-30 (middle bars) and 2030-40 (right bars). The dashed line shows the average decline rate over the period 2005-2010 (from EDGAR, 2011, and the assumption of 11% growth in GWP), and the shaded areas the range of decline rates projected by the models (excluding GCAM due to the afforestation dynamics) for immediate action on 500 ppm (lower area) and 450 ppm CO₂e (upper area).

We can distinguish two different measures that describe the impact of adopting a long term target on the emissions pathway: the emissions intensity decline rate after target adoption which captures the pace of emissions intensity reductions that are needed to still reach the target, and the increase in decline rate at the time of target adoption which describes the magnitude of the break in emissions intensity trends. Both measures can be important indicators for the challenges that adopting a long term target might bring, as the former relates directly to the magnitude of mitigation effort, while the latter relates to the challenge of instituting a departure from past trends. Another measure that was proposed in the literature is the emissions gap between projected 2020 emissions levels and cost-effective immediate action scenarios that aim to stabilize climate forcing at around 450 ppm CO₂e (UNEP, 2011; Höhne et al., 2012). This indicator can be used to relate observed emissions trends to idealized mitigation scenarios in the literature. With a large number of delayed action scenarios now being produced (Clarke et al., 2009; Jakob et al., 2012; Roegelj et al., 2012; Riahi et al., 2014; Kriegler et al., 2014b; Luderer et al., 2013, 2014, this study), the implications of current emissions trends can be more directly related to those delay scenarios. This will also help to relate the emissions gap indicator to other implications of delayed target adoption such as the (increase in) emissions intensity decline rates discussed above.

In the following, we calculate the emissions gap in the Durban Platform scenarios. Emissions increase until 2020 in both fragmented action scenarios with lenient (RefPol: 51-57 GtCO₂e) and stringent interpretation of Copenhagen pledges (StrPol: 49-54 GtCO₂e). This constitutes a small reduction compared to a baseline without climate policy (56-61 GtCO₂e), and somewhat higher emissions compared to the corresponding 450 and 500 ppm immediate action scenarios 450 and 500 (see Table 3 for a summary of emissions and climate outcomes across the scenarios of the study). The gap between projected 2020 emissions levels in the lenient reference policy and the 450 ppm

immediate action scenario is in the range of 3-17 GtCO₂e for all models but GCAM (23 GtCO₂e), which shows a large-scale afforestation signal directly after adoption of a long term target. This is in good agreement with the emissions gap estimates reported in UNEP (2013; 5-15 GtCO₂e for corresponding Cases 1-3). However, the notion of immediate action, and thus the reference point for the calculation of the emissions gap will evolve over time.

Our study also included a scenario in which the adoption of a global agreement is further delayed, and the fragmented reference policy is followed until 2030 (RefPol2030-500). This scenario has a much larger emissions gap and trend break in emissions at the time of target adoption than the DP scenarios (Figure 2). Reference policy emissions increase to 56-65 GtCO₂e by 2030, amounting to a significant gap of 5-21 GtCO₂e (500 ppm) and 13-29 GtCO₂e (450 ppm) to the immediate action scenarios. However, all models participating in the study could still implement the 500 ppm CO₂e target in such a setting. The case of reaching the 450 ppm target with a delay until 2030 was not taken up in the LIMITS study design, but one model included it as a sensitivity case (Aboumahboub et al., this volume). An in-depth analysis of the implications of delayed action until 2030 for the achievability of long-term mitigation targets is provided in a concurrent study (Riahi et al. 2014).

Across scenarios, we find that the emissions gap in the year of target adoption correlates both with the emissions intensity decline rate in the decade thereafter (Figure S3) and the increase in decline rate (Figure 3). The correlation with the increase in decline rate is closer because this measure more fully incorporates both factors that determine the emissions gap, i.e. the stringency of short-term action and the stringency of the long-term target. The finding of such a correlation may allow to abstract from a particular formulation of delay scenario. As the emissions gap is directly determined by the short term action (defining the realized emissions level in some future year) and the long term target (defining the cost-effective emissions level in that year), a mapping of these two key characteristics of delayed target adoption onto the emissions gap and consequently the implied (increase in) emissions intensity decline rate is conceivable. The results in Figure 3 roughly suggest a 1% per year increase in decline rate at the time of target adoption for each 3-4 GtCO₂e of emissions gap, although this result is preliminary and would need to be confirmed by future studies.

