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Scenarios on the feasibility of emissions reductions consistent with 2°C stabilization

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Scenarios on the feasibility of emissions reductions consistent with 2°C stabilization

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Abstract

While the international community aims to limit global warming below 2°C to prevent dangerous climate change, progress towards a global climate agreement to implement the emissions reductions required to reach this target is slow. This report summarizes the results of the UFOPLAN project “Scenarios on the feasibility of emissions reduction scenarios consistent with 2°C stabilization” conducted by PIK and Ecofys. We use an integrated energy-economy-climate modeling system to examine how a further delay of cooperative action increases economic mitigation challenges. With comprehensive emissions reductions starting in 2020 and full technology availability we estimate that maximum 21st century warming may still be limited to ~1.7°C. A further delay of climate policies results in a strong increase of short-term economic impacts of climate policies, and increases the lower limit of achievable climate targets by up to about 0.4°C in the scenarios considered. Our results show that progress in international climate negotiations within this decade is imperative to keep the 2°C target within reach.

In addition, we analyzed the achievements of the international negotiation process under the United Nations Framework Convention on Climate Change (UNFCCC). We argue that the UNFCCC made significant achievements, despite the fact that global greenhouse gas emissions are still increasing. These achievements include awareness raising, the agreement on principles and common goals, supporting preparatory actions to enable emissions reductions and the development of mechanisms to jointly reduce emissions.

Kurzbeschreibung

Die internationale Gemeinschaft hat sich das Ziel gesetzt, die globale Erwärmung auf unter 2°C zu begrenzen, um gefährlichen Klimawandel zu verhindern. Dennoch gibt es nur langsame Fortschritte hin zu einem globalen Klimaabkommen, um die nötigen Emissionsreduktionen zur Erreichung dieses Zieles umzusetzen. Dieser Bericht fasst die Ergebnisse des von PIK und Ecofys durchgeführten UFOPLAN-Projekts “Scenarios on the feasibility of emissions reduction scenarios consistent with 2°C stabilization” zusammen. Wir verwenden ein integriertes Energie-Wirtschafts-Klimamodellsystem um zu untersuchen, wie eine weitere Verzögerung kooperativer internationaler Politikmaßnahmen die wirtschaftlichen Herausforderungen des Klimaschutzes erhöht. Wir schätzen, dass der maximale Temperaturanstieg im 21. Jahrhundert noch auf ~1,7°C begrenzt werden kann, falls 2020 mit umfangreichen Emissionsreduktionen begonnen wird und ein volles Portfolio an Technologien zur Verfügung steht. Eine weitere Verzögerung der Klimapolitik zieht mit sich, dass die kurzfristigen wirtschaftlichen Auswirkungen von Klimaschutzmaßnahmen stark ansteigen würden und das niedrigste erreichbare Klimaziel in den betrachteten Szenarien bis etwa 0,4°C höher liegt. Unsere Ergebnisse zeigen, dass Fortschritte in den internationalen Klimaverhandlungen innerhalb dieses Jahrzehnts entscheidend sind, um das 2-Grad-Ziel in Reichweite zu halten.

Zusätzlich untersuchten wir die Errungenschaften des internationalen Verhandlungsprozesses im Kontext der Klimarahmenkonvention der Vereinten Nationen (UNFCCC). Wir legen dar, dass die UNFCCC Bedeutendes erreicht hat, trotz der Tatsache, dass die globalen Treibhausgasemissionen weiterhin ansteigen. Das Erreichte beinhaltet erhöhte Aufmerksamkeit, die Vereinbarung von Prinzipien und Zielen, Unterstützung für Vorbereitungen möglicher Emissionsreduktionen und die Entwicklung von Mechanismen zur gemeinsamen Emissionsreduktion.

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List of Abbreviations

BECCS	Bioenergy in combination with Carbon Capture and Storage
CCS	Carbon Capture and Storage
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Gross World Product
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
pp	percentage points
tn	trillion (10^{12})
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

1 Executive Summary

1.1 Motivation and background

Climate change is broadly recognized as one of the major global challenges humanity is facing (IPCC 2007). The ultimate goal stated in the United Nations Framework Convention on Climate Change is to "prevent dangerous anthropogenic interference with the climate system". In the Copenhagen Accord and the subsequent Cancun Agreements, the international community adopted the long-term target of limiting the increase of global mean temperature to no more than 2°C relative to pre-industrial levels (referred to as "2°C target" in the following[1]). While no level of global warming can be considered inherently safe, limiting global average temperature increase to 2°C above pre-industrial levels may reduce the risk of large-scale discontinuities, for instance the melting of the Greenland ice sheet (Lenton et al. 2008; Smith et al. 2009). Despite the broad recognition of the 2°C target, progress in the implementation of concrete greenhouse gas (GHG) emissions reduction policies has been slow. Even with the implementation of climate policy measures in several world regions (UNEP 2012), global GHG emissions have continued to rise (EDGAR 2011). Reaching the 2°C target with high likelihood implies a tight limit on cumulative future anthropogenic greenhouse gas emissions (Meinshausen et al. 2009; Matthews et al. 2009). Various reports have concluded that pledged national 2020 reduction targets ('Copenhagen pledges') fall short of the reductions required by 2020 to meet the 2°C target in a cost-optimal way (UNEP 2010, 2011a, 2012; Rogelj et al. 2010).

CO_2 emissions have a long-lasting effect on the climate system. To achieve climate stabilization by halting and eventually reversing the increase in atmospheric GHG concentrations, global GHG emissions must be reduced to near zero in the long run (Matthews and Caldeira 2008). This implies the need for a comprehensive global regulation of GHG emissions that covers all regions and sectors. Some mitigation options—such as carbon sinks in forestry or the combination of bioenergy use and carbon capture and storage (BECCS)—result in net negative emissions, and can therefore be used to offset residual emissions from energy use and industry. The decarbonization of economies requires a massive transformation in the way energy is produced and used. No single technology option is sufficient for this task. Currently, however, the deployment of a substantial portfolio of low-carbon technologies faces technical difficulties or limited political support. For instance, carbon capture and storage (CCS), large scale bioenergy production, or nuclear energy are subject to sustainability concerns and public opposition. Similarly, integrating major shares of wind and solar power is challenging because of fluctuating supply from these sources.

Against this background, an in-depth analysis of the achievability of the 2°C target is timely. Through a model-based scenario analysis, we addressed the following research questions (Part A):

- What are key requirements and implications of transformation pathways consistent with the 2°C target?

[1] The 2°C target describes the objective of limiting the increase in global mean temperatures to no more than 2°C relative to pre-industrial levels.

- How do further delays in comprehensive[2] global climate policies affect the attainability of the 2°C target?
- How do the costs of climate stabilization depend on the availability of key technology options?

In a second study we analysed the political enabling framework,.the UNFCCC (Part B):

- What is the impact of the policy framework (UNFCCC) enabling an achievement of the 2°C target?

The results are presented in detail in this final report of the project as well as in the research article “Economic mitigation challenges – how further delay closes the door for achieving climate targets” (published in Environmental Research Letters) and the article “What the UN process on climate change has achieved” (submitted for publication to peer-reviewed scientific journal).

1.2 Part A: Key Results on 2°C target achievability

To study the technological, institutional and economic requirements of meeting the 2°C target, we used the integrated energy-economy-climate model REMIND in combination with the probabilistic climate model MAGICC and evaluated a wide range of scenarios combining different assumptions regarding the start date of comprehensive global climate policies and technology availability.

We compared the following three international climate policy scenarios, which differ in terms of the with different start dates of comprehensive global climate action toward the 2°C target. They represent a wide range of possible outcomes of the currently on-going negotiations of the Durban Platform:

- Act2020 –an optimistic case assuming that the on-going Durban Platform negotiations result in an agreement by 2015 and a global climate policy regime is implemented in 2020
- Act2025 – assuming that the Durban Platform fails to increase ambition of 2020 emissions reductions, but yields a binding agreement on comprehensive reduction targets for 2025
- Act2035 – assuming a failure of the Durban negotiations resulting in a further delay of comprehensive emissions reductions until 2035

In addition, we consider a scenario in which we assume immediate action, i.e. comprehensive emissions reductions starting already in 2015 (Immediate). This scenario must be considered hypothetical, since none of the current climate negotiation tracks would be able to deliver such an outcome. Any of these scenarios is modeled through the end of the 21st century.

Along a second scenario dimension, we combine the policy cases with six variants of technology availability:

- Default – full technology portfolio
- NoCCS – no availability of carbon capture and storage (CCS)
- LimBio – reduced bioenergy potential (100 EJ compared to 300 EJ in all other cases)

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[2] In the remainder of this report “comprehensive” refers to climate policies address emissions from all regions and all major greenhouse gas emitting sectors.

- NucPO – phase-out of nuclear energy
- LimSW – penetration of solar and wind power limited to 20%
- LowEI – lower energy intensity, with final energy demand per economic output decreasing faster than historically observed

To evaluate how these policy and technology cases impact the feasibility of meeting climate targets, we examine the following indicators:

- **Aggregated mitigation costs**, calculated as macro-economic consumption losses relative to the gross world product (GWP) in the baseline scenario; both consumption losses and GWP are aggregated over the time horizon 2010-2100 and discounted at 5%;
- **Transitional growth reduction** – calculated as the reduction of income growth during the first decade after the phase-in of comprehensive mitigation policies and used as an indicator of the short-term distortions induced by the phase-in of climate policies;
- **Carbon market value,** defined as the aggregated and discounted value of greenhouse gases emitted from 2010–2100, used as a proxy for the potential distributional impactsü when defining the regional and sectoral burden sharing under a comprehensive cap-and-trade regime;
- **Energy price increase**, measured in terms of the climate-policy-induced short-term increase of the global final energy price index, as an indicator of the effect of climate policies on the energy bills of households and firms.

These indicators allow us to assess not only the long-term mitigation challenges, but also the challenges encountered at time-scales that are more relevant for today's decision-makers. Note that these economic indicators only measure efforts related to emissions reductions but do not account for avoided damages or co-benefits of climate change mitigation.

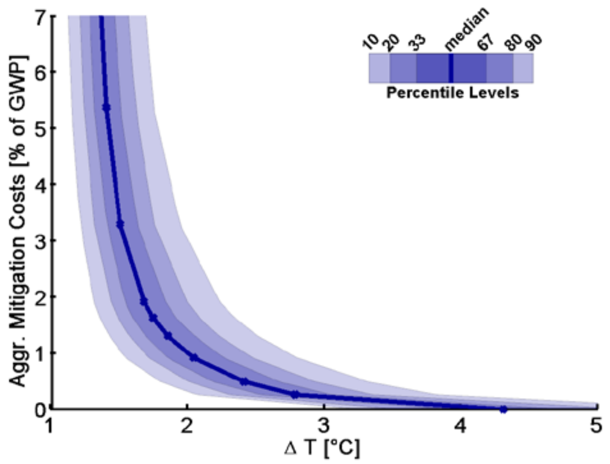
The results of the analysis allow us to draw conclusions regarding the impact of policy delay, the institutional challenges, and the role of mitigation technologies and energy efficiency.

(1) The 2°C target can still be met, but there is not much leeway

Our modeling indicates that it is technically and economically feasible for the international community to sufficiently restrain atmospheric GHG concentrations so that global warming can likely be limited to 2°C above preindustrial levels. However, this conclusion is very sensitive to assumptions about the timing and effectiveness of policies, the availability of mitigation technology options, and the climate system's response. Mitigation costs rise dramatically if the target stringency is beyond the reach of affordable mitigation options. A robust finding from our modeling is that for any given set of policy and technology assumptions, there is such a point beyond which mitigation costs increase disproportionately. We find that under favorable circumstances, the 2°C target is not yet beyond such a point but that there is limited leeway for inefficiency. Effective international cooperation and a broad portfolio of mitigation options are needed as otherwise the potential for affordable mitigation could fall short of the 2°C target.

The lack of leeway for achieving the 2°C target is illustrated in Figure 1. Based on our modeling, this figure shows the relation between maximum temperature increases and mitigation costs, assuming the implementation of a global climate policy regime in 2020 and a default range of technology options. The aggregate mitigation costs of limiting global warming to 2°C with 67% likelihood[3] are shown to be below 1.5% of gross world product. Even moderately more stringent targets, however, can increase the costs substantially. If circumstances are less favorable than assumed in this figure – e.g. policy delays, inefficient implementation, or technology barriers – the curve would move to the right, and the upsurge in mitigation costs would already occur around the 2°C target. The room for inefficiency and delay is therefore limited, as elaborated in the next sections.

Figure 1 : The tradeoff between maximum 21st century surface air temperature increase and aggregated mitigation costs for the Act2020 scenario with Default technology assumptions. Shaded bands show geophysical uncertainty ranges.

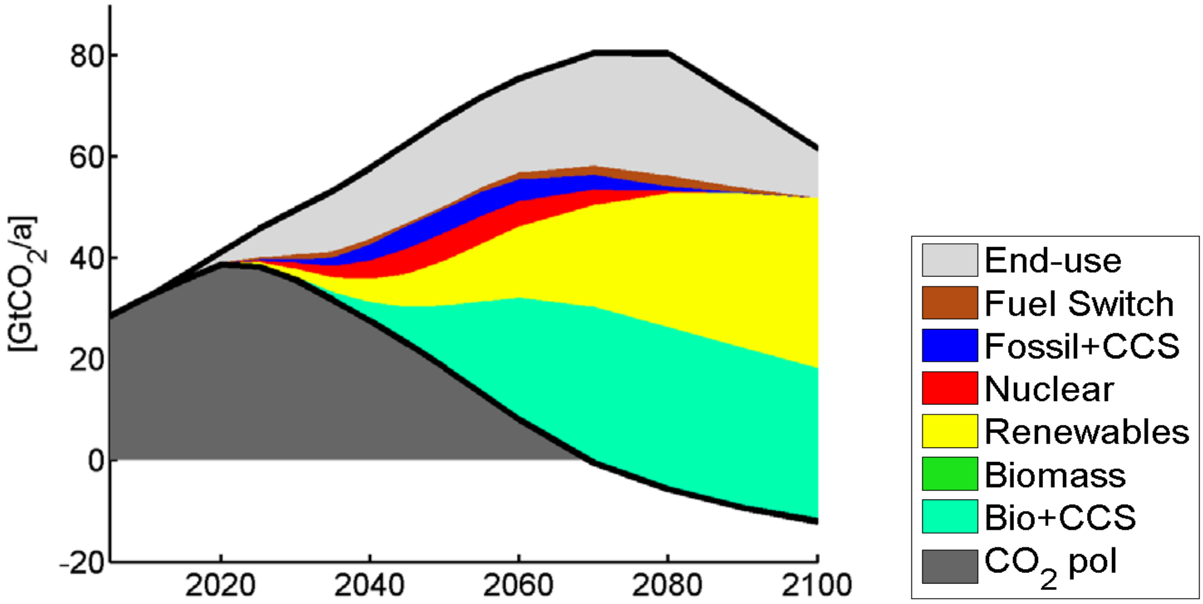


(2) 2°C requires a full-scale transformation of global energy systems

Climate stabilization requires a full-scale transformation of the global energy system to low-carbon technologies. In order to meet the 2°C target with high likelihood, global GHG emissions have to be cut in half relative to current levels by about mid-century and approach zero toward the end of the century. In case of any substantial delay in global cooperation on climate policy, a 2°C target may even require net-negative global GHG emissions by the end of the century in order to offset excess atmospheric concentrations of greenhouse gases due to the failure to reign in emissions in the near term.

[3] The 67% likelihood level corresponds to a "likely" chance in IPCC terminology. It will be used as a reference point throughout this report.

Figure 2: Contribution of technologies to the reduction of CO_2 emissions from the energy system.



No single technology is sufficient to deliver such an outcome. Rather, a portfolio of options is needed. Figure 2 shows how different technology groups contribute to emissions reductions for a 2°C scenario that assumes full technology availability. The costs for reaching the 2°C target with a likely chance[4] is a function of technology availability and the start date of comprehensive mitigation action, as shown in Figure 3. We observe that the impact of foregoing technology options depends on technology types. Unavailability of both fossil CCS and BECCS results in the greatest increase in the costs of mitigation. The similarity of the results of a) unavailability of BECCS and b) unavailability of both BECCS and fossil CCS underscores the importance of negative emissions, and suggest that BECCS is more crucial for low stabilization than fossil CCS. Limited bioenergy availability also increases the costs of mitigation substantially. In case of a nuclear phase-out, mitigation costs are only slightly higher than in the scenario with full technology availability. Limited deployment of solar and wind power has a relatively moderate impact on costs.

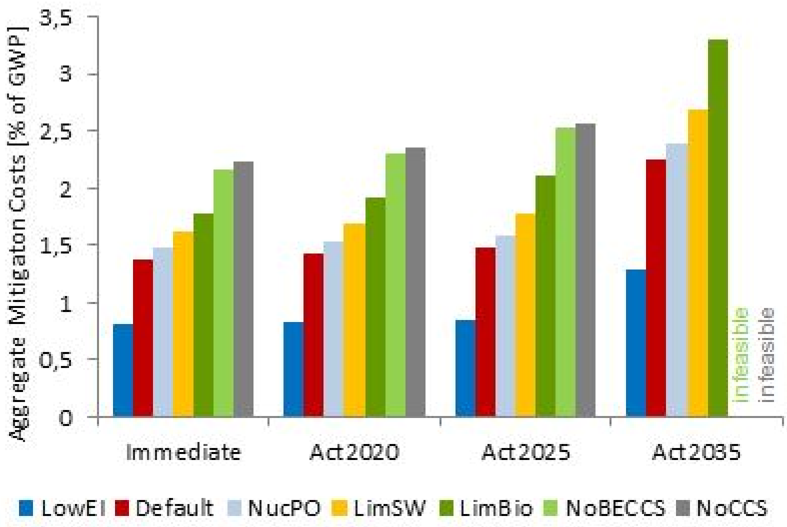
The results can be understood in terms of a principle difference between decarbonization patterns of electricity and non-electric energy supply. For power generation, a variety of alternative low-carbon options is available, such as nuclear, solar and wind power, carbon capture and storage and bioenergy. Transitioning to these options requires clear policy signals that establish a solid basis for investments so that the reliance on current, carbon-intensive power systems can be overcome. In addition, the large-scale deployment of low-carbon power options faces technical and political hurdles such as the intermittency of solar and wind power and the risks of nuclear power. Nonetheless, viable solutions are being developed and even if the barriers to some of these options remain unresolved, there are enough alternatives for low-carbon electricity to make up for limitations among some options. Our modeling indicates that decarbonizing the global electricity sector is techno-economically feasible regardless of whether this transformation relies heavily on nuclear power or primarily on renewable energy.