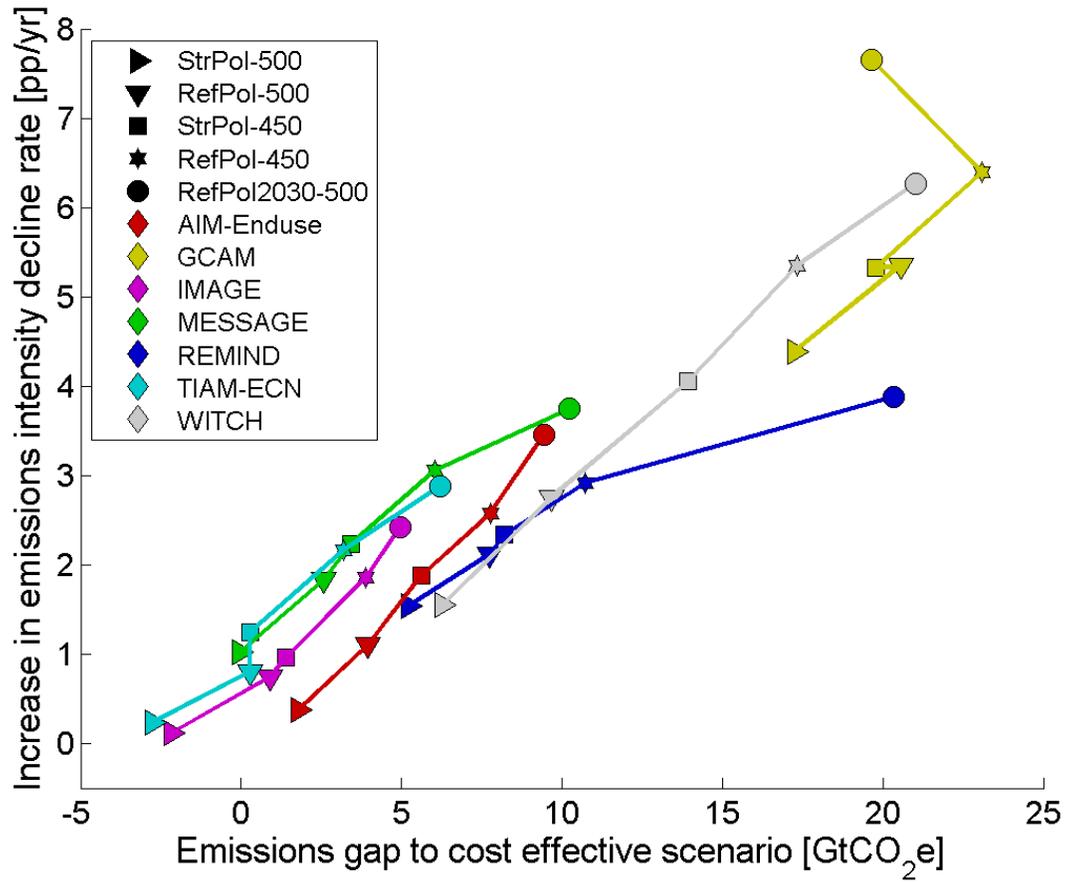


Figure 3: Emissions gap in the year of target adoption vs. the increase in annual average emissions intensity decline rate between the decades before and after target adoption.

Table 3: Global GHG emissions, atmospheric concentrations, and temperature consequences in the baseline, lenient and strengthened reference policy, immediate action and Durban Platform scenarios. The emissions gap for the Durban Platform scenarios is calculated w.r.t. to the corresponding immediate action scenario (relative to 450 for Baseline, RefPol, and StrPol). Numbers correspond to the full range across the scenarios except for 2020 emissions (gaps). Here, values for GCAM are shown separately in parentheses because GCAM exhibits a distinctly different emissions trajectory due to large scale deployment of afforestation around 2020 in the immediate action scenarios. Temperature values in square brackets include the full climate system uncertainty (2σ range) around a mean climate sensitivity of 3°C as derived from MAGICC for each emissions scenario. Note that for the climate simulations, emissions were harmonized to the same base year.

	Kyoto gas emissions 2020 GtCO ₂ e	Kyoto gas emissions gap 2020 GtCO ₂ e	Kyoto gas emissions 2030 GtCO ₂ e	Kyoto gas emissions gap 2030 GtCO ₂ e
Baseline	55-61	6-23 (27)	62-71	18-38
RefPol	51-57	3-17 (23)	56-65	13-29
StrPol	49-54	0-14 (20)	50-61	7-23
500	(32) 45-53	-	37-52	-
StrPol-500	49-54	(-3) - 6 (17)	32-49	(-5) - 2
RefPol-500	51-57	0-10 (21)	33-51	(-4) - 3
RefPol2030-500	51-57	0-10 (21)	56-65	5 - 21
450	(29) 37-50	-	32-44	-
StrPol-450	49-54	0-14 (20)	29-45	(-5) - 4
RefPol-450	51-57	3-17 (23)	29-45	(-4) - 5

	Cumulative CO ₂ fossil fuel and industry emissions (2010-2050) GtCO ₂	Cumulative Kyoto gas emissions (2010-2050) GtCO _{2e}	Cumulative CO ₂ fossil fuel and industry emissions (2010-2100) GtCO ₂	Cumulative Kyoto gas emissions (2010-2100) GtCO _{2e}
Baseline	1770-2010	2420-2820	5330-6080	6480-8070
RefPol	1590-1860	2190-2610	3640-4890	4940-6490
StrPol	1380-1700	1960-2400	2750-3950	3890-5320
500	1120-1400	1500-1940	1150-1590	2100-2720
StrPol-500	1170-1380	1520-1860	1150-1570	2070-2660
RefPol-500	1180-1400	1570-1910	1160-1590	2100-2690
RefPol2030-500	1240-1460	1750-2080	1170-1650	2170-2690
450	860-1270	1320-1660	690-1250	1720-2090
StrPol-450	910-1270	1400-1660	700-1240	1720-2190
RefPol-450	910-1290	1430-1680	700-1260	1730-2160

	CO _{2e} concentrations (2100) ppm	Temperature change (max) °C	Probability of exceeding 2°C (max) %
Baseline	930-1170	3.7-4.5 [2.9-5.9]	100
RefPol	760-920	3.1-3.7 [2.4-4.7]	96-100
StrPol	650-770	2.6-3.2 [2.1-4.0]	88-97
500	480-520	1.9-2.1 [1.5-2.7]	34-59
StrPol-500	480-520	1.9-2.1 [1.5-2.6]	35-56
RefPol-500	480-520	1.9-2.1 [1.5-2.7]	36-59
RefPol2030-550	490-520	1.9-2.1 [1.6-2.7]	41-61
450	450-480	1.7-1.9 [1.4-2.4]	21-41
StrPol-450	450-480	1.7-1.9 [1.4-2.4]	22-40
RefPol-450	450-480	1.7-1.9 [1.4-2.4]	24-41

5. Cumulative emissions and climate outcomes of Durban Platform Scenarios

The anthropogenic forcing of the climate system is a function of the accumulated stock of greenhouse gas emissions in the atmosphere, and therefore closely correlated with cumulative greenhouse gas emissions (Meinshausen et al. 2009; Matthews et al. 2009). This relationship can also be seen in the DP scenarios. Figure 4 shows the cumulative Kyoto gas emissions during 2010-2100 for the RefPol-450 and 500 scenarios. We observe that the models broadly agree on the cumulative amount of emissions that remain under the target, and that this amount increases with the forcing target. GCAM shows a bit lower overall emissions budgets because of the deep reduction of CO₂ emissions at the end of the century. It also projects the lowest forcing and climate outcome. Other differences are due to the fact that direct (Kyoto) forcing from the long-lived greenhouse gases controlled under the Kyoto protocol does not describe full anthropogenic forcing. Non-Kyoto forcing substances such as aerosols and tropospheric ozone add a net variation of -0.3 to 0.1 W/m² in the LIMITS scenarios, which is large enough to affect remaining Kyoto gas emissions budgets under the targets. Thus, non-Kyoto forcing can be an important consideration for 2°C mitigation pathways (Hansen and Sato 2001; Rose et al. 2014) although the bulk of anthropogenic forcing will come from Kyoto gas emissions.

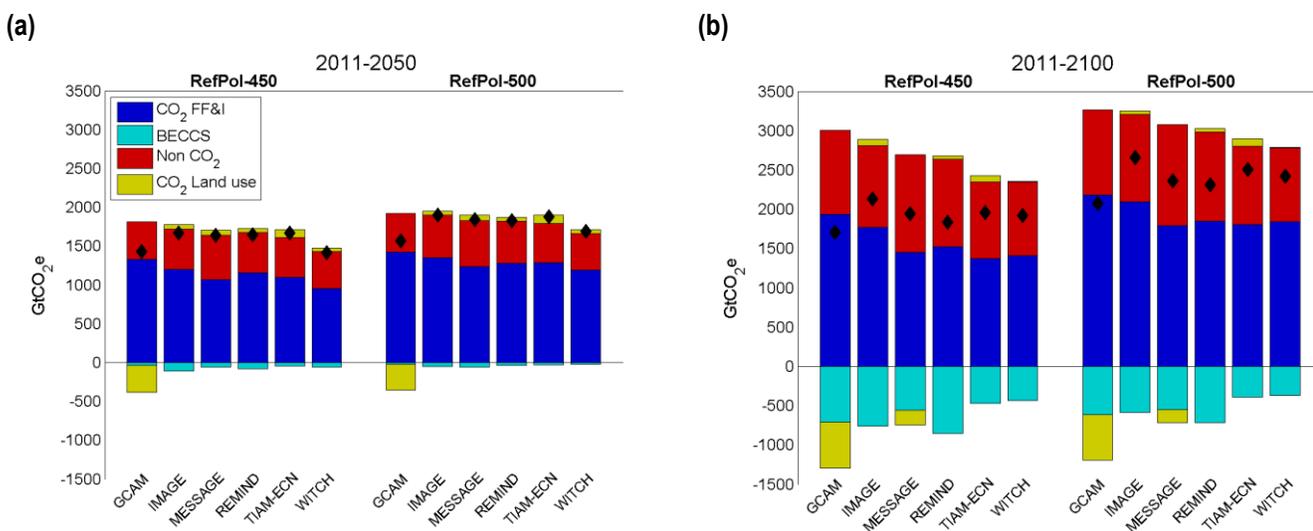


Figure 4: Cumulative global Kyoto gas emissions over the period 2011-2050 (a) and 2011-2100 (b) broken out into individual sectors. The black diamonds show net total cumulative emissions.

Figure 4 provides a breakdown of cumulative greenhouse gas emissions into CO₂ emissions from fossil fuel combustion and industry (FF&I), CO₂ emissions from agriculture, forestry and land use (AFOLU), and non-CO₂ emissions from a variety of sectors, the bulk of which is N₂O and CH₄ emissions from agriculture and waste. The LIMITS scenarios assume uniform emissions pricing of Kyoto gases to allocate emissions reductions between the different sectors. This implies that models exploit the cheapest abatement option at the margin across sectors. Differences in the sectoral breakdown of GHG emissions reflect differences in model assumptions about the abatement potential of individual sectors. However, a number of robust results can be identified. Although the share of CO₂ FF&I emissions has increased steadily in the past to two thirds of global GHG emissions in 2010 (EDGAR v.4) and is projected to increase further in the future, this trend is reversed under climate policy. The remaining cumulative CO₂ FF&I emissions are limited to two thirds or less of total emissions, particularly for the more stringent

450 ppm CO₂e target. Thus, fossil fuel-based energy use is the main venue for mitigation. The significance of the energy sector is further increased by the option to produce negative emissions from the combination of bioenergy production with CCS. Cumulative Non-CO₂ emissions are less responsive to the climate target, although it should be noted that cumulative numbers over the 21st century are not too indicative for the forcing of greenhouse gases with decadal or lower lifetime such as methane (Blanford et al. 2014). This reflects the common assumption in models that abatement options for these greenhouse gases cannot fully eliminate them. In many cases, this is because no obvious abatement technologies have been identified that would reduce emissions further (e.g. methane emissions from open-pit coal mines or from free roaming livestock). . Finally, the largest model differences can be seen for CO₂ emissions from land use. GCAM, MESSAGE and WITCH include the option to absorb atmospheric CO₂ by afforestation. Particularly GCAM uses this option extensively, starting as early as 2020 in the DP scenarios. Afforestation in GCAM amounts to a cumulated amount of 500 Gt CO₂ absorbed from the atmosphere. This is on the order of magnitude of the carbon dioxide that was put into the atmosphere by deforestation over the past 200 years (CDIAC). At such a scale, afforestation can compensate for a quarter or more of the residual emissions in the other sectors in stringent mitigation scenarios. However, the uncertainty about the scope and the institutional implications of land use based mitigation remains large (Calvin et al. 2014 a, 2014 b; Popp et al. 2013).