While the electricity sector can be readily decarbonized, only few options exist to reduce emissions from non-electric energy use in industry, buildings and transport. These include energy efficiency improvements, the switch to electricity as an energy carrier (e.g. by an

[4] In line with the uncertainty guidelines of the IPCC, we define a 67% probability level as "likely".

electrification of transport, or by using geothermal heat pumps in buildings), and the use of bioenergy. If global emissions are not curtailed fast enough, atmospheric GHG concentrations may reach levels that require any remaining emissions to be offset by negative emissions elsewhere. A primary means for achieving this is bioenergy in combination with carbon capture and storage (BECCS), which stores in the ground the CO_2 extracted from the atmosphere by energy crops. If BECCS is not an option because CCS technologies are unavailable, it becomes increasingly difficult to achieve the 2°C target even with a decarbonized electricity sector. The costs of achieving the 2°C target increases by about 65% if CCS is not available in our *Act2020* scenario, in which a global climate regime starts in 2020, and by about 75% if the policy start date is delayed until 2025 (Figure 3). If a global climate policy regime is delayed until 2035, the 2°C target is not feasible anymore without negative emissions through BECCS. Limited bioenergy potential also reduces the potential for BECCS and raises the cost of low climate stabilization. This outcome confirms the results of previous studies that have pointed out the crucial importance of BECCS for low stabilization despite the land use challenges that large-scale bioenergy use may entail (Edenhofer et al. 2010; Vuuren et al. 2010; Azar et al. 2010). Since nuclear, solar and wind power can be substituted for each other, the cost impacts of a nuclear phase-out or of limited potential for solar and wind energy are much more limited.

Figure 3: Mitigation costs as a share of gross world product (GWP), each aggregated over the 21st century and discounted at 5%, for the Act2020, Act2025 and Act2035 policy cases and different technology cases: default technology availability (Default) nuclear phase-out (NucPO), limited potential for solar and wind energy (LimSW), limited bioenergy availability (LimBio), and unavailability of carbon capture and storage (NoCCS). If global climate policy is delayed until 2035, meeting the 2°C target is infeasible in the NoCCS case.

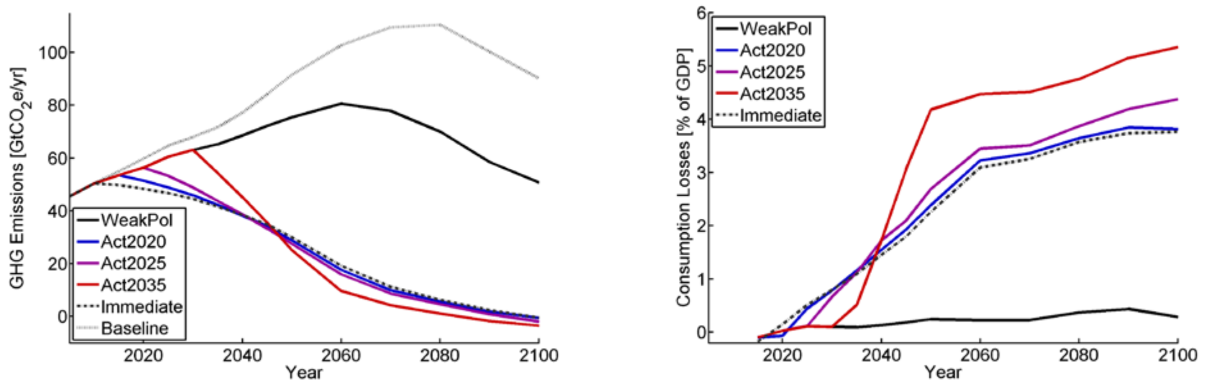


(3) A comprehensive global agreement on emission reductions needs to be implemented soon

The stated goal of the ongoing Durban negotiations is to limit global warming to 2°C above preindustrial levels through a comprehensive global climate policy regime envisaged to enter into force by 2020. Even if these aspirations are met, global GHG emissions would have to approach zero over the course of the century in order to prevent further temperature increase. Any delay of climate policies results not only in higher short term emissions, but also in fewer medium-term mitigation opportunities after the adoption of comprehensive emission reduction targets ("carbon lock-in"). The higher emissions have to be offset later by more rapid and deeper emission cuts in order to still reach the same climate stabilization target. (Figure 4a). The economic implications can be substantial, since delayed action necessitates the use of very expensive mitigation options that could be avoided if emissions are cut earlier. Our modeling shows that delaying the implementation of a global climate policy regime increases aggregate mitigation costs despite avoiding short-term costs and even if long-term costs are discounted at 5% per year (Figure 4b).

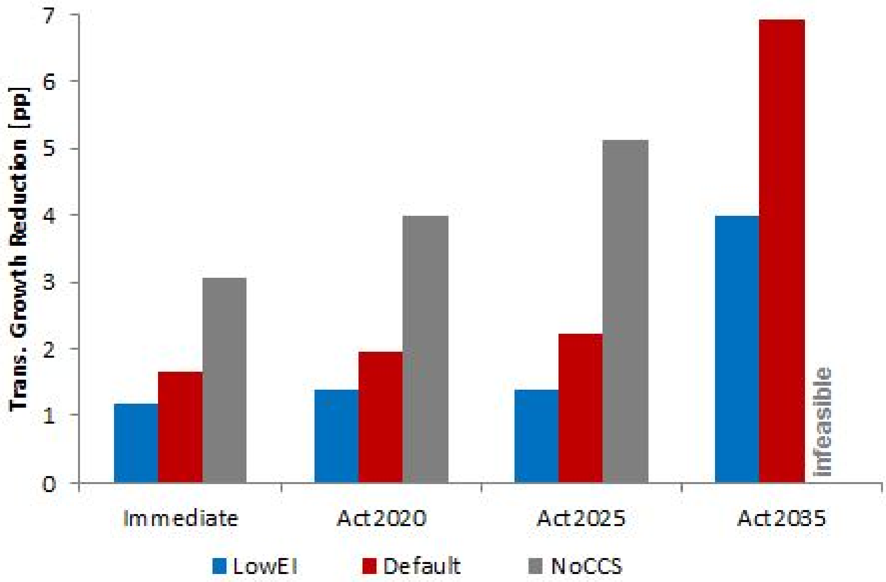
Figure 4: (a) Emission pathways, and (b) consumption losses for the Baseline and for scenarios with implementation of a global climate policy regime in 2020 (Act2020), 2025 (Act2025), or 2035 (Act2035).

A B



Among the most challenging implications of a delayed policy regime are the inertia of energy systems and the economic distortions that a rapid transition would entail. A policy delay would allow further expansion of carbon-intensive capacity that would need to be retired before the end of its economic lifetime if climate objectives are to be achieved. In scenarios with a delay of global cooperation until 2035, transitioning to climate policies in line with the 2°C target would reduce global consumption growth by about 7 percentage points during the transition decade under default technology assumptions. Measured against global consumption growth in the baseline of around 30% to 40% per decade of the first half of the 21st century, such a dramatic short-term effect would render the political feasibility of delayed mitigation questionable. For comparison, IMF data suggests that the financial crisis of 2008 reduced global economic output by around 5%. Only particularly favorable energy efficiency policies would limit transitory global consumption growth reduction to around 5 percentage points if stringent climate policies are delayed until 2035. By contrast, if comprehensive policies are implemented by 2025, growth reduction during the transition decade can be kept below 2.5 percentage points in the default technology case.

Figure 5: Transitional growth reduction during the decade following the implementation of a global climate policy regime in 2020 (Act2020), 2025 (Act2025), or 2035 (Act2035) under alternative technology assumptions: Default, low energy intensity (LowEI), and unavailability of CCS (NoCCS).



Our results also demonstrate that the reliance on technologies is greatly increased if mitigation action is delayed further. In case of a further delay, the cost markup induced by technology failure increases substantially (Figure 3). For the *Act2035* scenario, we even find that within the constraints implemented in our model it is impossible to reduce emissions sufficiently fast for reaching the 2°C target with a likely chance if CCS is unavailable.

(4) Dedicated energy efficiency policies can increase the leeway in the climate mitigation effort

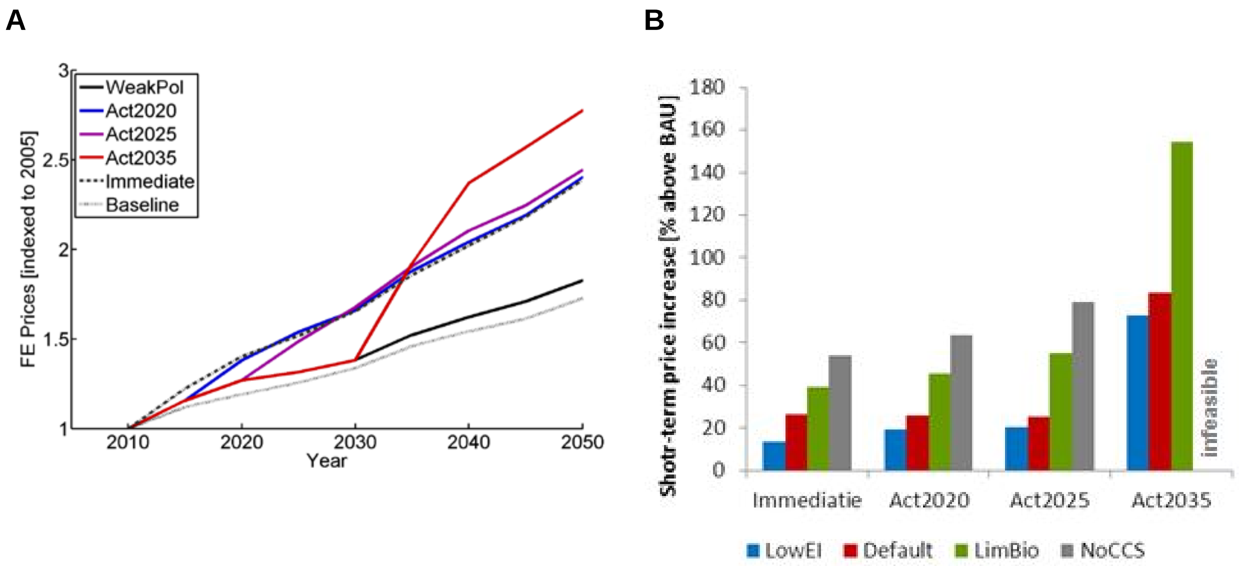
The implementation of carbon pricing leads to an increase in energy prices, and is therefore bound to increase the return on energy efficiency investment by increasing the value of energy savings. This mechanism of demand responses to increasing energy prices is taken into account in our scenarios and is captured by the energy-economic modeling framework. This effect is only moderate, though, since market failures and implementation barriers make it unlikely that carbon pricing alone is able to deliver the full cost-effective energy efficiency potential. Dedicated policies can help to remove barriers such as split incentives between landlords and residents, access to energy efficiency financing, and lacking information about appliance energy use. The energy intensity of economies can also substantially improve through behavioral changes that result in lower demand for final energy. Such behavior changes may not be directed but could be facilitated by policy.

When modeling a scenario under which the energy intensity of the global economy improves at a significantly faster than historical rate – resulting in a 25% lower energy intensity in 2050 than if historical trends continued – we observe that more leeway is created for affordable climate mitigation. For instance, the low-energy-intensity case reduces the transitional growth reduction during the first decade of comprehensive global climate policy by 29% if the policy is implemented in 2020 and even by 38% or 43% respectively if the policy is implemented in 2025 or 2035 (Figure 5). Since transitional costs are among the main barriers to stringent policy implementation, improved energy efficiency can significantly improve the feasibility of ambitious policies. Our analysis does not combine the low-energy-intensity case with cases in which mitigation technologies are limited, but it stands to reason that improved energy efficiency can also offset some of the mitigation cost impact of limited low-carbon energy supply options.

(5) We need strong institutions to deal with the economic challenges related to low stabilization pathways.

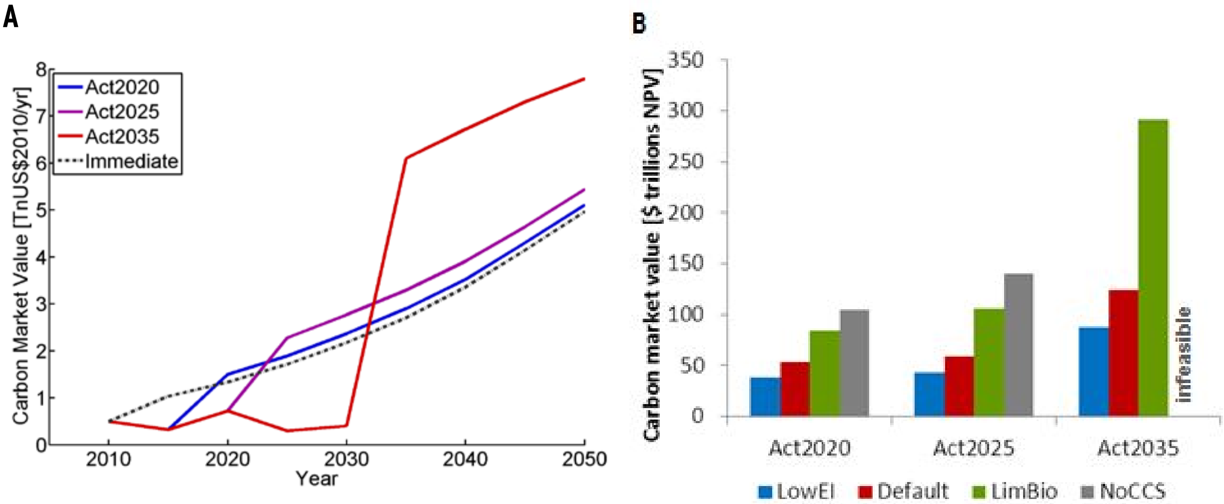
Managing the economic challenges and distributional questions associated with stringent climate change mitigation requires strong international and domestic institutions. Even if a comprehensive global agreement is implemented soon enough to avoid high aggregate economic costs, the impacts of policies will be felt harder during the initial transition period and, depending on the policy design, will likely raise distributional issues among and within countries. To avoid that the costs of mitigation policies fall disproportionately on the poor and to help consumers and businesses deal with policy-induced energy price increases requires effective institutions. Similarly, strong institutions are needed to help manage potential challenges arising from energy system transformations such as the impact of bioenergy on land use and nuclear power safety standards.

Figure 6: (a) Development over time of final energy prices indexed to 2010 under climate policy regimes Act2020, Act2025 and Act2035 as well as baseline conditions. (b) shows the short term energy price increase (first decade after target implementation) induced by climate polices, measured as difference to baseline (BAU) for different start dates of climate policies, and selected technology scenarios.



Energy price increases are among the most direct impacts of climate policies on households and firms. Their impact depends on the rate of the increases: if energy prices rise quickly, there is little time for adaptation through technological or behavioral changes. We assume that even without climate policy, energy prices would increase at a rate of roughly 20% per decade. If a comprehensive global agreement is implemented by 2020 and the default portfolio of mitigation options is available, pursuing the 2°C target leads to an additional energy price increase of around 20 percentage points over the first decade of implementation. Delaying a cooperative agreement until 2035 results in much stronger short-term price increases of up to 100 percentage points (Figure 6). Various industrialized countries have recently adjusted to strong energy price increases. For example, household electricity prices in Germany rose by 60% between 2000 and 2010 and US gasoline prices more than doubled between 1998 and 2008 (ENERDATA 2013). For developing countries, however, there is some evidence that rapid increases in energy prices can be causes of social unrest (Morgan 2008).

Figure 7: (a) Development over time of carbon market value under the climate policy regimes Act2020, Act2025 and Act2035 as well as immediate climate policy. (b) shows the aggregated carbon market value, cumulated over 2010-2100 and discounted at 5%. Delay of global action increases the long-term carbon market value.



Climate policies that are both stringent and efficient require carbon prices that are harmonized across regions and sectors so as to ensure equal mitigation costs at the margin (Stern 2007). Harmonizing carbon prices presents an institutional challenge as it raises the question of how to account for the needs of more vulnerable regions and sectors and how to distribute the potentially large revenues. This is true regardless of whether the approach is to harmonize carbon taxes among countries with very different economic conditions or to create an international emissions trading scheme that involves the allocation of national emission budgets and international capital flows. We can assess the potential distributional challenge of such capital flows by looking at the market value of the emissions covered by carbon pricing. Assuming a global cap and trade system starting in 2020 and achieving emissions reductions in line with the 2°C target, we find that the cumulated present value of emissions permits over the 21st century amounts to about US$50 trillion under default technology assumptions (Figure 7). This is comparable to the market value of crude oil consumed over the same period in the absence of climate policy. The distributional challenges are even larger if action is delayed until 2035 or if critical technology options are limited. For instance, if bioenergy availability is limited in order to reduce land use conflicts, the carbon market value more than doubles.

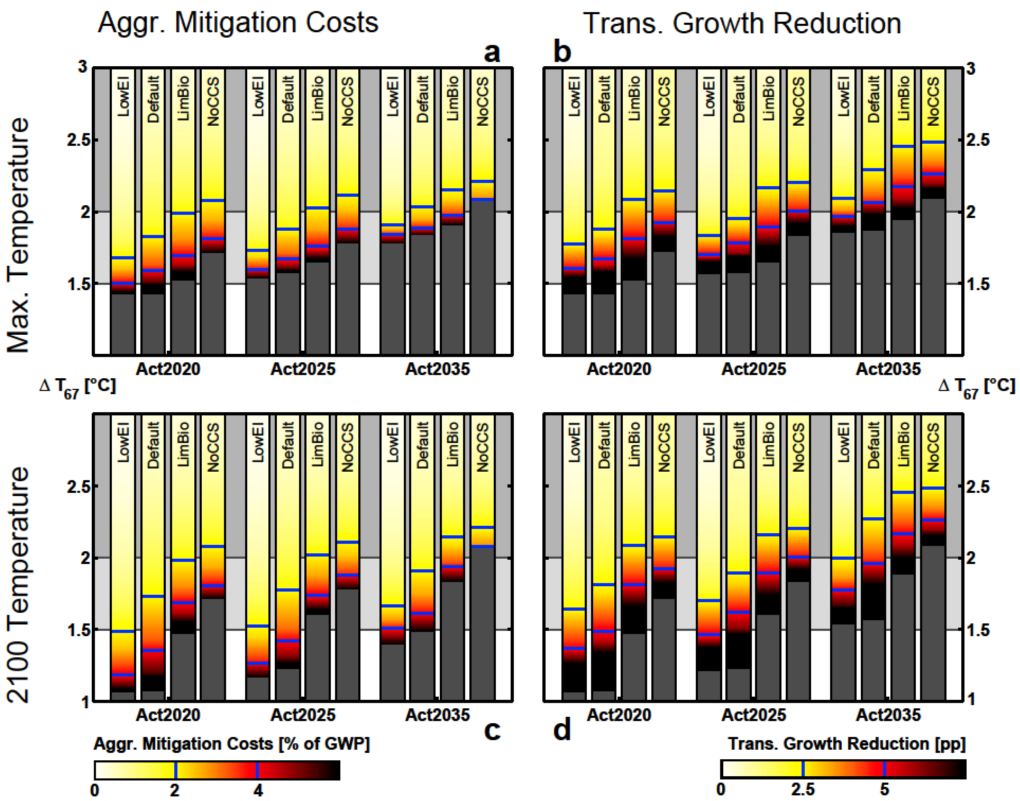
Higher carbon market values imply and higher stakes in the haggling about the distribution of policy costs and benefits across countries, economic sectors and societal groups. In any case, strong institutions are needed both at the national and international level to ensure that climate policies are implemented in a fashion that is widely accepted as fair and equitable.