While the remaining 21st century GHG emissions budget scales with the climate target, it is largely unaffected by the amount of delay in achieving the target. Excess emissions in an early period have to be compensated in the subsequent period until 2100. In addition, cumulative emissions over the period 2010-2030 vary only by around 10% or less with the choice of lenient vs. strengthened fragmented action until 2020, as well as the choice of 450 or 500 ppm long term target (Figure 1b). This implies that near term emissions reductions provide only a small share of required overall emissions reductions. As discussed above their significance lies more in preparing the ground for steep emissions reductions thereafter in particular in terms of limiting the associated trend break in emissions (intensity) growth.

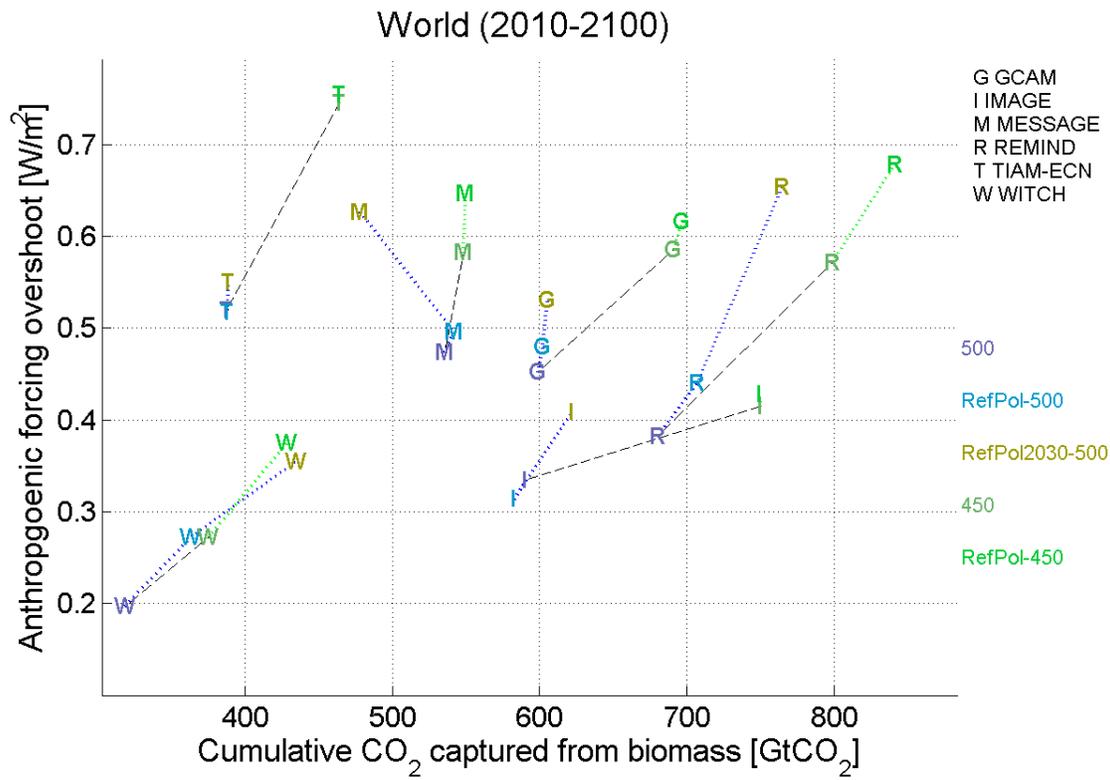


Figure 5: Radiative forcing overshoot (of Year 2100 forcing) vs. cumulative global negative emissions from BECCS for the period 2011-2100.

In the DP scenarios, 40-50% of the remaining 21st century emissions occur until 2030, and 68-85% until 2050⁵. Models partly compensate for the emissions reductions in the first half of the century by exploiting the potential for negative emissions from bioenergy use in combination with CCS (BECCS) in the second half. The resulting emissions trajectories lead to an overshoot, i.e. forcing levels that temporarily exceed the prescribed 2100 forcing target. Figure 5 reveals a relationship between increasing cumulative carbon dioxide absorption from the atmosphere via BECCS and increasing amount of forcing overshoot. Models differ in the extent of BECCS deployment, but most increase the deployment in line with an increasing stringency of the target and with decreasing near-term abatement. BECCS deployment can vary by up to 200 GtCO₂ across the set of LIMITS scenarios. BECCS, or more broadly the capability to produce negative emissions, is used to shift some of the required emissions reductions into the future, and to attenuate additional mitigation requirements due to excess emissions in an early period or a more stringent mitigation target. Thus, the deployment of negative emissions technologies is a key contributor to 2°C emissions pathways (van Vuuren and Riahi, 2011). The LIMITS study did not explore scenarios where BECCS was excluded from the technology portfolio, but other studies have shown that the unavailability of negative emissions severely impact the achievability and costs of the stringent mitigation targets (Edenhofer et al., 2010; Azar et al., 2010; Krey et

⁵ The share of short term CO₂ emissions from the fossil fuel and industry sector are even higher: 51-88% until 2030 and 82-144% until 2050 confirming the findings of Bertram et al. (2014).

al., 2014), and exacerbates the consequences of a delay in comprehensive global emission reductions (Riahi et al. 2014; Rogelj et al. 2013; Luderer et al., 2013).

The amount of overshoot also affects the climate outcome. Figure 6 shows the median estimate for global mean warming (left panel) and the probability of exceeding 2°C (right panel) for the DP and 2030 Delay scenarios (see also Table 3). All emissions trajectories overshoot the 2100 forcing target, and as a result lead to somewhat higher peak temperatures (left bars) than attained in 2100 (right bars). It can be seen that the emissions scenarios aiming at 450 ppm lead to a median peak warming well below 2°C and a likely chance (> 66%) of not exceeding the 2°C target in 2100. Scenarios aiming at 500 ppm have a median peak warming around 2°C (+/ 0.1°C), and are more likely than not (>50%; with the exception of IMAGE) to be below the 2°C target in 2100. Since all scenarios show a declining temperature trend at the end of the century, they will reach or maintain 2°C beyond 2100 if mitigation efforts are maintained. Their distinguishing feature is their probability of overshooting 2°C before 2100 ranging from 24-41% for 450 ppm to 36-59% for 500 ppm CO₂e in the DP scenarios investigated here. A constraint on the maximum probability of exceeding the 2°C target effectively constrains the peak warming in the scenarios. Furthermore, we deduce from the climate simulations with MAGICC that the DP scenarios will exceed 1.5°C warming with 84-99% probability, and therefore would be largely inconsistent with a temperature target of 1.5°C.

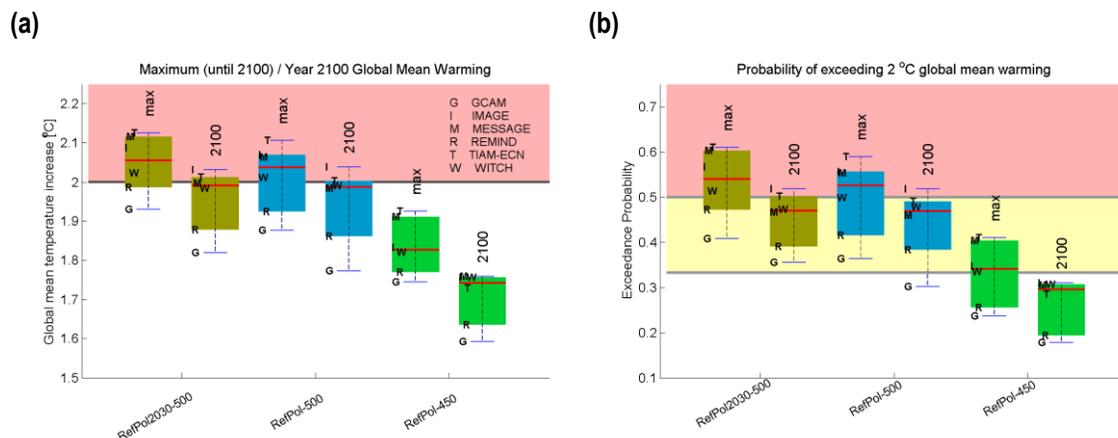


Figure 6: Median global mean warming (panel a) and probability of exceeding 2°C (panel b) for the Durban Platform Scenarios. The left (higher) bars show the maximum warming / exceedance probability in the 21st century; the right (lower) bars shows the warming / exceedance probability in 2100.

The results show that the two probabilities of overshooting 2°C in the 21st century and of exceeding 2°C in the long run, e.g. in 2100, are important characteristics of 2°C mitigation pathways. These probabilities will never be zero even under most stringent emissions pathways. It is a societal decision of what level of overshoot and exceedance probability would still be consistent with the recognition of the 2°C target in the UNFCCC process, a decision that may be seen akin to setting a risk threshold⁶. In any case, a determination of these parameters has significant implications for the stringency of mitigation action as highlighted by the differences in the 450 vs. 500 ppm DP scenarios.

⁶ The UNEP Gap Reports have used the definition of limiting the probability of overshooting 2°C to 33% (UNEP, 2011; UNEP, 2013).

6. Economic implications of Durban Platform scenarios

An important consideration for international climate negotiations will be the economic impact of a global climate treaty. This includes overall economic costs but also the immediate impact of adopting a long term mitigation target that caps the amount of future GHG emissions to be released into the atmosphere. It can be expected that the adoption of such a target after a period of fragmented action would lead to a rapid adjustment of expectations and quickly be reflected in carbon and energy price increases. Such price jumps may lead to higher transitory economic costs than over the long run.

Figure 7 shows global mitigation costs over the period 2030-2100. They are measured in terms of consumption losses in general equilibrium models (GE: MESSAGE, REMIND, WITCH; Figure 7a) and total abatement costs (= area under marginal abatement cost curve or additional total energy system costs) in partial equilibrium models (PE: GCAM, IMAGE, TIAM-ECN; Figure 7b), and expressed as fraction of consumption and economic output, respectively, in the baseline case without climate policy. It can be seen that costs increase over time relative to the consumption / economic output in the baseline as well as with the stringency of the mitigation target (RefPol-500 vs. RefPol-450). Net present value costs over the 21st century (using a discount rate of 5% for the period 2010-2100) for the DP scenarios range between 0.4-3.0% for the 500 ppm target and 0.6–5.3% for the 450 ppm target. In net present value terms, models project 30-80% higher costs for the 450 ppm target compared to the 500 ppm target. The large variation of costs between models is due to structural model differences and the difference in cost metrics. The model differences relate to both the ability of models to reduce emissions in response to carbon pricing and the economic impact of higher energy costs (Kriegler et al., 2013a). Concerning the former, models with lower responsiveness will assume higher carbon prices to implement the required emissions reductions, and vice versa. A comparison of the cost differences in Figure 7 with the difference in carbon prices projected by the models (Figure S4 in the SOM) shows a clear correlation between high carbon prices and high macroeconomic costs. Concerning the latter, consumption losses include economy wide effects while abatement costs do not, and thus can be expected to show a larger macroeconomic impact of higher energy costs. Regional mitigation costs can differ substantially from the global average, and are not only a function of global emissions reduction requirements, but also regional mitigation potentials and international burden sharing regimes. These factors and their impact on the distribution of regional mitigation costs are analyzed in a companion model comparison paper (Tavoni et al., this issue) and individual model studies (Aboumahboub et al., this issue).