(6) A further delay of climate policy increases the lower limit of achievable climate targets

Unless societies develop an unprecedented willingness to voluntarily accept short-term economic pain for long-term environmental gain, climate policies can only be successfully implemented if economic impacts can be kept at a moderate level. We estimate that the lower limit of achievable climate targets is roughly 1.7°C, if comprehensive mitigation policies are implemented in 2020, and the full portfolio of technologies is available. This estimate assumes the maximum acceptable economic impacts to be aggregate mitigation costs of 4% of GWP, a short-term reduction of net income growth of 5 percentage points, an aggregated carbon trade volume of US$ 100 per ton, and a short-term energy price increase induced by climate policy of 100 percentage points.

If comprehensive global climate policies are delayed by another 15 years, the lower limit of achievable climate targets increases by about 0.4°C because of the effects of delay on income growth during the transition phase (Figure 8). Similarly, unavailability of CCS increases the lower limit by about 0.3°C. The door to climate stabilization remains ajar, but with every year of policy delay it closes further, increasing the reliance on critical technologies.

Figure 8: (a) Overview of the combined effects of mitigation timing and technology availability on achievability of either not-to-exceed targets (upper panels), or 2100 temperature targets that allow for temporary overshoot (lower panels). Graphs show economic challenges (color shading) in terms of aggregated policy costs (left panels a,c), and transitional growth reduction (right panels b,d), as a function of maximum 2010-2100 temperature increase (a,b) or 2100 temperature increase (c,d). Dark grey areas at the base of bars indicate temperature target levels that were not achieved with the range of carbon price paths assumed.



(7) It is unlikely that we can prevent temperatures from exceeding 1.5°C over the course of the 21st century. Returning to 1.5°C by 2100 would require a massive policy effort and the large-scale generation of negative emissions.

For the preceding analysis, we focused on climate outcomes in terms of maximum temperature increases in the 2010-2100 period. This is equivalent to formulating climate targets as "not-to-exceed" targets. Our modeling shows it is unlikely that global warming can be kept below 1.5°C throughout the century. However, if temperature levels in 2100 are considered instead of maximum temperatures over the time frame of 2010–2100, lower climate targets are achievable despite a temporary overshooting of the target. In this interpretation, the 1.5°C target is very ambitious, but not out of reach. Temperature levels in 2100 can only be limited to 1.5°C without major economic disruptions if comprehensive emissions reductions materialize already by 2020, and if biomass in combination with carbon capture and storage (BECCS) is deployed at large-scale. This underscores crucial tradeoffs between climate target stringency and adverse environmental and societal side-effects, such as those implied by large-scale bioenergy use.

Overall, we find that technology portfolios have an even more critical influence on achievable 2100 temperature levels than on maximum temperatures. This is because for trajectories with overshoot, the effects of technologies only come to bear in a limited time frame (until the maximum temperature is reached), while in case of 2100 temperatures the effects of technology cumulate over the entire century.

1.3 Key results on the role of the UNFCCC process

In the paper “What the UN process on climate change has achieved” we analyzed the achievements of the international negotiation process under the United Nations Framework Convention on Climate Change (UNFCCC).

We find that the UNFCCC process has made substantial achievements in the ground work for action and is well placed and well on track to further advance these objectives:

- **Raising awareness**: In particular, the annual meetings under the UNFCCC regularly place the topic of climate change very high on the political agenda. The UNFCCC process attracted unprecedented attention at the end of 2009 when the conference in Copenhagen was to agree on a new international climate treaty. Over 100 heads of state, in total 40 000 participants came together, more than ever for any environmental conference. It forced country governments to form a position and formulate strategies on climate change.
- **Agreeing on principles and common goals**: The UN process agreed on globally accepted goals that guide action. The common goal agreed in 1992 to “preventing dangerous anthropogenic interference with the climate system” was specified in 2010/11 as the intent to “reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius”. The principle of “common but differentiated responsibilities and respective capabilities” of countries included in the text of 1992 has shaped the structure of commitments and actions by countries agreed subsequently. The universal membership of the UNFCCC provides the basis for such agreement with very broad scope and legitimacy. In fact only a UN body is able to provide such level of legitimacy.
- **Preparing for emission reductions - GHG inventories, projections, strategies**: The UNFCCC process has made substantial progress to encourage countries to prepare consistent, comparable and reviewed national greenhouse gas inventories, actions and strategies, which are now reported biannually. Such comprehensive information would not exist without the UNFCCC process. It is internationally consistent due to the universal membership to the process.
- **Developing international policy instruments to jointly achieve goals**: The UNFCCC process introduced carbon market mechanisms such as International Emissions Trading, Joint Implementation and the Clean Development Mechanism. These mechanisms are fully operational and served as the basis for national policy instruments, such as national emission trading schemes or voluntary offset mechanisms. Further mechanisms are under development, e.g. on reducing emissions from deforestation and degradation.

We also find that UNFCCC process has played a major role in other objectives of international cooperation, but these elements could still be further enhanced compared to the potential:

- **Sharing information on policies, technologies, institutions and actions by other actors**: The UN process established regularly reporting of national actions on climate change. A comprehensive discussion of this information is still limited. Countries within the UNFCCC process could work toward engaging in significantly more comprehensive analysis and discussion of best practices, positive examples and lessons learned from national policies and action, in addition to only reporting on them. This could be a future focus of the UNFCCC, eventually as important as setting GHG reduction targets.
- **Monitoring action by countries or other actors to increase transparency and assess if in total sufficient**: Actions by countries are currently reviewed only to a limited extent. For developed countries the review is explicitly limited to check whether the reporting guidelines were followed, not to assess if the action is comprehensive or sufficient to meet the targets. The details of the review of developing countries' actions is yet to be defined and implemented. The comprehensive information sharing could be supplemented by a stringent but facilitative review of progress of national actions. The enhanced reviews under the UNFCCC could aim to demonstrate that they are to the benefit of those that are reviewed. For example one could install voluntary pilot reviews for those countries that wish to be reviewed to build trust and help to develop review guidelines for the future. This could be complemented by independent additional review at the global level, currently performed by other organisations without a specific mandate from the UNFCCC (UNEP 2010, 2011, 2012; Höhne et al. 2011).
- **Incentivising national policies**: There are traceable examples showing that the preparatory work and the target setting of the UNFCCC process has directly led to national policies that reduced GHG emissions and that clearly would not have happened otherwise. Several countries recently implemented national climate laws that make their international emission reduction proposal for 2020 nationally binding. Mexico, Brazil and South Korea for example transformed the internationally proposed GHG target into national law. Australia implemented a clean energy future plan that is designed to meet its international pledge. Countries would not have had these targets without the UNFCCC process. In addition, various countries introduced national emission trading systems designed to implement commitments under the Kyoto Protocol or to be compatible with the Kyoto Protocol's mechanisms. These include, for example, the EU, Australia, New Zealand, Switzerland and Kazakhstan. Systems in California, Quebec, Regional Greenhouse Gas initiative (Northeastern USA) and very recently also in some Chinese jurisdictions and at the national level in South Korea were were encouraged by these emerging national systems.
- **Providing international assistance**: The UNFCCC has stimulated financial flows from developed to developing countries on climate change. The level of financing was significantly increased through the agreement in Copenhagen in 2009 on "fast start financing" of US$ 10 billion per year from 2010 to 2012 to be provided by developed countries following the principle of common but differentiated responsibilities. The establishment of the Green Climate Fund was agreed in 2010, which will be one of the

main international climate finance channels. Countries agreed to mobilize US$ 100 billion per year by 2020. However, the scale of financing is criticized as too low and too slow. Due to the lack of common rules, some governments label already existing flows as additional. A further criticism is that there is no equitable access to the resources (Axel Michaelowa and Katharina Michaelowa 2011).

- **Defining measurable GHG reduction targets / commitments / actions**: Substantial progress has been made with the setting of emission reduction targets / pledges for all major emitters. The first commitment set out in Article 4.2 (a) and (b) of the UNFCCC (UNFCCC 1992), stipulates that developed countries should implement national policies “with the aim of returning individually or jointly to their 1990 level by the turn of the century”. This indicative target was actually met. As a next step, the Kyoto Protocol established economy-wide binding targets for developed countries to collectively reduce their greenhouse gas emissions by 5.2% below 1990 levels in the period from 2008 to 2012. The agreement of concrete reduction targets of legally binding nature, together with a compliance procedure and possible penalties are unprecedented in international environmental law. After having signed the Protocol in 1997, the USA refrained to ratify it. Canada did ratify, but in December 2011 announced not to implement the reduction target and to withdraw from the Protocol completely. A second commitment period from 2013 to 2020 was agreed in 2012, including emission reduction targets for a limited number of developed countries. Some of the largest developed country emitters are still reluctant to join, e.g. USA, Canada, Japan and Russia.

In the run up to the Copenhagen conference in December 2009 and shortly thereafter all major countries submitted emission reduction proposals and actions for 2020. These proposals and actions were recorded and acknowledged in the Cancun Agreements adopted in December 2010, but do not have a legally binding nature. Still, all major developing countries actually submitted quantitative GHG emission reduction targets for 2020. This is remarkable, because until 2007 all of these countries had constantly resisted formulating any quantitative targets for themselves.

The 2°C limit has been an important benchmark for many countries when setting their national emission reduction target. For developed countries, the often mentioned range that is compatible with 2°C is 25% to 40% below 1990 in 2020 (Gupta et al. 2007; den Elzen and Höhne 2008, 2010). Countries like Japan (-25%) and Norway (-30% to -40%) seem to be influenced by this range. For developing countries the comparable range is -15% to -30% below a business as usual scenario in 2020 (den Elzen and Höhne 2008, 2010). Countries like Mexico (-30% from previously -20%), South Korea (-30%), South Africa (-34%), Brazil (-36% to -39%) and Indonesia (-26% to 41%) seem to be guided by these ranges.

Although not legally binding and in sum insufficient to limit temperature increase to below 2°C (UNEP 2012; Höhne et al. 2011), they constitute a major achievement and incentivise national policies to reduce emissions. It essentially also has overcome the formerly rigid divide between developed and developing countries. The general reluctance of countries to be bound internationally by measurable and ambitious targets is unlikely to be solved by any other process or institution.

Solving climate change is a global challenge. Our analysis showed that the UNFCCC process plays an essential role in solving this global challenge by facilitating and framing the international cooperation and has significant scope to enhance this role in the future.

2 Zusammenfassung

2.1 Motivation und Hintergrund

Der Klimawandel ist eine der wichtigsten Herausforderungen, der die Menschheit gegenübersteht (IPCC 2007). Das Ziel der Klimarahmenkonvention der Vereinten Nationen, ist die „Verhinderung einer gefährlichen anthropogenen Störung des Klimasystems". Im Copenhagen Accord und im Cancún Agreement hat sich die internationale Gemeinschaft das langfristige Ziel festgelegt, den Anstieg der globalen Durchschnittstemperatur auf nicht mehr als 2°C im Vergleich zum vorindustriellen Niveau zu begrenzen (im Folgenden als 2-Grad-Ziel bezeichnet[5]). Auch wenn kein Maß an globaler Erwärmung als inhärent sicher gelten kann, könnte eine Begrenzung des Temperaturanstiegs auf 2°C über dem vorindustriellen Niveau das Risiko gravierender Diskontinuitäten – wie z. B. das Abschmelzen des Grönlandeises – wesentlich verringern (Lenton et al. 2008; Smith et al. 2009). Trotz der breiten Anerkennung des 2-Grad-Ziels ist die Umsetzung konkreter Maßnahmen zur Reduzierung von Treibhausgasemissionen bisher nur langsam vorangeschritten. Obwohl verschiedene Weltregionen Klimapolitikmaßnahmen umgesetzt haben (UNEP 2012), sind die globalen Emissionen weiter gestiegen (EDGAR 2011). Um das 2-Grad-Ziel mit hoher Wahrscheinlichkeit zu erreichen, bedarf es einer engen Begrenzung der kumulativen zukünftigen Treibhausgasemissionen (Meinshausen et al. 2009; Matthews et al. 2009). Verschiedene Studien kamen zu dem Ergebnis, dass von diversen Nationen zugesicherte Reduktionsziele für 2020 (‚Kopenhagen-Versprechen‘) hinter dem zurückbleiben, was bis 2020 erforderlich ist, um das 2-Grad-Ziel auf kostenoptimalem Weg erreichen zu können (UNEP 2010, 2011a, 2012; Rogelj et al. 2010).

CO_2-Emissionen haben dauerhafte Auswirkungen auf das Klimasystem. Um eine Klimastabilisierung durch ein Abstoppen oder letztendlich eine Umkehr des Anstiegs der atmosphärischen Treibhausgaskonzentration zu erreichen, müssen die globalen Treibhausgasemissionen langfristig auf nahe Null reduziert werden (Matthews and Caldeira 2008). Hierzu bedarf es einer umfassenden globalen Regulierung der Treibhausgasemissionen, die alle Regionen und Sektoren umfasst. Es gibt Klimaschutzoptionen, die netto zu negativen Emissionen führen – wie z. B. Kohlenstoffsenken im Landnutzungssektor oder die Verwendung von Bioenergie in Kombination mit Kohlenstoffabscheidung und –speicherung (CCS). Diese negativen Emissionen können verbleibende Emissionen kompensieren. Tiefgreifende Emissionsreduktionen setzen eine umfassende Transformation der Energieerzeugung und -nutzung voraus. Keine einzelne Technologieoption ist für diese Aufgabe ausreichend. Allerdings sind viele Klimaschutztechnologien noch nicht ausgereift oder gesellschaftlich umstritten. So gibt es Zweifel an der Nachhaltigkeit von Kernenergie, CCS und der großflächigen Erzeugung von Bioenergie. Andererseits stellt die Integration großer Anteile von Strom aus Sonnen- und Windkraftwerken, deren Erzeugung fluktuiert und nur eingeschränkt prognostizierbar ist, eine große Herausforderung dar.

Angesichts dieser Sachlage ist eine ausführliche Analyse zur Erreichbarkeit des 2-Grad-Ziels wichtig. Mittels einer modellbasierten Szenarienanalyse (Teil A) behandelten wir die folgenden Forschungsfragen:

- Welches sind die in Übereinstimmung mit dem 2-Grad-Ziel wichtigsten Voraussetzungen und Implikationen von Transformationspfaden?

[5] Das 2-Grad-Ziel beschreibt das Ziel, den Anstieg der globalen Durchschnittstemperatur auf nicht mehr als 2°C gegenüber dem vorindustriellen Niveau zu begrenzen.

- Wie wirken sich weitere Verzögerungen bei der Einführung umfangreicher[6] Klimaschutzmaßnahmen auf die Erreichbarkeit des 2-Grad-Ziels aus?
- Wie beeinflusst die Verfügbarkeit von Technologieoptionen die Kosten der Klimastabilisierung?
- In einer zweiten Studie (Teil B) analysierten wir den politischen Rahmen für ein umfangreiches Klimaabkommen auf Basis der Klimarahmenkonvention der Vereinten Nationen (UNFCCC):
- Wie beeinflusst die Klimarahmenkonvention (UNFCCC) die Möglichkeit, das 2-Grad-Ziel zu erreichen?

In diesem Bericht werden die aus der Studie entstandenen Schlüsselergebnisse zusammengefasst. Die Ergebnisse sind detailliert in den Aufsätzen „Economic mitigation challenges – how further delay closes the door for achieving climate targets“ und „What the UN process on climate change has achieved“ dargestellt. Beide Aufsätze wurden zur Veröffentlichung in begutachteten wissenschaftlichen Zeitschriften eingereicht.

2.2 Teil A: Zentrale Ergebnisse der Szenarienanalyse zur Erreichbarkeit des 2-Grad-Ziels

Um die technologischen, institutionellen und wirtschaftlichen Anforderungen zur Erreichung des 2-Grad-Ziels zu untersuchen, haben wir das integrierte Energie-Wirtschafts-Klimamodell REMIND zusammen mit dem probabilistischen Klimamodell MAGICC verwandt und unterschiedliche Szenarien untersucht, welche verschiedene Annahmen bezüglich des Beginns eines umfassenden Klimaregimes und der Technologieverfügbarkeit verbinden.

Wir haben die folgenden drei internationalen Klimapolitikszenarien miteinander verglichen, welche sich hinsichtlich des Beginns umfassender globaler Klimaschutzmaßnahmen, die mit dem 2-Grad-Ziel vereinbar sind, unterscheiden. Sie stellen eine Bandbreite möglicher Ergebnisse der laufenden Verhandlungen zur Durban Plattform on Enhanced Action dar:

- Act2020 – ein optimistischer Fall mit der Annahme, dass die Durban-Plattform-Verhandlungen bis 2015 zu einer Vereinbarung führen, und ein globales Klimapolitikregime mit umfassenden Emissionsreduktionen bis 2020 umgesetzt wird
- Act2025 – nimmt an, dass die Durban-Plattform über die bestehenden Versprechen hinaus keine höheren Ambitionen für 2020-Emissionsreduktionen erreicht, aber eine bindende Vereinbarung hinsichtlich umfassender Reduktionsziele für 2025 erwirkt
- Act2035 – nimmt das Scheitern der Durban-Plattform Verhandlungen an, mit dem Ergebnis einer weiteren Verzögerung umfassender Emissionsminderungen bis 2035

In jedem dieser Fälle nehmen wir an, dass bis zur Einführung des globalen Klimaregimes die Klimaschutzanstrengungen schwach und die Klimapolitik fragmentiert bleiben. Hierzu formulieren wir ein Szenario „WeakPol“, in welchem verschiedene Nationen moderate Emissionsreduktionen und Energiepolitikmaßnahmen umsetzen, die einer unambitionierten Auslegung der Kopenhagen-Pledges und deren Fortschreibung entsprechen. Darüber hinaus betrachten wir ein Szenario, in welchem wir annehmen, dass mit den globalen, umfassenden Emissionsreduktionen zur Erreichung des 2°C Ziels sofort begonnen wird (“Immediate“). Dieses Szenario ist als hypothetisch zu betrachten, da keiner der heutigen Klimaverhandlungsstränge in der Lage wäre, solch ein Ergebnis zu liefern. Jedes dieser Szenarien ist bis zum Ende des 21. Jahrhunderts modelliert.

[6] In diesem Dossier steht die Bezeichnung „umfangreich“ für Klimaregime, welche die Treibhausgasemissionen aller Regionen und aller emittierender Sektoren abdecken.