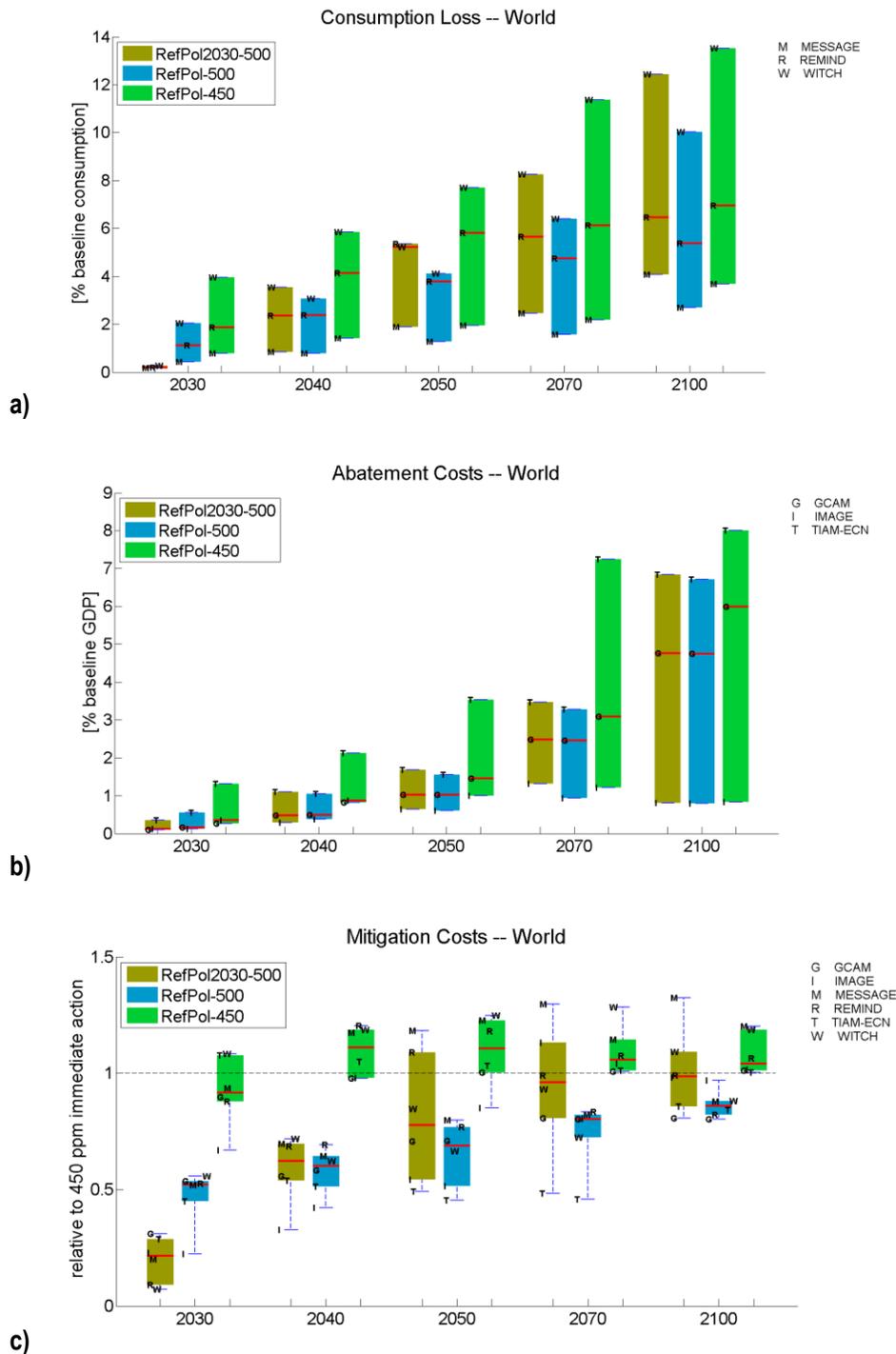


Figure 7: Mitigation costs over time for the Durban Platform scenarios with lenient reference policy and the “delay until 2030” scenario. Shown are (a) consumption losses as a fraction of baseline consumption as projected in general equilibrium models (MESSAGE, REMIND, WITCH), (b) abatement costs measured in terms of the area under the MAC (IMAGE, GCAM) or total additional energy system costs (TIAM-ECN) as a fraction of baseline output, and (c) mitigation costs relative to the 450 ppm immediate action scenario. A value of one indicates identical costs at the given point in time between the given and the 450 ppm scenario.

An important question is how delayed adoption of a long target affects the mitigation cost profile over time. Figure 7 shows mitigation costs relative to the costs in the 450 ppm CO₂e immediate action scenario in order to distill the delay signal more clearly. It is characterized by lower short term costs, high longer term costs, and more rapidly rising costs at the time of target adoption (see RefPol-450 case). Higher long term costs arise from two factors: emissions reductions need to be steeper in order to compensate for excess emissions in the early period and emissions reductions are more costly due to a larger carbon lock-in of the energy system at the time of adopting the target (Bertram et al., 2014). It is important to note that the magnitude of both of these factors increase with the time of delay, up to the point where ambitious long term targets can no longer be reached (Riahi et al., 2014). As can be seen from Figure 7c, the costs of the RefPol2030-500 scenario in which a failure of the Durban Platform negotiations delays the adoption of a long term target until 2030 shows significantly higher long term costs compared to the RefPol-500 Durban Platform scenario. Thus, a further delay of target adoption by a decade (from 2020 to 2030) can be very costly, as was also found by Luderer et al. (2013, 2014) and Roegelj et al. (2013). Moreover, we expect the cost penalty of delay to increase with the stringency of the long term target that is aimed for (see supplementary material to Aboumahboub et al., this issue, who have calculated a RefPol2030-450 scenario as a sensitive case).