Wir kombinieren die verschiedenen Politikszenarien mit sechs unterschiedlichen Szenarien zur Technologieverfügbarkeit:

- Default – komplettes Technologieportfolio
- NoCCS – keine Verfügbarkeit von Kohlenstoffabscheidung und –speicherung
- LimBio – verringertes Bioenergiepotential (100 EJ verglichen mit 300 EJ in allen anderen Fällen)
- NucPO – Ausstieg aus der Atomenergie
- LimSW – Anteil von Solar- und Windenergie begrenzt auf 20%
- LowEI – geringere Energieintensität, wobei der endgültige Energiebedarf pro Wirtschaftsleistung schneller zurückgeht als historisch beobachtet

Um abzuschätzen, wie diese Politik- und Technologiefälle sich auf die wirtschaftliche Erreichbarkeit des Einhaltens von Klimazielen auswirken, untersuchen wir die folgenden Indikatoren:

- **Aggregierte Vermeidungskosten**, berechnet als Anteil der makroökonomischen Konsumverluste am Weltbruttosozialprodukt im Basisszenario; sowohl die Konsumverluste als auch das Weltbruttosozialprodukt sind über den Zeitraum 2010-2100 aggregiert und mit 5% diskontiert.
- **Kurzfristige Wachstumseffekte** – berechnet als die Verringerung des Einkommenswachstums während der ersten Dekade nach Einführung eines umfassenden Klimaschutzregimes. Übergansvermeidungskosten dienen als Indikator für die kurzfristigen, durch die Einführung von Klimaschutzmaßnahmen verursachten ökonomischen Verwerfungen.
- **Kohlenstoffmarktwert**, definiert als der aggregierte und diskontierte Wert der Zertifikate, die für die zwischen 2010-2100 emittierten Treibhausgase benötigt werden. Der Kohlenstoffmarktwert ist ein Indikator für die potentiellen Verteilungsauswirkungen bei der Bestimmung regionaler und sektoraler Lastenverteilung unter einem umfassenden Emissionshandelsregime.
- **Energiepreisanstieg**, gemessen als zusätzlicher, durch Klimapolitik verursachter, kurzfristiger Anstiegs eines globalen Endenergiepreisindexes. Dieser Wert dient als Indikator für den Effekt von Klimapolitik auf die Energierechnung von Haushalten und Firmen.

Diese Indikatoren ermöglichen es uns, nicht nur die langfristigen, sondern auch die kurz- bis mittelfristigen Vermeidungsherausforderungen zu ermitteln. Übergangsvermeidungskosten und der Anstieg der Energiepreise wirken sich kurzfristig aus, und sind daher besonders relevant für heutige Entscheidungsträger. Es gilt zu beachten, dass diese wirtschaftlichen Indikatoren nur Maßnahmen zur Emissionsreduzierung messen, nicht aber vermiedene Klimaschäden oder Zusatznutzen des Klimaschutzes.

Die Resultate der Analyse erlauben es uns, die Bedeutung des Zeitablaufs von Klimapolitik, institutionelle Herausforderungen und die Rolle von Vermeidungstechnologien und Energieeffizienz zu beurteilen.

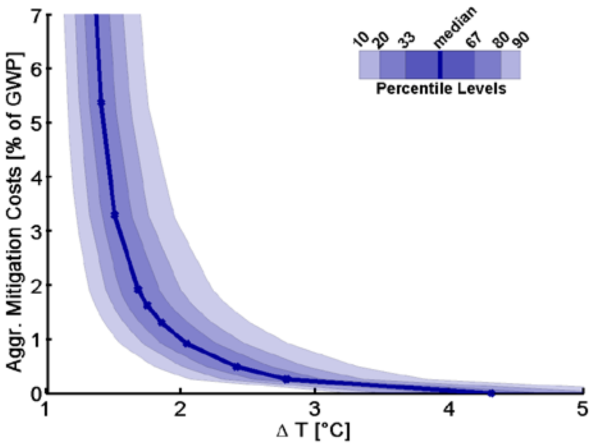
(1) Das 2°-Ziel kann noch erreicht werden, allerdings besteht nur noch wenig Spielraum

Unsere Modellrechnungen zeigen, dass es technisch und wirtschaftlich darstellbar ist, atmosphärische Treibhausgasemissionen in einem Maße zu reduzieren, das die globale Erwärmung mit großer Wahrscheinlichkeit auf 2°C gegenüber dem vorindustriellen Niveau begrenzen würde. Allerdings hängt diese Schlussfolgerung stark von Annahmen bezüglich Zeitvorgaben und Effektivität von Klimapolitik, der Verfügbarkeit von

Vermeidungstechnologieoptionen und der Klimasensitivität ab. Vermeidungskosten steigen überproportional stark, wenn günstige Vermeidungsoptionen erschöpft sind. Ein wesentliches Ergebnis unserer Modellberechnungen besteht darin, dass es für jedwede Politik- und Technologieannahme einen Punkt gibt, an dem Vermeidungskosten überproportional ansteigen. Wir stellen fest, dass unter optimistischen Annahmen das 2-Grad-Ziel noch immer zu moderaten Kosten erreichbar ist, es aber nur noch einen sehr begrenzten Spielraum für weitere klimapolitische Verzögerungen oder Flexibilität bei der Wahl von Klimaschutztechnologien gibt.

Der geringe Spielraum, um das 2-Grad-Ziel zu erreichen, wird aus Abb. 9 deutlich. Sie zeigt den aus den Modellrechnungen abgeleiteten Zusammenhang zwischen Temperaturanstieg und Vermeidungskosten unter der Annahme, dass 2020 ein globales Klimaregime eingeführt wird und das Standardportfolio an Technologieoptionen zur Verfügung steht. Bei einer Begrenzung der globalen Erwärmung auf 2°C mit einer Wahrscheinlichkeit[7] von 67% betragen die aggregierten Langfristkosten weniger als 1,5% des weltweiten Bruttosozialproduktes. Selbst geringfügig strengere Ziele können jedoch die Kosten deutlich erhöhen. Unter pessimistischeren Annahmen – z. B. Politikverzögerungen, ineffiziente Implementierung oder Technologieschranken – würde dies die Kurve nach rechts verschieben und der Aufwärtstrend bei den Vermeidungskosten würde bereits um das 2-Grad-Ziel herum stattfinden. Wie in den nächsten Abschnitten beschrieben, ist der Raum für Ineffizienz und Verzögerung daher eng bemessen.

Abb. 9: **Das Verhältnis zwischen dem Temperaturanstieg im 21. Jahrhundert (maximale Anstiege der bodennahen Lufttemperaturen im Zeitraum 2010-2100 gegenüber dem vorindustriellen Niveau) und den aggregierten Vermeidungskosten für das Act2020-Szenario mit Standard-Annahmen zum Technologieportfolio. Die schattierten Bereiche zeigen geophysikalische Unsicherheitsbereiche an.**



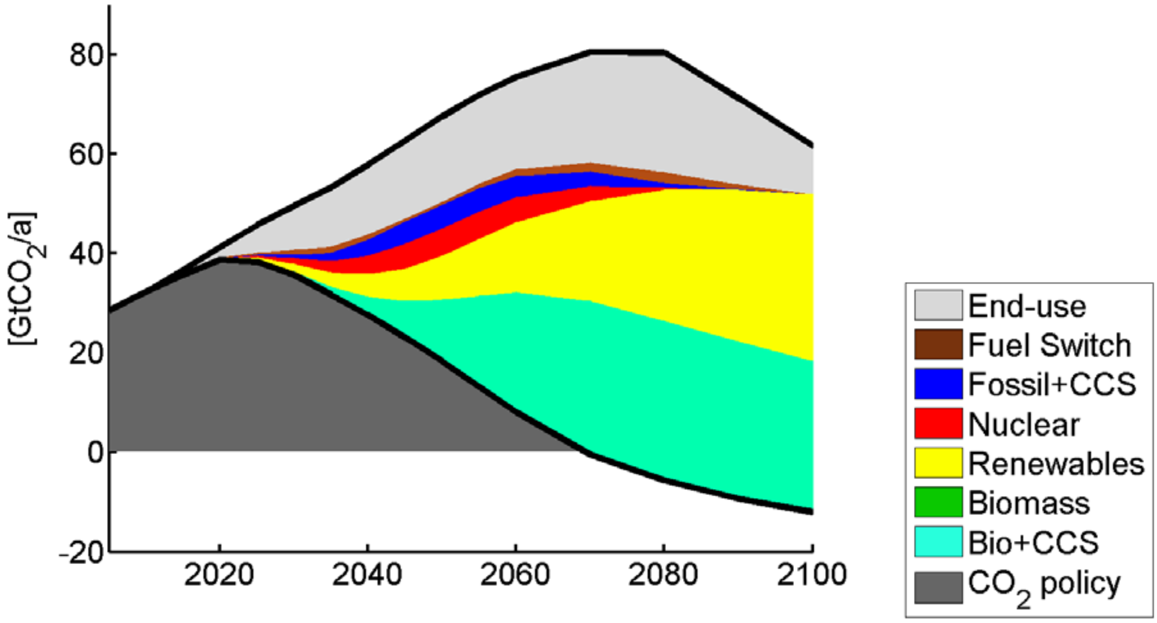
(2) 2°C erfordert eine umfassende Transformation des globalen Energiesystems

Klimastabilisierung erfordert eine umfassende Umwandlung des globalen Energiesystems hin zu kohlenstoffarmen Technologien. Um das 2-Grad-Ziel mit einer mittleren bis hohen Wahrscheinlichkeit zu erreichen, müssen die globalen Treibhausgasemissionen im Verhältnis zu den heutigen Werten bis Mitte des Jahrhunderts um annährend die Hälfte reduziert werden,

[7] Ab einem Wahrscheinlichkeitsniveau von 67% wird in den Berichten des IPCC ein Ereignis als wahrscheinlich bezeichnet. In diesem Bericht wird dementsprechend das 67% Wahrscheinlichkeitsniveau durchgehend als Referenzpunkt für die Erreichung von Klimazielen benutzt..

und bis zum Ende des Jahrhunderts Null erreichen. Wenn sich die Verabschiedung und Implementierung einer globalen Vereinbarung zum Klimaschutz weiter verzögert, müssen die globalen Treibhausgasemissionen langfristig negativ werden, um die Erreichung des 2°C-Ziels sicher zu stellen.

Abb. 10: Beitrag der Technologien zur Reduzierung von CO_2-Emissionen aus dem Energiesystem.

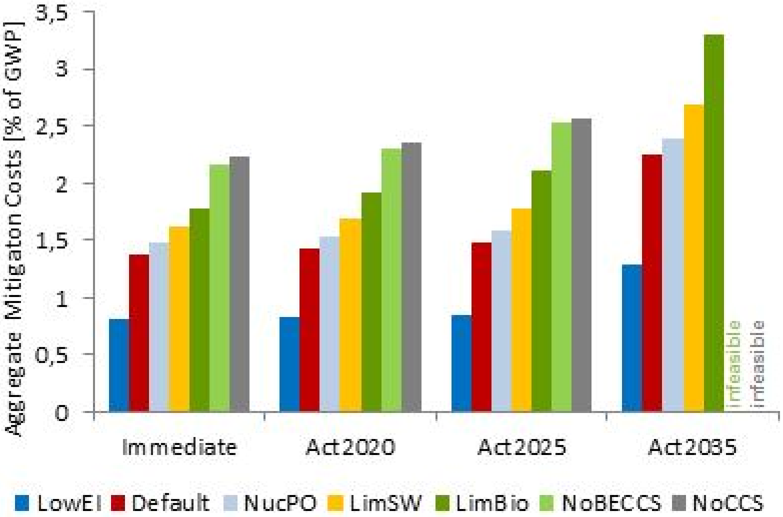


Keine einzelne Technologie ist hinreichend, um die dramatischen Emissionsreduktionen herbeizuführen, die im Laufe der kommenden Jahrzehnte erforderlich sind. Es wird vielmehr ein Portfolio an Optionen benötigt. Abb. 10 zeigt, wie unterschiedliche Technologiegruppen zur Emissionsreduzierung in einem 2°-Szenario, das von einer vollständigen Technologieverfügbarkeit ausgeht, beitragen. Die Kosten, das 2-Grad-Ziel mit ziemlicher Wahrscheinlichkeit zu erreichen, sind eine Funktion von Technologieverfügbarkeit und dem Starttermin für umfassende Vermeidungsmaßnahmen, wie in Abb. 11 gezeigt. Wir stellen fest, dass die ökonomische Auswirkung des Verzichts auf Technologien verschieden sind. Die Nichtverfügbarkeit von CCS-Technologien führt zu einem besonders großen Anstieg bei den Vermeidungskosten. Die Ähnlichkeit bei den Ergebnissen für a) NoBECCS (Nichtverfügbarkeit von BECCS) und b) NoCCS (Nichtverfügbarkeit von sowohl BECCS als auch fossilem CCS) unterstreicht die Bedeutung von negativen Emissionen und legt nahe, dass BECCS für eine Stabilisierung auf niedrigem Niveau wichtiger ist als fossiles CCS. Begrenzte Verfügbarkeit von Bioenergie lässt die Vermeidungskosten ebenfalls erheblich steigen. Im Falle des Ausstieges aus der Atomenergie sind die Vermeidungskosten hingegen nur geringfügig höher als im Szenario mit kompletter Technologieverfügbarkeit. Ein begrenzter Einsatz von Solar- und Windenergie hat nur eine relativ geringe Auswirkung auf die Klimaschutzkosten.

Diese Ergebnisse spiegeln strukturelle Unterschiede zwischen der Dekarbonisierung elektrischer und nicht-elektrischer Energieversorgung wieder. Eine Reihe von alternativen kohlenstoffarmen Optionen steht für die Stromerzeugung zur Verfügung wie z. B. Solar und Windenergie, Kernenergie oder Kohlenstoffabscheidung und –speicherung und Bioenergie. Falls einzelne dieser Technologieoptionen nicht oder nur eingeschränkt zur Verfügung stehen, können sie relativ leicht durch andere Technologien ersetzt werden. Unsere Modellergebnisse zeigen, dass die Dekarbonisierung des globalen Elektrizitätssektor technisch-wirtschaftlich machbar ist, ungeachtet, ob diese Umgestaltung stark auf Atomenergie oder vorwiegend auf erneuerbare Energie baut. Während der Elektrizitätssektor sich ohne weiteres dekarbonisieren lässt, gibt es nur wenige Optionen, um Emissionen aus nicht-elektrischer Energienutzung in der Industrie, in Gebäuden und im Transport zu reduzieren. Diese umfassen Verbesserungen der Energieeffizienz, der Wechsel zur Elektrizität als Energieträger (z. B. durch die Elektrifizierung des Transports oder durch die Verwendung geothermaler Wärmepumpen in Gebäuden) und die Nutzung von Bioenergie.

Nachhaltig angebaute Bioenergie ist nicht nur als klimafreundliche, nicht-elektrische Energiequelle bedeutsam. Sie könnte auch eine wichtige Rolle spielen, um in Kombination mit Kohlenstoffabscheidung und –speicherung negative Emissionen zu erzeugen (BECCS). Falls BECCS durch Nichtverfügbarkeit von CCS-Technologie keine Option darstellt, wird es zunehmend schwieriger, selbst mit einem vollständig dekarbonisierten Elektrizitätssektor das 2-Grad-Ziel zu erreichen. Angesichts der schwachen gegenwärtigen globalen Minderungsanstrengungen wächst die Notwendigkeit und Bedeutung von Technologien zur Entnahme von CO_2 aus der Atmosphäre. Die aggregierten Kosten zur Erreichung des 2-Grad-Ziels steigen um ca. 65% im *Act2020*-Szenario, falls CCS nicht verfügbar ist, und um ca. 75%, im *Act2025*-Szenario (Abb. 11). Falls ein globales Klimaregime sich bis 2035 verzögert *(Act2035)*, kann die 2°C-Grenze nicht mehr ohne negative Emissionen durch BECCS eingehalten werden. Begrenztes Bioenergiepotential verringert ebenfalls das Potential für negative Emissionen durch BECCS und lässt die Kosten für eine niedrige Klimastabilisierung steigen. Dies erhärtet die Ergebnisse früherer Studien, in denen auf die Wichtigkeit von BECCS für die Niedrigstabilisierung hingewiesen wurde (Edenhofer et al. 2010; Azar et al. 2010), und wirft ein Schlaglicht auf die Wichtigkeit, Landnutzungsmanagement und Klimaschutz zusammen zu denken.

Abb. 11: Vermeidungskosten als Anteil am weltweiten Bruttosozialprodukt (GWP), jeweils für das gesamte 21. Jahrhundert aggregiert und um 5% diskontiert, für die Act2020, Act2025 und Act2035 Klimapolitikszenarien und verschiedenen Annahmen zur Technologieverfügbarkeit: Verfügbarkeit des Standard-Technologieportfolios (Default), Ausstieg aus der Kernenergie (NucPO), begrenztes Potential für Solar- und Windenergie (LimSW), begrenzte Verfügbarkeit von Bioenergie (LimBio), Nichtverfügbarkeit von Kohlenstoffabscheidung und -speicherung mit Bioenergie (NoBECCS) und Nichtverfügbarkeit von Kohlenstoffabscheidung und -speicherung (NoCCS). Falls die globale Klimapolitik sich bis 2035 verzögert, kann das 2°-Ziel in den NoCCS und NoBECCS-Fällen nicht erreicht werden.

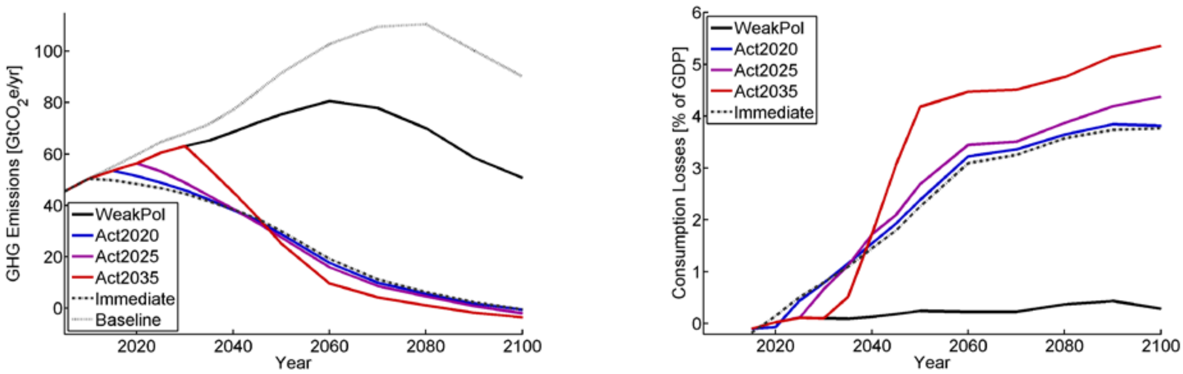


(3) Eine umfassende globale Vereinbarung zur Emissionsreduzierung muss bald umgesetzt werden

Das erklärte Ziel der andauernden Durban-Verhandlungen ist es, die globale Erwärmung durch ein umfassendes Klimaregime, das 2020 in Kraft treten soll, auf 2°C über vorindustriellem Niveau zu begrenzen. Selbst wenn dieser Zeitplan eingehalten wird, müssen die globalen Treibhausgasemissionen am Ende des Jahrhunderts gegen Null tendieren, um einen weiteren Temperaturanstieg zu verhindern. Weitere Verzögerungen in der Klimapolitik führen nicht nur kurzfristig zu höheren Emissionen, sondern auch zu einer Einschränkung des mittelfristigen Vermeidungspotentials. Die kurz- bis mittelfristigen Mehremissionen müssen später durch schnellere und tiefgreifendere Emissionsverringerungen ausgeglichen werden, um das gleiche Klimastabilisierungsziel noch zu erreichen (Abb. 12a). Dieses Unterfangen wird allerdings dadurch erschwert, dass durch einen weiteren Aufbau emissionsintensiver, langlebiger Infrastruktur und eine zögerliche Entwicklung neuer Technologien in 20 oder 30 Jahren weniger Vermeidungsoptionen zur Verfügung stehen würden, selbst wenn bis dahin stringente Klimapolitiken umgesetzt sind. Der Einfluss von Verzögerungen in der internationalen Klimapolitik auf wirtschaftlichen Auswirkungen des Klimaschutzes kann beträchtlich sein, weil verspätetes Handeln kostspielige Vermeidungsoptionen erfordert, die vermeidbar sind, wenn Emissionen frühzeitig gesenkt werden. Unsere Modellergebnisse zeigen, dass eine verzögerte Implementierung eines globalen Klimaregimes trotz der Vermeidung kurzfristiger Kosten die aggregierten Vermeidungskosten erhöht, selbst wenn langfristige Kosten mit 5% diskontiert werden (Abb. 12b). Verzögertes Handeln erhöht auch die Notwendigkeit von Technologien, die noch nicht kommerziell verfügbar sind oder deren Nachhaltigkeit noch fraglich ist (siehe Punkt (6) unten).

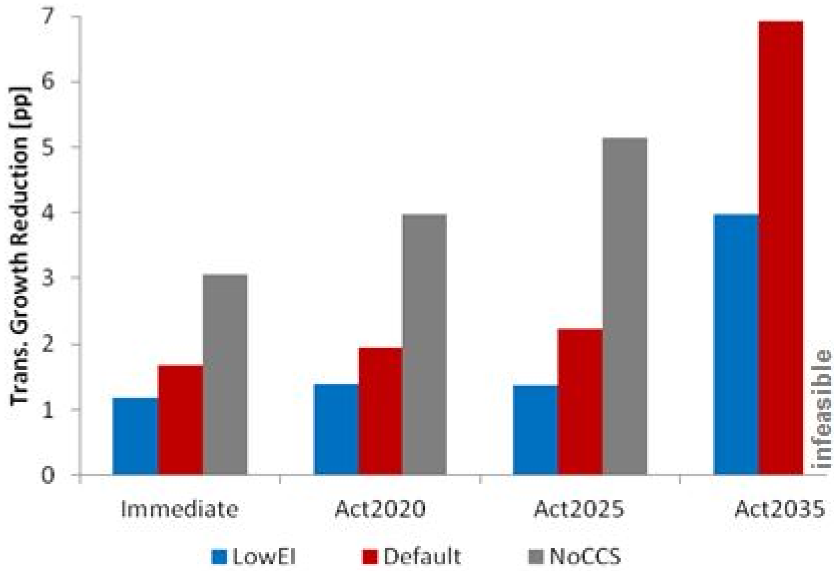
Abb. 12: (a) Emissionspfade und (b) Klimaschutzkosten (ausgedrückt als makro-ökonomische Konsumverluste) für das Basisszenario und für Szenarien, die ein globales Klimaregime im Jahr 2020 (Act2020), 2025 (Act2025), oder 2035 (Act2035) umsetzen.

A B



Eine Weiterführung schwacher Klimapolitik würde zu einem weiteren Zubau kohlenstoffintensiver Kraftwerkskapazitäten führen. Die künftige Einführung einer stringenteren Klimapolitik würde diese Kapazitäten unwirtschaftlich werden lassen – wodurch zahlreiche Anlagen vorzeitig stillgelegt werden müssten. In Szenarien mit einer Verzögerung bei der globalen Kooperation bis 2035 und voller Technologieverfügbarkeit würde der Übergang zu Klimapolitiken, die sich in Einklang mit dem 2-Grad-Ziel befinden, das globale Konsumwachstum im Übergansjahrzehnt um ca. 7 Prozentpunkte verringern, verglichen mit 2 Prozentpunkten bei einer Implementierung der Emissionsminderungen bereits 2020. Gemessen an einem für den Basisfall angenommenen globalen Konsumwachstum von ca. 30 bis 40% pro Jahrzehnt in der ersten Hälfte des 21. Jahrhunderts würde solch ein dramatischer kurzfristiger Effekt die politische Machbarkeit eines verzögerten 2-Grad-Ziels in Frage stellen. Daten vom IMF zum Vergleich besagen, dass die Finanzkrise von 2008 die globale Wirtschaftsleistung um ca. 5% verringert hat. Die Ergebnisse zeigen auch, dass gezielte Politikmaßnahmen zur Steigerung der Energieeffizienz eine die kurzfristige Reduktion des Konsumwachstums verringern können, die Effekte verzögerter Klimapolitik aber nicht ausgleichen.

Abb. 13: Kurzfristige Wachstumsminderung während des ersten Jahrzehnts nach Implementierung eines globalen Klimapolitikregimes im Jahr 2020 (Act2020), 2025 (Act2025) oder 2035 (Act2035) unter alternativen Technologieannahmen: Standard (Default), Niedrigenergieintensität (LowEI) und Nichtverfügbarkeit von CCS (NoCCS).



Unsere Ergebnisse zeigen auch, dass der Bedarf an unsicheren und möglicherweise nicht-nachhaltigen Technologien sich stark erhöht, wenn die Vermeidungsmaßnahmen sich weiter verzögern. Im Falle einer weiteren Verzögerung wirkt sich die Einschränkung von Technologieoptionen noch viel stärker auf die Kosten aus (Abb. 11, 13). Für das *Act2035*-Scenario lässt sich sogar sagen, dass es im Rahmen der in unserem Modell verwendeten Annahmen unmöglich ist, die Emissionen ausreichend schnell zu reduzieren, um das 2-Grad-Ziel mit einer hohen Wahrscheinlichkeit zu erreichen, wenn CCS nicht verfügbar ist.

(4) Politikmaßnahmen zur Steigerung der Energieeffizienz können den Spielraum beim Klimaschutz erhöhen

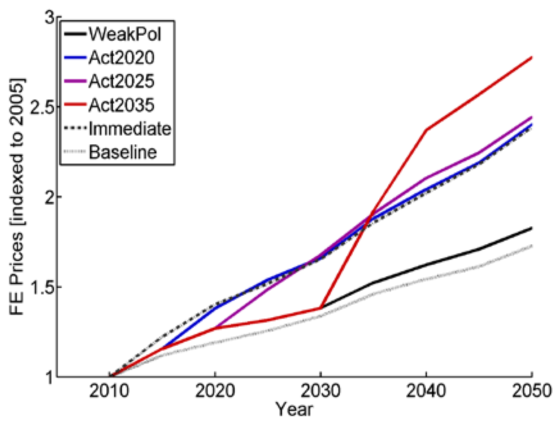
Die Einführung eines CO_2-Preises führt zu einem Anstieg der Energiepreise und erhöht daher die Wirtschaftlichkeit von Energieeffizienzinvestitionen. Diese Preis-induzierte Verbesserung der Energieeffizienz ist in unserem Energie-Ökonomie-Klima-Modell vollständig erfasst. Aufgrund von Marktversagen und Umsetzungshemmnissen bestehen darüber hinaus noch weitere kosteneffektive Potenziale zur Steigerung der Energieeffizienz, zu deren Nutzung die Einführung eines CO_2-Preises allein nicht hinreichend ist. Beispiele hierfür sind gegensätzliche Anreize für Eigentümer und Mieter, Finanzierungsschwierigkeiten für Energieeffizienzinvestitionen, und fehlende Informationen über den Energieverbrauch von elektrischen Geräten. Gezielte Politikmaßnahmen können dazu beitragen, diese Probleme zu beseitigen, und dadurch Energieeffizienzverbesserungen zu beschleunigen. Der Energieverbrauch kann auch durch Verhaltensänderungen und eine verringerte Energienachfrage beträchtlich verbessert werden. Solche Verhaltensänderungen können zwar von der Politik nicht gesteuert, wohl aber erleichtert werden. Ein hier untersuchtes Szenario, bei welchem sich die Energieintensität der globalen Wirtschaft bedeutend schneller als im historischen Schnitt verbessert – mit einer 25% geringeren Energieintensität im Jahre 2050 im Vergleich zur Fortschreibung historischer Trends – zeigt, dass erhöhte Energieeffizienz den Spielraum für bezahlbare Klimavermeidung erhöht. In diesem Fall reduzieren sich z. B. die kurzfristigen Klimaschutzkosten um 29%, wenn das Klimaregime 2020 umgesetzt wird, und sogar um 38% bzw. 43%, wenn das Regime 2025 oder 2035 eingeführt wird (Abb. 13). Daher können begleitende Maßnahmen zur Verbesserung der Energieeffizienz die Akzeptanz ambitionierter Klimapolitik erheblich verbessern.

(5) Wir brauchen starke Institutionen, um mit den wirtschaftlichen Herausforderungen von Niedrigstabilisierungspfaden umzugehen

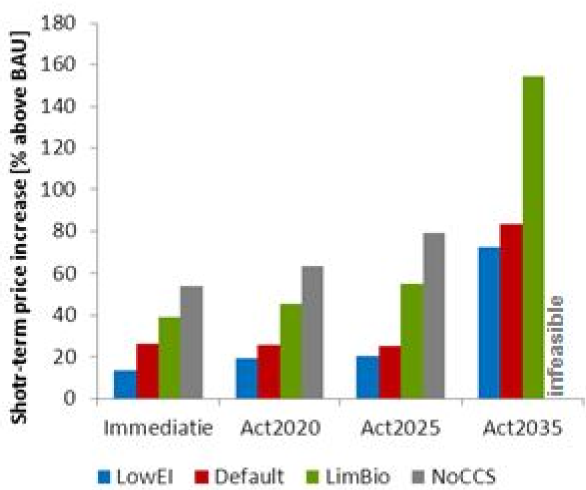
Der Umgang mit den wirtschaftlichen Herausforderungen und Verteilungsfragen strikter Klimaschutzbemühungen benötigt starke internationale und nationale Institutionen. Selbst im Falle eines zeitnah erreichten, umfassenden globalen Klimavertrages werden die wirtschaftlichen Folgen von Klimapolitik erheblich sein. Insbesondere führen die damit einhergehende Einführung eines CO_2-Preises, die Effekte auf Energiepreise und die Umbewertung von Vermögensgegenständen zu potentiell massiven Umverteilungen. Um zu vermeiden, dass arme Bevölkerungsschichten unverhältnismäßig stark belastet werden, und um Konsumenten und Unternehmen mit der Bewältigung von durch die Politik verursachten Energiepreisanstiegen zu helfen, bedarf es effektiver Institutionen. Gleichfalls werden starke Institutionen benötigt, um die Herausforderungen zu bewältigen, die durch die Transformation der Energiesysteme entstehen, wie z. B. die Auswirkung von Bioenergieproduktion auf Landnutzung und Kernenergiesicherheitsstandards.

Abb. 14: (a) Zeitliche Entwicklung des globalen Endenergiepreisniveaus (Indexierung relativ zu 2010) unter den Klimapolitikregimen Act2020, Act2025 und Act2035 sowie Baseline. (b) zeigt den durch Klimapolitik verursachten kurzfristigen Energiepreisanstieg (während des ersten Jahrzehnts nach Implementierung des Klimaziels), gemessen als Differenz zur Basislinie für unterschiedliche Startpunkte des Klimaregimes und unterschiedliche Technologieannahmen.

A

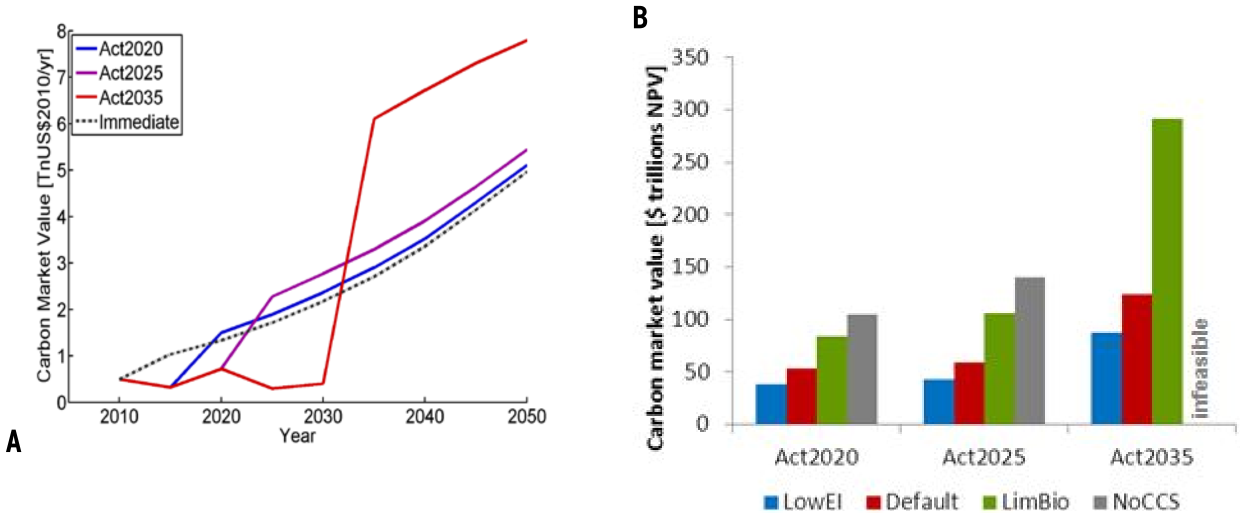


B



Haushalte und Unternehmen sind direkt vom durch Klimapolitik verursachten Anstieg der Energiepreise betroffen. Selbst ohne Klimapolitik würden die Energiepreise nach unseren Annahmen um ca. 20% pro Jahrzehnt ansteigen. Wenn ein umfassendes globales Klimaregime bis 2020 implementiert ist und sämtliche Technologieoptionen zur Verfügung stehen, führt das 2-Grad-Ziel zu einem zusätzlichen, kurzfristigen Energiepreisanstieg von ca. 20 Prozentpunkten. Eine Verzögerung der kooperativen Vereinbarung bis 2035 führt zu weit höheren kurzfristigen Preisanstiegen bis zu 100 Prozentpunkten (Abb. 14).

Abb. 15: (a) Zeitliche Entwicklung des Kohlenstoffmarktwertes unter den Klimapolitikregimen Act2020, Act2025 und Act2035 sowie unmittelbare Klimapolitik. (b) zeigt den aggregierten Kohlenstoffmarktwert, kumuliert von 2010-2100 und diskontiert mit 5%.



Die Einführung eines international und sektoral einheitlichen CO_2-Preises ist eine notwendige Voraussetzung für ökonomisch effiziente Klimapolitik (Stern 2007). Andererseits stellt die Einführung eines CO_2-Preise eine institutionelle Herausforderung dar, weil dadurch potentiell massive Umverteilungen induziert werden. Insbesondere gilt es sicher zu stellen, dass besonders vulnerable Regionen und Bevölkerungsschichten nicht unverhältnismäßig stark belastet werden. Wir können das potentielle Umverteilungsvolumen durch Klimapolitik bewerten, indem wir den Marktwert der Emissionen betrachten, die durch Kohlenstoffbepreisung abgedeckt würden. Im Act2020 Szenario führt die Umsetzung des 2-Grad-Ziels zu einem kumulierten Gegenwartswert der Emissionsrechte für das 21. Jahrhundert von 50 Billionen US$ (Abb. 15). Dies ist vergleichbar mit dem Gegenwartswert des Rohöls, das im gleichen Zeitraum bei nicht vorhandener Klimapolitik verbraucht wird. Der Verteilungsherausforderungen sind sogar höher, wenn die Einführung eines global vereinheitlichten Klimaschutzregimes bis 2025 verzögert wird oder wenn kritische Technologieoptionen begrenzt sind. Eine Einschränkung der Bioenergienutzung führt beispielsweise zu einer Verdoppelung des Kohlenstoffmarktwerts.

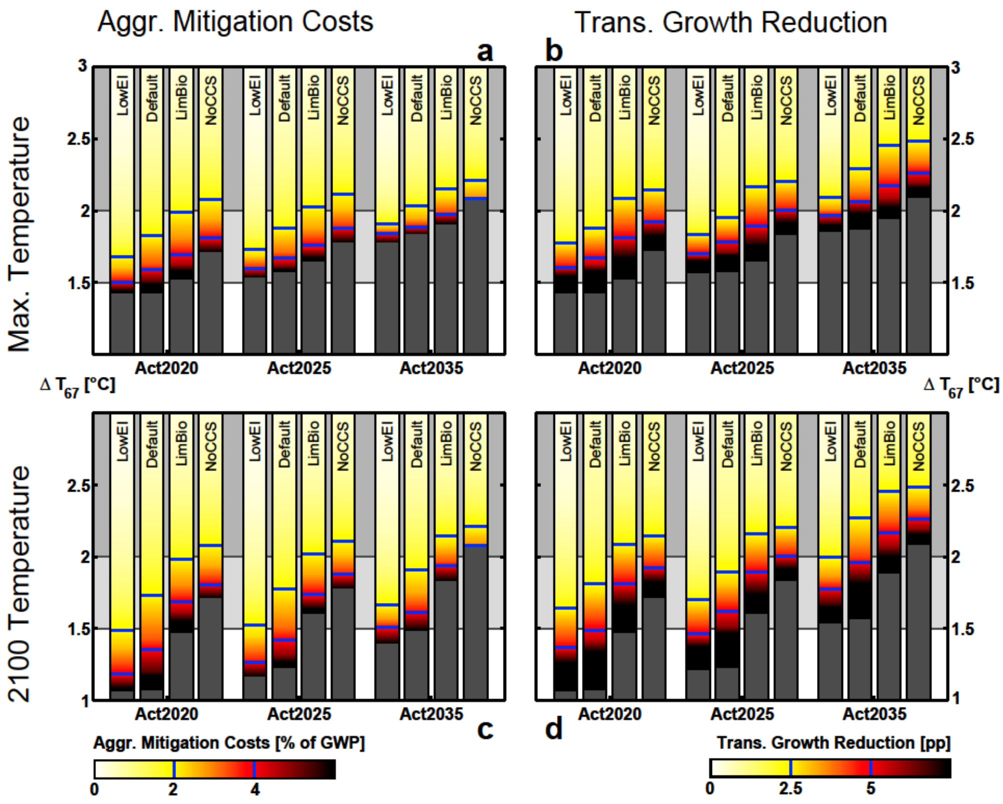
Ein höherer Gegenwartswert der Emissionszertifikate impliziert einen höheren Streitwert beim Feilschen um die Verteilung von Emissionsreduktionsverpflichtungen zwischen Ländern und Wirtschaftssektoren. Sowohl auf nationaler als auch auf internationaler Ebene sind starke Institutionen nötig, um die Umsetzung von Klimapolitiken so auszugestalten, dass sie als weitgehend fair und gerecht akzeptiert werden.