Delaying target adoption from today (global action as of 2015 in the 450 and 500 cases) to 2020 (global action as of 2025 in the RefPol-450/500 cases) leads to a smaller increase of long term costs of up to 20% (RefPol-450, see Figure 7c) compared to a further delay to 2030. While this confirms results from concurrent studies (Luderer et al., 2013, 2014), the cost penalty due to delay is, however, lower than found in earlier studies (Clarke et al. 2009; Jakob et al. 2012). There are several reasons for this. First, Clarke et al. (2009) study a much stronger delay situation with non-Annex I countries adopting the long term target only during the 2030-70 period. Second, most models now include the ability to produce net negative emissions, and rely on it to achieve deep emissions cuts in the second half of the century. This abatement strategy allows considerable extra flexibility in the early periods, limiting the cost penalty of the delayed effort. Third, all scenarios in this study –even the delayed ones– assume interim policies which limit emissions. Finally, earlier studies assumed mitigation action to start already in 2010, which resulted in a greater differential between the immediate and delayed action scenarios, but is counter-factual from today’s point of view.

Besides higher long term costs, the effect of delay will be most visible in transitional cost increases at the time of adopting a long term target after a period of fragmented action (Luderer et al., 2013, 2014). To explore the transitional impact in greater detail, we investigate the reduction of consumption growth in the two decades after target adoption across the DP scenarios (2020-40) and the 2030 Delay scenario (2030-50). Such reductions in consumption growth are directly linked to the increase in consumption losses at the time of target adoption⁷. Figure 8 shows that consumption growth is reduced the stronger, the less stringent short term action (RefPol vs StrPol), the more stringent the long term target (450 vs 550) and the longer the adoption of the target is delayed (2020 vs. 2030). The latter two factors show the largest impact on growth rates. Particularly a delay of adopting the target until 2030 leads to a doubling or more of percentage point decreases in consumption growth rates compared to the immediate action cases and also the Durban Platform scenarios (with the exception of WITCH which shows a approx. 60% increase relative to the DP scenarios). This highlights the fact that not only long term costs, but also transitional impacts are significantly increased when delaying target adoption by another decade.

⁷ Formally, if g is the growth rate of consumption between, e.g., 2020 and 2030 in the baseline, cl_1 and cl_2 consumption losses in fraction of baseline consumption at the begin and end of the period, then g will be reduced (in percentage points) to first order by $\Delta cl (1+g+cl_1)$, with $\Delta cl = 100 (cl_2-cl_1)$ the rise in consumption losses in percentage points.

The magnitude of the consumption growth reductions can be compared to projections of the impact of the financial and economic crisis on Europe although they mostly refer to output rather than consumption. EU27 output was growing at around 2.5% per year in the period 2003-2007 before the crisis hit. The World Economic Outlook (IMF, 2013) projects EU27 output to grow by only 6.5% over the period 2008-2017, and to return to post-crisis growth rates of 2% per year thereafter. Assuming that in the absence of the crisis, output in the EU would have grown at a steady 2% per year, Europe is currently suffering a 15 percentage point reduction of GDP growth in one decade. Care should be taken, however, in comparing this number with the model results in Figure 8, because it refers to output, not consumption, to EU27 rather than the world economy, and to 10 years rather than 20 years as in Figure 8. In addition, it needs to be noted that despite the inclusion of a period of fragmented action until 2020/30, other modeling assumptions are optimistic. This includes the efficient implementation of the climate regime after the adoption of the target, globally efficient markets and the full availability of mitigation options. If some of these assumptions are not met, global economic costs as well as transitional impacts on output and consumption growth can be higher.

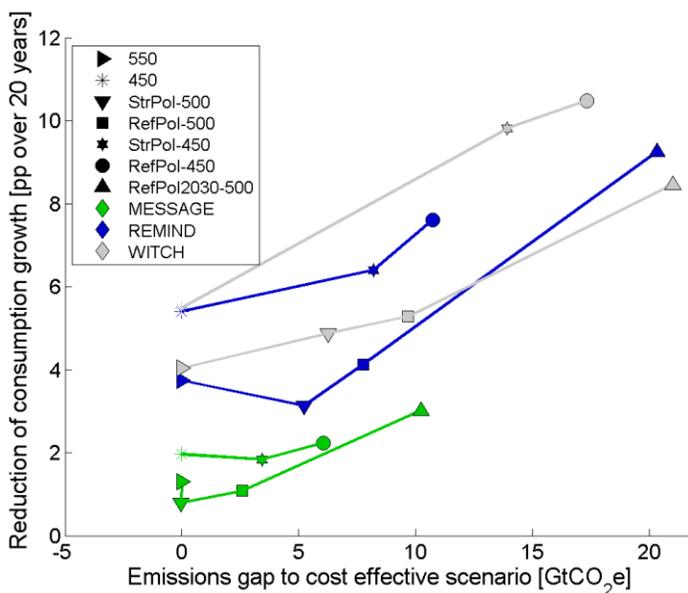


Figure 8: Reduction of consumption growth over the two decades following target adoption (2020-2040 for the DP scenarios and 2030-50 for the RefPol2030-500 case) with respect to the consumption growth in the baseline w/o climate policy (in percentage points) as projected by the general equilibrium models in the study. The consumption growth rate reductions in the period 2020-40 for the 450 and 550 ppm CO₂e immediate action scenarios are also shown for comparison. Results are plotted against the emissions gap to the immediate action scenario at the time of target adoption (cf. Figure 3).

7. Conclusions

The LIMITS study on Durban Platform scenarios investigated a set of different outcomes of the Durban Platform negotiations on a global climate agreement to take effect in 2020. In particular, the study assumed two different long term forcing targets with a significant probability to limit global mean warming to 2°C, and two different levels of mitigation effort until 2020. The study also investigated a number of “Durban failure” scenarios including a scenario

where the adoption of a global treaty is delayed until 2030, and two scenarios which project fragmented action in the absence of a global treaty over the entire 21st century. The scenarios were run by an ensemble of seven integrated assessment and energy-economy models allowing an evaluation of the robustness of results against structural model uncertainty. The climate outcome of the various climate policy scenarios was derived with the climate model MAGICC which provides a probabilistic representation of uncertainty about the climate response.