(6) Eine weitere Verzögerung bei der Klimapolitik erhöht die untere Grenze erreichbarer Klimaziele

Klimapolitik kann nur erfolgreich umgesetzt werden, wenn die wirtschaftlichen Folgen des Klimaschutzes auf moderatem Niveau gehalten werden. Auf Basis der Modellergebnisse lässt sich abschätzen, dass die untere Grenze erreichbarer Klimaziele bei 1,7°C liegt, wenn umfassende Vermeidungspolitiken 2020 umgesetzt werden und das gesamte Portfolio an Technologien zur Verfügung steht. Diese Schätzung geht von den Folgenden maximal akzeptablen wirtschaftlichen Auswirkungen aus: aggregierte Vermeidungskosten von 4% des weltweiten Bruttosozialprodukts, eine kurzfristige Verringerung des Nettoeinkommenswachstums von 5 Prozentpunkten, ein aggregiertes Kohlenstoffhandelsvolumen von 100 US$ pro Tonne und ein kurzfristiger durch Klimapolitik entstandener Energiepreisanstieg von 100 Prozentpunkten.

Wenn umfassende globale Klimapolitiken sich um weitere 15 Jahre verzögern, steigt die untere Grenze erreichbarer Klimaziele um 0,4°C – insbesondere wegen der Auswirkungen der Verzögerung auf die kurzfristige Wachstumsdynamik (Abb. 16). Andererseits erhöht der Verzicht auf oder die Nichtverfügbarkeit von CCS die untere Grenze um ca. 0,3°C. Zurzeit ist das Fenster zur Klimastabilisierung bei 2°C noch einen Spaltbreit geöffnet – mit jedem Jahr verzögerter Klimapolitik schließt es sich jedoch weiter, und die Abhängigkeit von kritischen Technologien steigt.

Abb. 16: (a) Übersicht der kombinierten Effekte der Verzögerung von Klimaschutz und der Technologieverfügbarkeit auf die Erreichbarkeit von Klimazielen. Die oberen Diagramme zeigen maximale Temperaturanstiege, die unteren Diagramme im Jahr 2100 erreichte Temperaturniveaus. , die ein temporäres Überschreiten erlauben (untere Illustration). Die Balken zeigen die wirtschaftlichen Herausforderungen (Farbschattierung) in Form von langfristigen, über die Zeit aggregierten Klimaschutzkosten (linke Bilder a,c) und kurzfristigen Wachstumseffekte (rechte Bilder b,d) als Funktion des maximalen 2010-2100-Temperaturanstiegs (a,b) oder des 2100-Temepraturanstiegs (c,d). Die dunkelgrauen Bereiche am unteren Ende der Balken zeigen Temperaturniveaus, die im Spektrum der modellierten Kohlenstoffpreispfade nicht erreichbar waren.



(7) **Es ist unwahrscheinlich, dass ein Temperaturanstieg über 1,5°C im Laufe des 21. Jahrhunderts verhindert werden kann. Eine Rückkehr auf 1,5°C bis 2100 würde eine enorme Politikanstrengung und den massiven Einsatz von Technologien zur Erzeugung von negativen Emissionen erfordern.**

In der vorangegangenen Analyse konzentrierten wir uns auf den von Treibhausgasemissionen induzierten maximalen Temperaturanstieg im Zeitraum 2010-2100. Dies entspricht der Formulierung von Klimazielen als „nicht zu überschreitende“ Obergrenzen. Unsere Ergebnisse zeigen, dass es unwahrscheinlich ist, dass die globale Erwärmung über das gesamte Jahrhundert hinweg unterhalb von 1,5°C gehalten werden kann. Falls jedoch Klimaziele an Temperaturniveaus im Jahr 2100 gekoppelt werden (anstatt an Maximaltemperaturen im Laufe des 21. Jahrhunderts), können niedrigere Temperaturniveaus erreicht werden. Diese weisen dann allerdings in der Regel ein zeitweiliges Überschreitens des Klimaziels auf. In dieser Interpretation ist das 1,5-Grad-Ziel sehr ambitioniert, aber nicht unerreichbar. Temperaturniveaus im Jahr 2100 können nur dann ohne gravierende wirtschaftliche Auswirkungen auf 1,5°C begrenzt werden, wenn umfassende Emissionsreduzierungen bereits 2020 beginnen und wenn Biomasse in Kombination mit Kohlendioxidabscheidung und –bindung (BECCS) in großem Umfang angewendet wird. Dies unterstreicht die Notwendigkeit, abzuwägen zwischen der Stringenz von Klimaschutzzielen und potentiellen ökologischen und sozialen Nebeneffekten, z. B. durch großangelegte Nutzung von Bioenergie.

Insgesamt lässt sich feststellen, dass der Einsatz von Technologien einen noch größeren Einfluss auf erreichbare 2100-Temperaturniveaus hat als auf Maximaltemperaturen. Im Falle der Maximaltemperatur kommen die Effekte von Technologien nur in einem begrenzten Zeitrahmen zu tragen (bis die Maximaltemperatur erreicht ist), während sich im Falle von 2100-Temperaturen die Auswirkungen der Technologie über das gesamte Jahrhundert kumulieren.

2.3 Teil B: Hauptergebnisse der Analyse "What the UN process on climate change has achieved"

In dem wissenschaftlichen Artikel "What the UN process on climate change has achieved" haben wir die Ergebnisse des internationalen Verhandlungsprozesses der Klimarahmenkonvention der Vereinten Nationen (UNFCCC) analysiert.

Die Analyse zeigt, dass der UNFCCC Prozess wesentliche Schritte erzielt hat, um Länder zu tatsächliche Handlungen zu motivieren, und auf dem richtigen Weg ist, diese noch weiter voranzubringen:

- **Bewusstseinsbildung**: Insbesondere die jährlichen Treffen der UNFCCC positionieren das Thema Klimawandel weit oben auf der politischen Agenda. Der UNFCCC-Prozess hat Ende 2009 große Aufmerksamkeit auf sich gelenkt als die Kopenhagen Konferenz über ein neues Klimaabkommen abstimmen sollte. Über 100 Staats-und Regierungschefs von insgesamt 40 000 Teilnehmern kamen zusammen, mehr als je zuvor für eine Umweltkonferenz. Das setzte die Regierungen unter Druck, eine Position zu finden und Strategien zum Klimawandel zu formulieren.
- **Einigung auf Grundsätze und gemeinsame Ziele**: Der UN-Prozess hat dazu beigetragen, dass die Mitgliedsländer sich auf global anerkannte Ziele einigten, die einen Handlungsrahmen geben. Das im Jahr 1992 gemeinsam vereinbarte Ziel, "eine gefährliche anthropogene Einwirkung auf des Klimasystems zu verhindern", wurde im Jahr 2010/11 weiter spezifiziert: "die globalen Emissionen zu reduzieren, um so den Anstieg der globalen Temperatur unter 2 Grad Celsius zu halten". Das Prinzip der "unterschiedlichen Verantwortlichkeiten unter Berücksichtigung der nationalen Umstände" der Länder wurde im Text des Jahres 1992 aufgenommen und hat die Struktur der Verpflichtungen und Maßnahmen der Länder nachträglich dementsprechend beeinflusst. Die universelle Mitgliedschaft der UNFCCC ist die Voraussetzung für eine solche Vereinbarung mit sehr weitem Anwendungsbereich und Legitimität. In der Tat war bisher nur dieses UN-Gremium in der Lage, ein solches Maß an Legitimität gewährleisten.
- **Vorbereitung für Emissionsreduktionen – Inventare von Treibhausgasemissionen, Prognosen, Strategien**: Der UNFCCC-Prozess hat erhebliche Fortschritte darin erzielt, die Vorbereitung einheitlicher, vergleichbarer und überprüfter Inventare von

Treibhausgasemissionen, sowie Maßnahmen und Strategien in Ländern zu fördern, über die halbjährlich berichtet wird. Solche umfassenden Informationen würden nicht ohne den UNFCCC-Prozess existieren. Außerdem sind diese aufgrund der universellen Mitgliedschaft innerhalb des Prozesses international einheitlich aufbereitet.

- **Entwicklung internationaler politischer Instrumente um gemeinsam Ziele zu erreichen**: Der UNFCCC-Prozess hat Kohlenstoff-Marktmechanismen, wie etwa International Emissions Trading, Joint Implementation und Clean Development Mechanisms eingeführt. Diese Mechanismen sind voll funktionsfähig und dienen als Grundlage für die nationalen politischen Instrumente, wie etwa den nationalen Emissionshandel oder freiwillige Ausgleichsmechanismen. Weitere Mechanismen sind noch in der Entwicklung, z. B. für die Reduzierung von Emissionen aus Entwaldung und Degradierung. Darüber hinaus fanden wir auch heraus, dass der UNFCCC-Prozess eine entscheidende Rolle in anderen Zielsetzungen internationaler Zusammenarbeit gespielt hat.

Die Analyse zeigt des Weiteren, dass der UN-Prozess andere Bereiche der internationalen Kooperation vorangebracht hat, und dass hier das volle Potential noch nicht ausgeschöpft ist:

- **Der Austausch von Informationen über Strategien, Technologien, Institutionen und Maßnahmen mit anderen Akteuren**: Der UN-Prozess hat eine regelmäßige Berichterstattung über nationale Maßnahmen gegen den Klimawandel festgesetzt. Eine umfassende Analyse dieser Informationen ist allerdings in diesem Rahmen nur in begrenztem Maße möglich. Länder, die am UNFCCC-Prozess beteiligt sind, könnten sich dahingehend positionieren, dass die Akteure eine umfassendere Analyse der Berichte durchführen und damit Diskussion von positiven Beispielen und gesammelten Erfahrungen aus den nationalen Politiken und Maßnahmen fördern. Neben der Festlegung der THG-Reduktionsziele könnte die UNFCCC schwerpunktmäßig diesen Austausch federführend voranbringen.
- **Überwachung der Handlungen/Maßnahmen von Staaten oder anderen Akteuren um die Transparenz zu erhöhen und zu beurteilen ob diese insgesamt ausreichend sind**: Die Politikmaßnahmen von Ländern werden derzeit nur in begrenztem Umfang überprüft. Für Industrieländer ist die Überprüfung auf die Einhaltung der Leitlinien für die Berichterstattung begrenzt. Es wird im Rahmen dieser Überprüfung nicht beurteilt, ob nationale Maßnahmen umfassend oder ausreichend genug sind, um die gesetzten Ziele zu erreichen. Das genauere Vorgehen, um Maßnahmen in Entwicklungsländern zu überprüfen, ist noch nicht definiert. Der umfassende Informationsaustausch könnte durch eine verbindliche, aber dennoch unterstützende Überprüfung der Fortschritte der nationalen Maßnahmen ergänzt werden. Zum Beispiel könnte man erste freiwillige Bewertungen für diejenigen Länder einrichten, die überprüft werden wollen, um Vertrauen aufzubauen. Die Erkenntnisse aus diesen pilotartigen Überprüfungen könnten eine gute Grundlage für die Entwicklung von zukünftigen Leitlinien bilden. Dies könnte durch eine unabhängige zusätzliche Überprüfung auf globaler Ebene ergänzt werden, die derzeit von anderen Organisationen ohne konkretes Mandat der UNFCCC durchgeführt wird (UNEP 2010, 2011, 2012; Höhne et al. 2011).

- **Schaffung von Anreizen für nationale Politik**: Es gibt nachvollziehbare Beispiele, die zeigen, dass die Vorbereitungsarbeiten und die Zielsetzung im UNFCCC-Prozess direkt zu nationalen Politikstrategien zur THG-Reduzierung geführt haben, die ansonsten nicht stattgefunden hätten. Mehrere Länder haben nationale Klimagesetze eingeführt, die ihren internationalen Vorschlag zur Emissionsreduktion für 2020 national verbindlich machen. Mexiko, Brasilien und Südkorea zum Beispiel übernahmen das international angestrebte THG Ziel in einem Landesgesetz. Australien setzt in Zukunft einen Plan um, der entworfen wurde, um die internationalen Versprechen einzuhalten. Die Länder hätten sich ohne den UNFCCC-Prozess nicht auf diese Zeile geeinigt. Darüber hinaus haben verschiedene Länder nationale Emissionshandelssysteme entwickelt, um Verpflichtungen des Kyoto-Protokolls umzusetzen oder diese mit dem Kyoto-Protokoll-Mechanismen zu vereinbaren. Dazu gehören zum Beispiel die EU, Australien, Neuseeland, die Schweiz und Kasachstan. Systeme in Kalifornien, Quebec, Regional Greenhouse Gas Initiative (Nordosten der USA) und vor kurzem auch in einigen chinesischen Provinzen und Städten sowie das nationale System in Südkorea wurden von diesen sich entwickelnden nationalen Systemen motiviert.
- **Bereitstellung internationaler Unterstützung**: Die UNFCCC hat Finanzierungsmechanismen durch die Industrieländer für die Entwicklungsländer angeregt. Die Höhe der Finanzierung durch Industrieländer wurde durch ein Abkommen in Kopenhagen im Jahr 2009, das "Fast Start Finanzierung", auf 10 Milliarden US $ pro Jahr von 2010 bis 2012 erheblich erhöht. Die Einrichtung des Green Climate Fund wurde 2010 vereinbart, der zu einem der wichtigsten Kanäle internationaler Klimafinanzierung wird. Die Länder haben vereinbart, 100 Milliarden US $ pro Jahr bis 2020 zu mobilisieren. Jedoch wird der Umfang der Finanzierung als zu niedrig und zu langsam kritisiert. Aufgrund des Fehlens von gemeinsamen Regeln geben einige Regierungen bereits bestehenden Finanzflüsse als zusätzliche an. Ein weiterer Kritikpunkt ist, dass es keinen gerechten Zugang zu den Ressourcen gibt (Axel Michaelowa und Katharina Michaelowa 2011).
- **Festlegung messbarer Reduktionsziele / Verpflichtungen / Maßnahmen**: Erhebliche Fortschritte wurden mit der Einführung der Reduktionsziele für die größten Emittenten gemacht. Die erste Verpflichtung in Artikel 4.2 (a) und (b) der UNFCCC (UNFCCC 1992), sieht vor, dass die Industrieländer nationale Politiken umsetzen "um das Ziel, einzeln oder gemeinsam, das Emissionsniveau von 1990 bis zur Jahrhundertwende“ zu erreichen. Diese Zielvorgabe wurde tatsächlich erfüllt. In einem nächsten Schritt legte das Kyoto-Protokoll gesamtwirtschaftlich verbindliche Ziele für die Industrieländer fest, um gemeinsam deren Treibhausgas-Emissionen um 5,2% unter dem Niveau von 1990 im Zeitraum von 2008 bis 2012 zu senken. Die Vereinbarung konkreter Reduktionsziele, die rechtlich verbindlich sind, zusammen mit einem Nichterfüllungsverfahren und den möglichen Sanktionen sind beispiellos im internationalen Umweltrecht. Nach der Unterzeichnung des Protokolls im Jahr 1997 verzichteten allerdings die USA darauf, dieses zu ratifizieren. Kanada hat es zwar ratifiziert, aber im Dezember 2011 angekündigt, das Reduktionsziel nicht umzusetzen und aus dem Protokoll vollständig auszutreten. Eine zweite Verpflichtungsperiode von 2013 bis 2020 wurde im Jahr 2012 einschließlich Reduktionszielen für eine gewisse Anzahl der Industrieländer vereinbart.

Einige der größten zögern noch sich anzuschließen, z. B. USA, Kanada, Japan und Russland.

Im Vorfeld der Konferenz in Kopenhagen im Dezember 2009 und kurz danach haben alle größeren Länder Vorschläge und Maßnahmen zur Emissionsminderung bis 2020 eingereicht. Diese Vorschläge und Maßnahmen wurden im Rahmen der Vereinbarungen von Cancún festgehalten, die im Dezember 2010 verabschiedet wurden, sind aber nicht rechtlich verbindlich. Dennoch haben alle größeren Entwicklungsländer tatsächlich quantitative THG Reduktionsziele für 2020 vorgelegt. Das ist insofern bemerkenswert, als dass bis 2007 genau diese Länder sich anhaltend der Formulierung eigener quantitativer Ziele widersetzt hatten.

Das 2°C-Ziel ist ein wichtiger Maßstab für viele Länder bei der Festlegung ihrer nationalen Reduktionsziele. Für die Industrieländer liegt der Anteil der Reduktionen, die mit dem 2°C im Jahr 2020 zu vereinbaren sind, bei 25% bis 40% gegenüber dem Jahr 1990 (Gupta et al 2007; Den Elzen und Höhne 2008, 2010). Länder wie Japan (-25%) und Norwegen (-30% bis -40%) haben genau diesen Bereich als Zielmarke deklariert. Für die Entwicklungsländer liegt der vergleichbare Bereich bei -15% bis -30% unterhalb eines business-as-usual-Szenarios im Jahr 2020 (den Elzen und Höhne 2008, 2010). Länder wie Mexiko (-30% von zuvor 20%), Südkorea (-30%), Südafrika (-34%), Brasilien (-36% bis -39%) und Indonesien (-26% bis 41%) scheinen sich an diesen Bereichen zu orientieren.

Obwohl rechtlich nicht bindend und in der Summe eigentlich nicht ausreichend, um den Temperaturanstieg auf unter 2°C zu begrenzen (UNEP 2012. Höhne et al 2011), stellen diese eine große Errungenschaft und Anreize für nationale Politiken dar, um die Emissionen zu reduzieren. Damit wurde auch wesentlich die vormals starre Kluft zwischen Industrie- und Entwicklungsländern überwunden. Die allgemeine Zurückhaltung der Länder, sich auf messbare und ambitionierte Ziele festzulegen, wird wahrscheinlich von keinem anderen Prozess und keiner anderen Institution gelöst werden.

Den Klimawandel zu lösen ist eine globale Herausforderung. Diese Analyse zeigt, dass der UNFCCC Prozess eine essentielle Rolle bei der Lösung dieses Problems spielt, in dem er Ambitionen und Maßnahmen unterstützt und einen Rahmen für internationale Kooperation vorgibt. Diese Rolle könnte noch signifikant ausgebaut werden.

3 Introduction

This report synthesizes the results obtained from the project "Scenarios on the feasibility of emissions reduction scenarios consistent with 2°C stabilization" (German Title: "Szenarien zur Darstellung der Machbarkeit von 2 Grad-Emissionsminderungsszenarien– Technologien, Kosten, Potenziale – international/regional").

In 1992 the United Nations Framework Convention on Climate Change was established, with the ultimate objective to "prevent dangerous anthropogenic interference with the climate system" (UNFCCC 1992). While Climate Change is broadly recognized as one of the foremost global challenges (IPCC 2007; Stern 2007; World Bank 2012), negotiations on a global climate agreement have made slow progress. In the Copenhagen Accord, the international community agreed on the long-term target of limiting the increase of global mean temperature to no more than 2°C relative to pre-industrial levels (referred to as "2°C target" in the remainder of this document). The subsequent Cancun and Durban climate conferences reaffirmed this target. While no level of global warming can be considered inherently safe, stabilization of climate change at 2°C above pre-industrial levels may substantially reduce the risk of large-scale discontinuities such as, among others, melting of the Greenland ice sheet or ceasing of the Indian summer monsoon (Lenton et al. 2008; Smith et al. 2009)). Despite the recognition of the 2°C target, progress in the implementation of concrete emissions reduction policies has been slow. Although a series of climate policy measures were adopted in several world regions (UNEP 2011, 2012), global emissions have been rising over the last decade with only a small downturn in 2008-2009 in the wake of the financial crisis (EDGAR 2011). Reaching the 2°C target with high likelihood implies a tight limit on cumulative future anthropogenic greenhouse gas (GHG) emissions (Meinshausen et al. 2009). Various reports have concluded that pledged national 2020 reduction targets fall short of initializing the energy system transformations needed to meet the 2°C target in an cost-optimal way (UNEP, 2010, 2011; Rogelj et al., 2010, 2011). International climate policy is currently at cross-roads. With the Durban Platform on Enhanced Action, a new negotiation track has been established to increase the ambition level of 2020 climate policy pledges, and to close a global agreement on comprehensive emission reductions after 2020. Our analysis shows that a successful outcome of the post-Durban negotiations can keep the door for limiting global warming to 2°C open. By contrast, if climate negotiators fail to agree on comprehensive global emission reduction, the 2°C target is likely to get out of reach.