A number of important findings could be derived, some of which are new and some of which support findings from other studies. First, extrapolating the fragmented action at the level of ambition of current emissions reduction pledges as assumed in this study (see Section 2 and the SOM for the assumptions underlying the reference scenarios), global greenhouse gas emissions return to 60-140% of today's level by 2100. This leads to atmospheric greenhouse gas concentration in excess of 650 ppm in 2100 and rising, which is inconsistent with ambitious climate policy objectives. Mitigation pathways towards the 2°C target require a near phase out of global emissions by 2100. These results confirm findings by other studies (e.g., Blanford et al., 2014; Kriegler et al. 2014b; Luderer et al. 2014).

Second, negative emissions technologies are a key element of implementing the emissions pathways in the Durban Platform scenarios. As shown in previous studies, negative emissions allow a phase out of net global emissions in the long run by compensating for residual emissions in sectors with limited abatement potential (Azar et al., 2006; Kriegler et al., 2013). They also offer the flexibility to shift some emissions reductions into the future accommodating for the delay in implementing a global climate treaty and smoothening the transition into a global climate regime (van Vuuren and Riahi, 2011; Tavoni and Socolov, 2013). We find that the more stringent the long term stabilization target and the larger the excess emissions in an early period, the larger the deployment of negative emissions technologies in the long run.

Third, further flexibility in implementing stringent mitigation pathways results from the allocation of emissions reductions onto sectors as shown, e.g., by Blanford et al. (2014). Fossil fuel combustion is the main venue for mitigation, while a socket of hard to mitigate non-CO₂ emissions mostly from the land use sector is retained even under tight emissions controls. Land use based mitigation can potentially play a large role by compensating fossil fuel emissions via afforestation and supplying bioenergy, but uncertainties are large (Popp et al. 2014).

Fourth, due to the overshoot nature of the Durban Platform emissions pathways that is largely determined by the choice of long term forcing target, global mean warming peaks during the 21st century and is characterized by declining temperatures in the year 2100. This means that those Durban Platform scenarios studied here that exceed 2°C over the course of the 21st century will eventually return to 2°C by 2100 or early in the 22nd century if emissions reduction efforts are maintained. However, such peak-and-decline temperature trajectories are greatly aided by the availability of negative emissions technologies, and will be difficult to realize without them. The two probabilities of overshooting the 2°C limit during the 21st century and of exceeding it in the long run, e.g. in the year 2100, are key parameter for judging the consistency of Durban Platform scenarios with the 2°C target. Defining these probabilities is a societal choice and akin to setting a risk threshold. It will largely determine the stringency of the long term mitigation target and the overall shape of 2°C emissions pathways.

Fifth, the stringency of near-term action as well as the choice of long-term target determine the emissions gap between delayed target adoption and immediate action. They also determine the break in emissions trends at the time of target adoption, as e.g. reflected in a rapid increase in the emissions intensity decline rate (measured in terms of total GHG emissions per unit GDP; the largest part of it is the decarbonization rate of the energy sector) at that

time. The magnitude of the emissions gap as well as the emissions intensity decline rates can be used as measure for the challenges that adopting a long term target might bring. Both quantities, the emissions gap and the increase in emissions intensity decline rates at the time of target adoption, were found to be tightly correlated across the participating models and study scenarios. In general, the larger the emissions gap, the greater the implied emissions intensity decline rates and the larger the mitigation challenge.

Sixth, long term mitigation costs of the Durban Platform scenarios are somewhat higher compared to the immediate action cases due to two factors: deeper emissions reductions in the long run that are required to compensate for excess emissions in earlier periods, and a larger carbon lock-in that makes mitigation more expensive. Both factors increase in significance with the time of delay, and we observe a substantially larger impact on long term costs for the case of delaying the adoption of a long term mitigation target until 2030 rather than 2020.

Seventh, transitional economic impacts occur at the time of target adoption as rising mitigation costs lead to a reduction of output and consumption growth particularly in the decades thereafter. The transitional impact on growth rates is sensitive to a delay in adopting a long term target. Concretely, the general equilibrium models in this study project that growth rate reductions at least double if the long term target is only adopted in 2030. Thus, a further delay of a global climate treaty until 2030 substantially increases the transitional challenges as well as the long term costs (Rogelj et al. 2013; Luderer et al. 2013, 2014).

The findings need to be put into the context of the scope of the LIMITS study. While a set of plausible outcomes of Durban Platform negotiations were covered, other scenarios are conceivable. In particular, our study has made idealized assumptions about the implementation of a global treaty after 2020. Those include a globally uniform carbon price exploiting the cheapest mitigation option in the sector and region at the margin, and the assumption of well-functioning markets. Economic impacts of the Durban Platform scenarios will be higher under less favorable conditions. In addition, all models included the availability of producing negative emissions, albeit to different degrees. An exclusion of negative emissions technologies can greatly reduce the achievability of 2°C emissions pathways (Riahi et al., 2014; Krey et al., 2014). Our analysis could only touch upon the institutional challenges that the implementation of 2°C pathways and the transition to a global climate regime could entail. It does not discuss the incentives of the major economies to join such an effort. More research will be needed on the regional implications of 2°C pathways (Tavoni et al., 2014; van Sluisveld et al. 2014; Aboumahboub et al., 2014). It should be noted that our economic assessment of the Durban Platform scenarios focused exclusively on the direct impacts of mitigation, and did not include the benefits from avoided climate change impacts (World Bank 2012) and the co-benefits from climate action to other policy objectives (Mc Collum et al., 2011; Riahi et al., 2012), both of which can be substantial.

Based on the results from the Durban Platform scenarios in this study, we conclude that the Durban Platform negotiations can still deliver an outcome that could be broadly consistent with the 2°C target, if they successfully implement global climate action on a long term target by 2020. However, a further delay of adopting a long term goal until 2030 will make the 2°C target substantially more challenging, raising doubts about the possibility of maintaining the 2°C target in such circumstances. The Durban Platform negotiations can therefore play an important role in keeping open the option to limit global mean warming to 2°C.

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