The research presented in this report was funded by the German Federal Environment Agency under the Umweltforschungsplan UFOPLAN FKZ 3710 41 135. The objective of the project was to explore transformation pathways for limiting global warming to no more than 2°C. The Umweltbundesamt requested scenarios that are politically promising, yet fully considerate of relevant economic, technological and political constraints. It further requested the consideration of the role of the UNFCCC process as an enabling framework to keep global temperature rise below 2°C.

The research conducted in the context of the project consists of several components. On the one hand, we performed an analysis of a very large ensemble of model-based climate change mitigation scenarios. We produced these scenarios using the integrated energy-economy-climate model REMIND developed at PIK. This analysis allows us to understand how the achievability of the 2°C target hinges on the timing of emission reductions and the availability of technologies. On the other hand, we analyze the achievements of the United Nations Framework Convention on Climate Change, and its potential role in the future.

The key products of this project are two research articles, which were submitted to peer-reviewed scientific journals. Since they are reproduced in the following chapters, the structure of this report deviates from the structure of conventional UFOPLAN project reports. Chapter 4 presents an expanded and further elaborated version of the article “Economic mitigation challenges – how further delay closes the door for achieving climate targets”. The manuscript to this article is currently under consideration for the *Environmental Research Letters*. Chapter 5 of this report presents the manuscript “What the UN process on climate change has achieved”, which is currently under consideration for *Energy Policy*. Articles, as submitted to the respective journal, are attached in the appendix to this report.

4 Model-based analysis of climate change mitigation scenarios consistent with 2°C

4.1 Introduction and Motivation

Despite the broad recognition of the internationally recognized 2°C target, progress in the implementation of concrete emissions reduction policies has been slow. Even with the implementation of climate policy measures in several world regions (UNEP 2012), global emissions have continued to rise. Reaching the 2°C target with high likelihood implies a tight limit on cumulative future anthropogenic greenhouse gas (GHG) emissions (Meinshausen et al. 2009; Matthews et al. 2009). Various reports have concluded that pledged national 2020 reduction targets ('Copenhagen pledges') fall short of the reductions required to meet the 2°C target in a cost-optimal way (UNEP 2010, 2012; Rogelj et al. 2010).

CO_2 emissions have a long-lasting effect on the climate system. Stabilizing the climate at a given temperature therefore requires near-zero global GHG emissions in the long-term (Matthews and Caldeira 2008). This implies (a) the need for a comprehensive global regulation of GHG emissions that covers all regions and sectors, and (b) the importance of mitigation options that allow for the generation of net negative emissions, such as carbon sinks in forestry, or the combination of bioenergy use and carbon capture and storage (BECCS).

A major strand of the scientific literature on climate change mitigation discusses the results of model-based mitigation scenarios. (B.S. Fisher et al. 2007; GEA 2012). It is well established that decarbonization of economies requires a massive transformation in the way energy is produced and used. No single technology option is sufficient, but rather a portfolio of technologies is required to achieve climate stabilization. Currently, the deployment of many low-carbon technologies faces technological difficulties or limited political support. For instance, carbon capture and storage (CCS), large scale bioenergy production and nuclear energy are subject to sustainability concerns and public opposition. Similarly, integrating major shares of wind and solar power is challenging because of fluctuating supply from these sources.

In the past most climate mitigation scenarios were prepared under the idealistic assumptions of fully flexible technology choice, globally coordinated climate policies ensuring that emission abatement would occur where it is cheapest, and the immediate start of climate policies (B.S. Fisher et al. 2007; Knopf et al. 2011). Meanwhile, several studies have considered climate mitigation scenarios with restricted technology portfolios (Edenhofer et al. 2010; Azar et al. 2010; Tavoni et al. 2012), while others have investigated climate stabilization after a period of fragmented and delayed climate policy (Clarke et al. 2009; Jakob et al. 2012; Luderer et al. 2012a). These studies showed that both technology availability and fragmented climate policy have a strong effect on the achievability of climate targets. Our study presents an analysis of the combined effects of delayed action and technology failures. So far, this has been done only by few previous studies (Rogelj et al. 2012a, 2013; van Vliet et al. 2012) .

This study fills crucial research gaps. Currently available studies have almost exclusively used carbon prices and inter-temporally aggregated mitigation costs as indicators of mitigation effort. However, policymakers are much more concerned about the shorter-term effects and distributional impacts of mitigation policies. Our work quantifies the trade-offs between the stringency of long-term climate targets on the one hand, and policy-relevant socio-economic challenges on the other—such as transitory costs, short-term energy price increases, and the potential redistribution of wealth induced by a global cap-and-trade regime. By analyzing these economic challenges of alternative transformation pathways, we examine how a further delay of global action forecloses long-term stabilization levels and reduces the leeway in technology choices.

4.2 Study design

4.2.1 Modeling framework

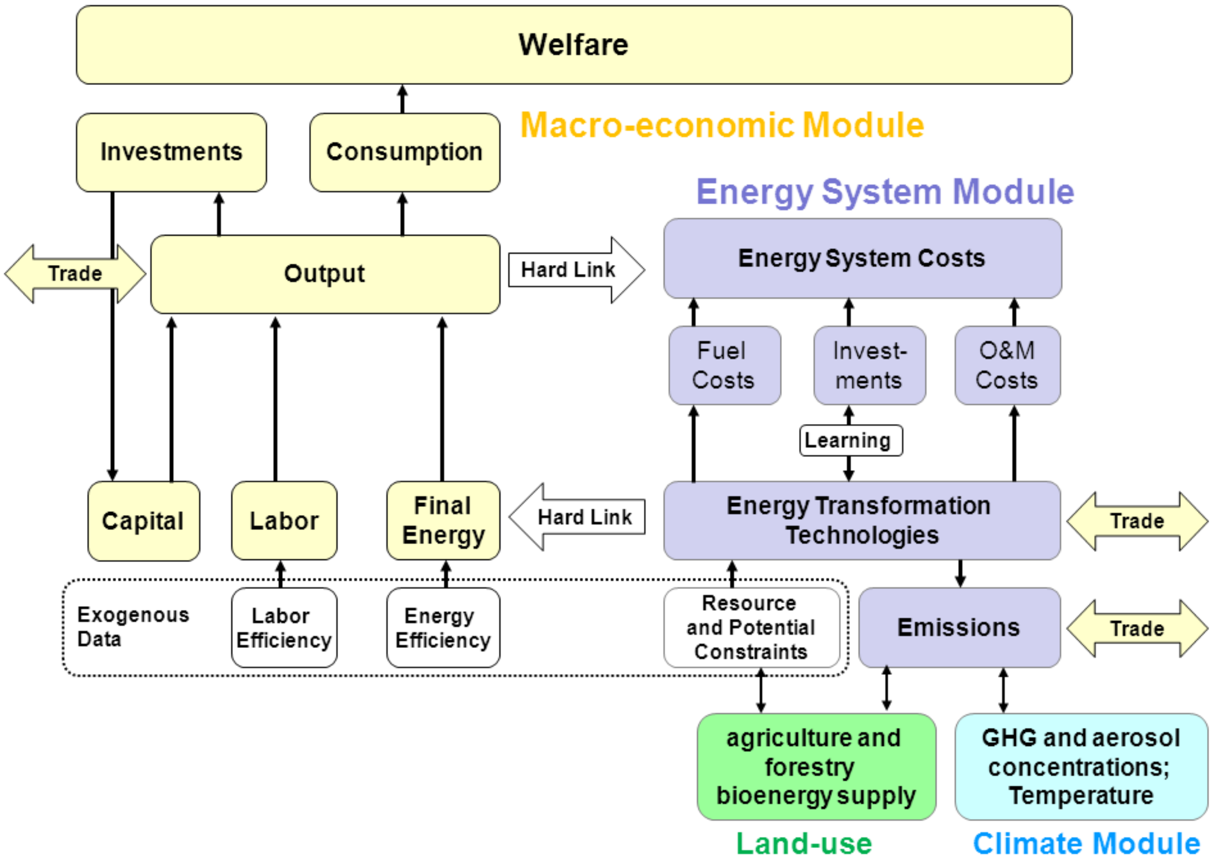
Our analysis combines a state-of-the-art integrated energy-economy-climate model (REMIND) with the probabilistic reduced-form climate model MAGICC. The following sections provide an overview of these modeling frameworks.

4.2.2 The integrated energy-economy-climate model REMIND

We use version 1.5 of the energy-economy-climate model REMIND to derive greenhouse gas (GHG) emission pathways and policy cost estimates for a large ensemble of mitigation scenarios with different assumptions of technology availability, timing of cooperative action, and carbon price levels under a global cooperative climate policy regime.

A detailed description of REMIND 1.5 is available from (Luderer et al. 2013). REMIND is a global model of the energy-economy-climate system spanning the period 2005-2100, with 5-year time steps between 2005 and 2060, and ten year time steps thereafter. The macro-economic core of REMIND is a intertemporal general equilibrium model in which global welfare is maximized over a long time horizon. This macro-economic approach is found in similar form in other integrated assessment models such as RICE (Nordhaus and Yang 1996) or MERGE (Manne et al. 1995). The model computes a unique Pareto-optimal solution which corresponds to the market equilibrium in the absence of non-internalized externalities. The world is divided into 11 regions: there are five individual countries (China, India, Japan, United States of America, and Russia) and six aggregated regions formed by the remaining countries (European Union, Latin America, Sub-Saharan Africa without South Africa, a combined Middle East / North Africa / Central Asia region, Other Asia, Rest of the World). Trade is explicitly represented for final goods, primary energy carriers, and, in case of climate policy, emissions allowances. Macro-economic production factors are capital, labor, and final energy. The economic output is available for investments into the macro-economic capital stock as well as for consumption, trade of goods, and financing the energy system.

Figure 4.1: General structure of the REMIND model. The model is composed several sub-modules. The macro-economic module describes the inter-relation between economic output and the input factors capital, labor and energy. The energy system represents the conversion of primary energy resources to final energy carriers.



The macro-economic core and the energy system module are hard-linked via final energy demand and costs incurred by the energy system. Economic activity results in demand for final energy such as transport energy, electricity, and non-electric energy for stationary end-uses. This final energy demand is determined by a production function with constant elasticity of substitution (nested CES production function). The energy system module accounts for endowments of exhaustible primary energy resources (coal, oil, gas and uranium) as well as renewable energy potentials (biomass, hydro power, wind power, solar energy, geothermal energy). The scale and cost of bioenergy resources is derived from the global land-use model MAgPIE, which also accounts for direct and indirect GHG emissions associated with bioenergy production. Virtually all bioenergy in climate mitigation scenarios is used in conversion technologies of the 2nd generation, relying on lingo-cellulosic biomass as a feedstock. REMIND represents capacity stocks of more than 50 technologies for the conversion of primary energy into secondary energy carriers as well as for the distribution of secondary energy carriers to end use sectors. In particular, the model accounts for the possibility of combining fossil fuel and bioenergy use with carbon capture and storage (CCS). Since trees and crops extract CO_2 from the atmosphere, deploying bioenergy in combination with CCS (BECCS) can result in net negative emissions. As shown by the results for technology-constrained scenarios, BECCS technologies are of crucial importance for the achievability of low stabilization targets. REMIND does not have any hard limits on the expansion rate of new technologies. In order to mimic real-world inertias in technology up-scaling, a cost penalty (“adjustment costs”) is applied that scales with the square of the relative change in capacity investments. This yields technology diffusion rates that are broadly in line with historical patterns (Wilson et al. 2013). The retirement of fossil capacities before the end of their technological life-times is possible, but limited to a rate of 4% per year.

REMIND calculates energy related non- CO_2 GHG and aerosol emissions via time-dependent emission factors. Emissions from agriculture and land-use are obtained from the land-use model MAgPIE (Lotze-Campen et al. 2008). Emission reduction potentials of non-energy related CO_2, CH_4 and N_2O emissions are represented via marginal abatement cost curves. Emissions of F-Gases are prescribed exogenously based on RCP data (van Vuuren et al. 2011a).

REMIND has been used for numerous analyses of the economics of climate change mitigation (Leimbach et al. 2010a; b; Bauer et al. 2012a; b; Luderer et al. 2012c). REMIND has also participated in a number of past model inter-comparison exercises (Edenhofer et al. 2010; Luderer et al. 2012a; Calvin et al. 2012), and is currently involved in several on-going inter-comparison exercises.

4.2.3 The probabilistic climate model MAGICC

To represent uncertainties in the carbon cycle and climate system response to emissions, we employ the reduced complexity climate model MAGICC (version 6) (Wigley and Raper 2001; Meinshausen et al. 2011a; c). Here, we employ a probabilistic setup of the model. The parameter space has been constrained by historical observations of ocean heat uptake (Domingues et al. 2008) and surface temperatures over land and ocean in both hemispheres (Brohan et al. 2006), using a Metropolis Hastings Markov Chain Monte Carlo approach as described in Meinshausen et al. (2009). A 600-member ensemble of the resulting joint distribution of the 82-dimensional parameters space has then been drawn, so that the marginal climate sensitivity distribution closely represents the IPCC Fourth Assessment Report conclusions in regard to our uncertainty on climate sensitivity (Rogelj et al. 2012b). Differing from the setup in Meinshausen et al. (2012), Rogelj et al. (2013), we include a probabilistic permafrost module (Schneider von Deimling et al. 2012)—thereby accounting for the effect of potential climate feedback from permafrost by additional release of carbon dioxide and methane release from the upper soil compartment. The omission of the permafrost feedback effect has previously been regarded as a research gap (Hatfield-Dodds 2013), although we note that the temperature effect until 2100 is limited.

We consider all important greenhouse gases, tropospheric ozone precursors, the direct and indirect aerosol effects and landuse albedo. CO_2, CH_4, N_2O, sulfur, black carbon and organic carbon emissions are endogenous results from the REMIND model, while other forcing components are complemented from corresponding RCP emission scenarios (van Vuuren et al. 2011a; b; Masui et al. 2011). For emissions of ozone-depleting substances we assume the WMO2006 emissions scenario – consistent with the setup for creating the RCP GHG concentration profiles (Meinshausen et al. 2011b).

4.2.4 Scenario design

Our analysis is based on a large set of climate mitigation scenarios compiled along the dimensions of (i) near-term climate policies and timing of global cooperative mitigation action, (ii) availability of low carbon technologies, and (iii) stringency of long-term climate policies, controlled by different globally harmonized carbon price levels. The combination of these dimensions yields a scenario ensemble of 285 different REMIND runs, each representing one energy-economic development pathway. For each scenario, the GHG emission trajectories resulting from REMIND were used to calculate 600 climate realizations with the probabilistic climate model *MAGICC*, yielding a total of 171'000 climate model simulations. The variations along the different scenario dimensions are presented and motivated in the following.

4.2.5 Near-term climate policy frameworks

In the long-term, any climate stabilization target requires near-zero emission levels. As a consequence, climate policy will only be successful if it eventually establishes a comprehensive climate regime that covers virtually all countries and emitting sectors. This scenario dimension explores delay in setting up such a global comprehensive climate policy regime. The specifications of these different climate policy scenarios (P0 – P4) follow those of the RoSE study (Luderer et al. submitted).

P0. Weak-policy baseline (WeakPol)

This scenario is designed as a reference scenario that includes weak climate policies. It is meant to represent the unambitious end of short- and long-term climate policy developments. It was constructed by considering existing climate policies, thus, a weak interpretation of the 2020 Copenhagen Pledges, and an extrapolation of these targets beyond 2020, based on emissions intensity (GHG emissions per unit of GDP). Three country groups are considered: industrialized countries (Group I), developing countries excluding resource exporters (Group II), and fossil resource exporters of the former Soviet Union and Middle East (Group III). Climate policy is assumed to remain fragmented, with no emissions trading between regions until 2020. Limited trading of emissions between industrialized and developing countries is allowed after 2020. It is assumed that resource-exporting countries (Group III) will not adopt any binding targets. Furthermore, it is assumed that land-use emissions will not be subject to carbon pricing. The assumptions of the WeakPol scenarios with regard to regional emission reduction targets are described in detail in Luderer et al. (2013).

P1. Global Cooperative Action Starting in 2020 *(Act2020)*

The Act2020 scenario considers the most optimistic possible outcome of the current climate negotiation process under the Durban Platform. It assumes that a global climate agreement is reached by 2015, and that comprehensive emission reductions are implemented from 2020 onwards. Until 2015, the model follows the weak policy scenario, without anticipating more stringent future climate policies. Starting with the 2020 model time step, a global cooperative climate regime is implemented with comprehensive regional and sectoral coverage.

P2. Global Cooperative Action Starting in 2025 *(Act2025)*

The Act2025 scenario considers a somewhat more pessimistic outcome of the Durban Platform, assuming that it fails to deliver 2020 emission reductions beyond the unconditional Copenhagen Pledges, and that the implementation of comprehensive global emissions reductions is delayed until 2025.

P3. Global Cooperative Action Starting in 2035 *(Act2035)*

The Act2035 scenario assumes a failure of the Durban Platform negotiations, resulting in unambitious and fragmented climate policies for the coming 20 years. It follows the WeakPol scenario until 2030 without anticipating more stringent future climate policies. Comprehensive global emissions reductions start in 2035.

P4. Immediate action *(Immediate)*

In the immediate action scenario we assume that global cooperative climate mitigation policies start immediately, with global comprehensive emission reductions starting in 2015. It must be considered hypothetical, since none of the current climate negotiation tracks would be able to deliver such an outcome.

4.2.6 Technology availability

Earlier studies (Edenhofer et al. 2010; Azar et al. 2010; Tavoni et al. 2012) have shown the crucial importance of low-carbon technologies for costs and achievability of low stabilization targets. To further explore the influence of technology availability on the lower limit of achievable climate targets, we produced seven scenario sets with different idealized assumptions about technology availability. With the exception of the NoBECCS case, the scenario specifications (T1 – T7) are identical to those used in the EMF27 study (Kriegler et al. 2013).

T1. Full technology portfolio *(Default)*

All technologies represented in the REMIND model are assumed to be available. Default assumptions regarding final energy demand are implemented, with autonomous energy intensity improvements (AEII), i.e., reductions in final energy demand per unit of GDP in absence of climate policy, in line with the historical rate of about 1.2%/yr. Bioenergy use is limited to 300 EJ/yr.

T2. No carbon capture and storage *(NoCCS)*

All conversion technologies with carbon capture and storage, both with fossil fuels or bioenergy as feed-stocks, are excluded from the mitigation portfolio. This scenario setting is motivated by the slow progress in up-scaling CCS to commercial scale, due to concerns about potential environmental impacts and limited public acceptance of geological storage in some countries, as well as institutional barriers.

T3. No bioenergy combined with carbon capture and storage *(NoBECCS)*

All technologies that combine bioenergy use with carbon capture and storage are excluded from the mitigation portfolio. Specific challenges applying to BECCS in addition to those of CCS include (a) the lower technological maturity of BECCS technologies, (b) sustainability constraints to bioenergy production (see LimBio case), (c) institutional challenges related to incentivizing negative emissions.

T4. Low bioenergy availability *(LimBio)*

The global bioenergy potential is limited to 100 EJ. This scenario is motivated by a variety of concerns about the sustainability of large-scale bioenergy production regarding (a) scarcity of arable land, (b) potential freshwater demand for irrigation, (c) effect on food prices, (d) potential indirect land-use change emissions (ILUC) induced by bioenergy production, and (e) potential loss of biodiversity.

T5. Nuclear phase-out *(NucPO)*

No nuclear capacity additions beyond those currently under construction. This scenario is motivated by limited public acceptance of nuclear power in view of (a) security concerns in the aftermath of the Fukushima accident, (b) challenges related to nuclear waste disposal, and (c) proliferation concerns.

T6. Limited Wind and Solar Power *(LimSW)*

The share of electricity production from wind and solar power is limited to 20% of total electricity in each region. This scenario is motivated by the challenges related to the fluctuating supply from variable renewable energy sources.

T7. Low energy intensity *(LowEI)*

This set of scenarios assumes autonomous energy intensity improvements that are higher than those in the Default scenario, and exceed those observed historically. Baseline energy intensity is 25% lower than in Default in 2050, and 40% lower than in Default in 2100. The LowEI scenarios describe a world in which behavioral changes result in lower demand for final energy, and barriers for energy efficiency improvements are decreased.

4.2.7 Carbon price levels

We explore the effect of long-term climate policy stringency on climate stabilization levels and mitigation costs by varying the uniform carbon price signal applied in the global cooperative climate regime. We use 2020 reference carbon price levels of 5, 10, 20, 30, 40, 50, 100, 200 and 500 US$$_{2005}$/t CO_2. Since the model's responsiveness to carbon pricing is highest at low to medium prices, we chose to use more narrowly spaced price steps below 50 US$$_{2005}$/t CO_2. By default, we assume carbon prices to increase by 5% per year. This rate is very close to the model-endogenous discount rate, thus implying inter-temporal efficiency in minimizing cumulated GHG emissions.

We derived emission prices for non- CO_2 Kyoto gases based on global warming potentials from the IPCC AR4. We also calculate scenarios without any climate policies as a baseline for measuring the effect of mitigation.

4.2.8 Economic indicators of the mitigation challenge

For the analysis, we derived four indicators as proxies for the potential economic and political challenges associated with the implementation of climate policies: (i) aggregated mitigation costs as a measure for costs in the long run, (ii) transitional consumption growth reduction as a proxy of short-term economic effects, (iii) the aggregated carbon trade volume as a proxy for potential distributional conflicts under an international cap-and-trade system, and (iv) transitory energy price increases during the phase-in of comprehensive climate policies. They are defined and motivated in the following.

Aggregated mitigation costs (AMC) quantify the intertemporally aggregated impact of climate mitigation policies on affluence. They are commonly used for characterizing long-term mitigation scenarios (B.S. Fisher et al. 2007; Edenhofer et al. 2010; Luderer et al. 2012a). We calculate them as aggregated discounted consumption losses expressed relative to aggregated, discounted gross world product GWP in the baseline:

$$AMC = \left(\sum_{t=2010}^{2100} (C_{Baseline} - C_{Pol}) \cdot (1+\delta)^{2010-t}\right) \Big/ \left(\sum_{t=2010}^{2100} GWP_{Baseline} \cdot (1+\delta)^{2010-t}\right) \cdot 100\%,$$

where C denotes consumption, and a discount rate δ of 5% p.a. is used. While aggregated mitigation costs typically only amount to a few percent of cumulative economic output, they can be very significant in absolute terms. For the REMIND GWP baseline used here, each % of cumulative costs corresponds to discounted aggregated costs of US$ 19.6 tn in values of 2010. We use reference mitigation cost values of 2% and 4% of GWP for the analysis of climate target achievability. This can be compared to the target to devote 0.7% of the gross national product (GNP) of OECD countries to Official Development Assistance (ODA) (United Nations 2002).

Transitional growth reduction (TGR): Economic losses occurring during the transition from a regime without climate policy to a regime with stringent climate policies are a crucial barrier to the implementation of climate policies. We define the transitional growth reduction as the maximum of the difference between decadal consumption growth rate in the baseline and in the policy scenario, in units of percentage points [pp]:

$$TGR = \max_{2010<t<2050} \left(g_{Baseline}(t) - g_{Pol}(t)\right),$$

where for each scenario

$$g(t) = \left(C(t+5\text{a}) - C(t-5\text{a})\right) / C(t) \cdot 100\,\%$$

is the decadal rate of consumption growth in units of %.

In the baseline, i.e., without climate policies, globally aggregated consumption grows at a rate of around 30-40 % per decade in the first half of the 21st century. The transition from a weak, fragmented climate policy regime to a regime with stringent and comprehensive emission reductions can slow consumption growth markedly. The timing of climate policy has important implications for the incidence of mitigation costs over time (see also Section 4.2). In case of immediate action, costs for reaching the 2°C target with a high likelihood are well below 1% of gross world product (GWP) in 2020 and increase gradually over time. For the scenarios with delayed cooperative action, the picture looks different: As the weak policies only have a small effect on the economy, near-term costs in the delayed scenarios with delayed cooperative action are rather small. Once a stringent global climate regime is implemented, however, costs increase to levels that exceed those in the immediate scenario reaching the same long-term target.

In some extreme scenarios, the transition from the weak, fragmented climate policy regime to stringent climate policies can therefore result in transitory mitigation costs of 10pp or higher. Such dramatic short-term effects render the political feasibility of such pathways questionable. For comparison, based on data of the International Monetary Fund (IMF 2012) the financial crisis of 2008 can be estimated to have reduced global economic output by around 5%. Another study estimated the effect on the economies of the US and Europe to be of similar magnitude (Gros and Alcidi 2010). For the purpose of this study, we use a reference range of 2.5-5 pp to examine how climate policy induced consumption growth reductions limit economically achievable climate targets.

Energy price increases are among the most direct impacts of climate policies on households and firms. The impact of high energy prices will depend on the rates of price increases: if energy prices rise quickly, there is little time for adaptation through technological or behavioral changes. To examine the effect of climate policies on energy prices, we derive a global final energy price index recursively, by calculating the market value of the final energy demand basket at time t relative to the price the same final energy basket would have cost one period, i.e., 5 years, earlier:

$$EPX(t) = EPX(t-5a) \cdot \sum_r \sum_i p_{i,r}(t)\, FE_{i,r}(t) \Big/ \sum_r \sum_i p_{i,r}(t-5a)\, FE_{i,r}(t)$$

Where $p_{i,r}(t)$, $FE_{i,r}(t)$ are the demands and prices of final energy carrier i in region r, respectively, and EPX(2010) is set to unity for normalization. This method is akin to the calculation of a chained consumer price index. The decadal growth rate of the energy price index can be readily calculated as

$$g_{EPX}(t) = (EPX(t+5\text{ a}) - EPX(t-5\text{ a}))/\,EPX(t) \cdot 100\,\%$$

The maximum climate-policy-induced short-term energy price increase, in units of percentage points [pp] follows as

$$EPI = \max_{2010<t<2050} \left(g_{EPX,BaU}(t) - g_{EPX,Pol}(t)\right).$$

Figure 4.3d shows the development of the global energy price index over time. Energy prices would increase by a rate of roughly 20% per decade even if no climate policies were implemented, reflecting increasing global energy demand and a gradual depletion of fossil resources. Climate policy adds to this. In the Act2020 scenario and under Default technology assumptions, reaching the 2°C target implies a maximum additional energy price increase of around 20 pp in the decade following the implementation of the mitigation target. A further delay of a cooperative agreement results in much stronger short-term price increases of up to 100 pp in Act2035 (see next section).

Recently, substantial price increases have occurred in various industrialized countries, such as a 60% price increase in household electricity prices in Germany between 2000 and 2010, or a more than 100% price increase for gasoline in the US between 1998 and 2008 (ENERDATA 2013). For developing countries, there is some evidence that increases in energy prices can be causes of social unrest (Morgan 2008). For instance, a 70% increase of gasoline prices and a trebling of electricity prices (albeit in a much shorter time frame than a decade) were an important trigger for riots that occurred in Indonesia in 1998 (Purdey 2006). This leads us to assume that critical levels of transitional, climate-policy-induced energy price increases might be in the range of 50-100 pp.

Carbon Market Value: Not only aggregated costs, but also distributional effects of climate policy matter. In order for climate policies to be efficient, carbon prices need to be harmonized across regions and sectors, so as to ensure equal mitigation costs at the margin (Stern 2007). While carbon pricing results in costs for emitters, it also produces potentially large revenues, for instance for the government in case of a carbon tax or full auctioning of emission permits in the context of an emissions trading scheme. Similarly, in the context of an international emissions trading scheme, the allocation of the permissible emissions budget across individual countries determines capital flows induced by emissions trading, and therefore has strong distributional implications (Lueken et al. 2011; Luderer et al. 2012b). We therefore use the cumulated carbon market value as an indicator of the institutional challenges to manage distributional conflicts arising from emissions trading both on the national and international level, and define it as

$$CMV = \sum_{t=2010}^{2100} p_{CO2}(t) \cdot E(t) \cdot (1+\delta)^{2010-t}$$

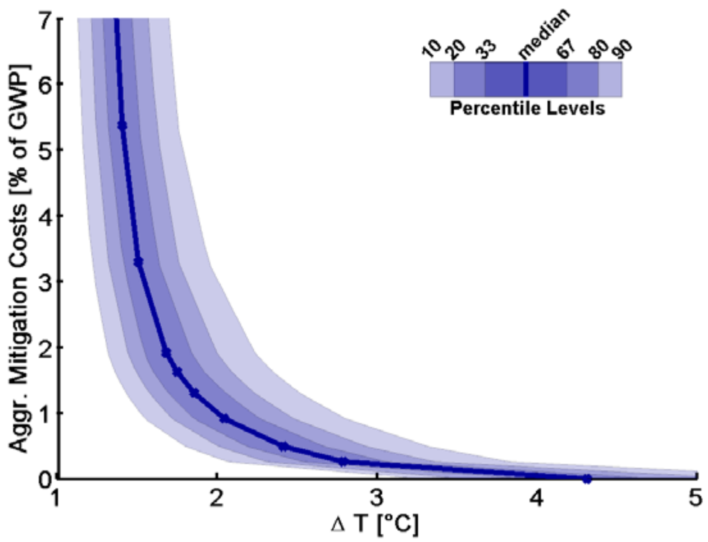
where E refers to all positive greenhouse gas emissions, but excludes negative emissions from BECCS, and p_{CO2} (t) is the price of CO_2.

The carbon market value as a function of temperature levels is quite sensitive to timing of mitigation action and technology availability. In the Act2020 scenario, reaching the 2°C target with a cap-and-trade regime that covers all regions and sectors implies an aggregated carbon market value of about US$ 56 tn in values of 2010 (Figure 4.2c). The aggregated market value of fossil fuels consumed in a baseline scenario without climate policy is similar in magnitude, with oil accounting for US$ 46 tn, and coal, oil and gas combined for US$ 83 tn in values of 2010. We therefore assume that critical levels for the inter-temporally aggregated carbon market value might be in the range of US$2010 50-100 tn.

4.3 Temperature-cost tradeoff curves

Relating mitigation to maximum temperature increase until 2100 establishes temperature-cost tradeoff curves, as shown in Figure 4.2. The lower the maximum temperature over the 21st century, the higher the inter-temporally aggregated mitigation costs as a share of GWP. This property gives rise to the notion of an economic achievability frontier, i.e., a lower limit of achievable climate targets for a given macro-economic cost level. The temperature-cost tradeoff curves are highly convex, i.e., costs increase disproportionally with the increasing stringency of the long-term temperature target.

Figure 4.2: The "Achievability Frontier" describing tradeoff between 21st century surface air temperature (maximum increase during 2010-2100 relative to pre-industrial levels) and aggregated mitigation costs for the Act2020 scenario with Default technology assumptions. Shaded bands show geophysical uncertainty ranges.



The climate system's response to anthropogenic emissions is subject to substantial uncertainties, which we address explicitly using the probabilistic reduced-form climate model MAGICC. In the *Act2020* scenario with Default technology assumptions, limiting global warming to below 2°C with a 50% likelihood (ΔT50) results in long-term mitigation costs of around 1.0% of GWP. Reaching the target with a likelihood of two-thirds (ΔT67) implies long-term costs of 1.4%. There is a very tight, approximately linear relationship between ΔT50 and ΔT_{67} based on which we calculated the secondary axis in Figure 4.2 and Figure 4.4. In the remainder of the analysis, temperature targets refer to levels achieved with 67% likelihood.

4.4 The effect of delayed action

For all economic mitigation challenge indicators, a further deferral of comprehensive global emissions reductions results in a shift of the temperature-cost-tradeoff curves towards higher temperatures (Figure 4.2). This implies not only an increase of mitigation challenges for a given climate target, but also an increase of the lower level of climate targets achievable at a given mitigation challenge level, as indicated by the arrows in the figure. For climate targets around 2°C, the effects of delay on inter-temporally aggregated costs are substantial. This is in spite of the fact that lower costs in the short-term partially offset the higher long-term costs, which are subject to greater discounting (Figure 4.3a).

The longer the climate policy regime remains weak and fragmented, the higher are the emissions reduction rates required after the implementation of comprehensive climate policies to reach low stabilization targets (Figure 4.3a, see also (Stocker 2012)). This is mirrored in the development of policy costs measured in terms of consumption losses over time, which show an abrupt increase of costs in case of action delayed until 2035 (Figure 4.3a). The effect of delay on the transitional growth reduction after implementation of comprehensive emissions reductions is therefore even more pronounced than the effect on aggregated mitigation costs. For aggregated mitigation costs in the range of 2–4% of GWP, lowest achievable climate targets in Act2035 exceed those found for Act2020 by 0.2–0.3°C. For transitional mitigation costs in the range of 2.5–5 pp, the shift even amounts to ~0.4°C. Recent macro-economic data suggest that a short-term growth reduction of 5pp is comparable the effect of the financial crisis (IMF 2012).

The impact of mitigation timing on short-term energy price increases is similar to that the transitional growth reductions, with a shift of lowest climate targets achievable at energy price increases of 50-100pp shifting by slightly less than 0.4°C (Figure 4.2d). Increases of final energy prices in comparable magnitude have been observed in the past for individual regions or energy carriers. For Act2020 and default technology assumptions, the 2°C target induces a relatively moderate short-term energy price increase of around 25pp.

Carbon pricing—which ensures economic efficiency (Fisher et al. 1996)—emerges as a crucial institutional challenge. If the 2°C target is implemented in the Act2020 scenario, the cumulated present value of emissions permits in 2010–2100 amounts to approximately US$ 50 tn, which is comparable to the market value of crude oil consumed over the same period in the baseline scenario without climate policy. If action is delayed until 2035, the carbon market value implied by 2°C stabilization more than doubles, and lowest climate targets achievable at cumulated carbon market values of US$ 50–100 tn shift by ~0.3°C.

Figure 4.2: Temperature-cost-tradeoff curves showing the effect of timing of global comprehensive mitigation action on (a) aggregated mitigation costs, (b) transitional consumption growth reductions, (c) carbon market value, and (d) energy price increase (Default technology assumptions). Temperature targets (maximum 2010-2100 temperatures) reached with a 67% likelihood (lower axis) or 50% likelihood (upper axis) of are shown. Numbers indicate shift in terms of ΔT67.

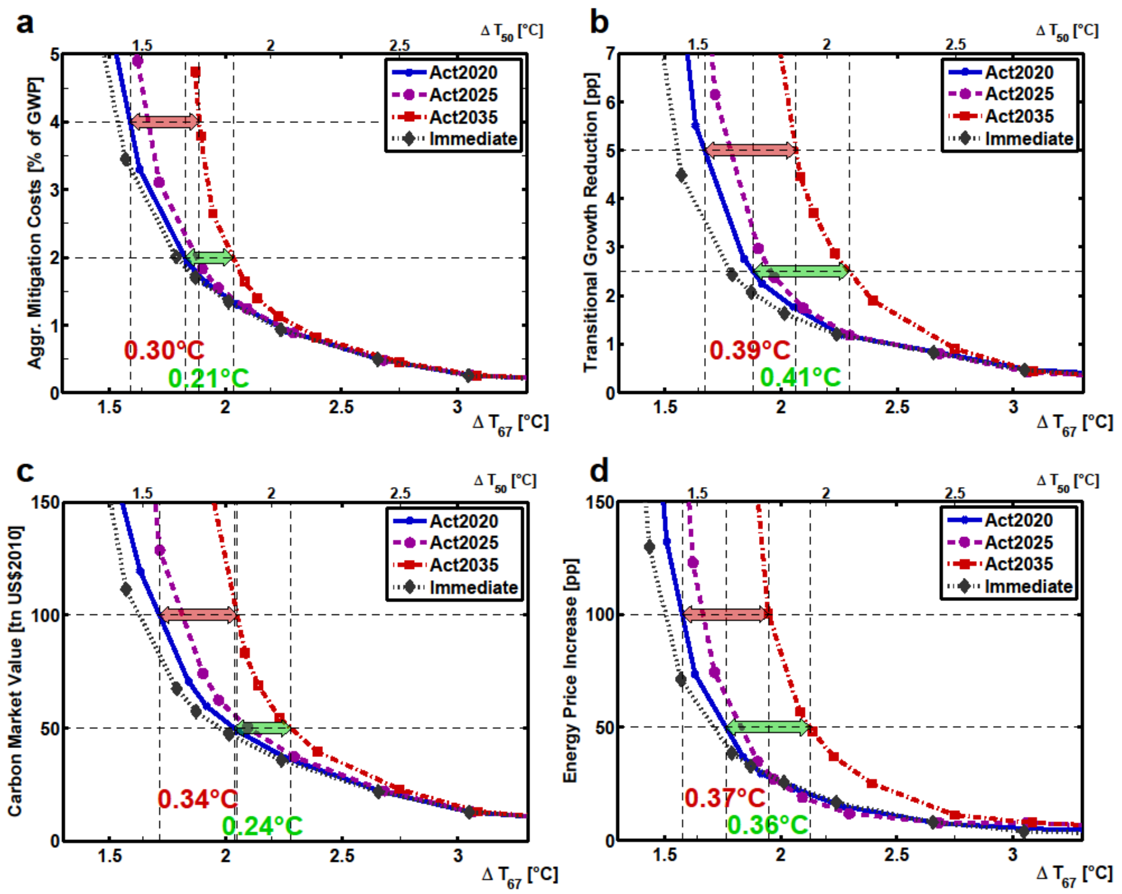
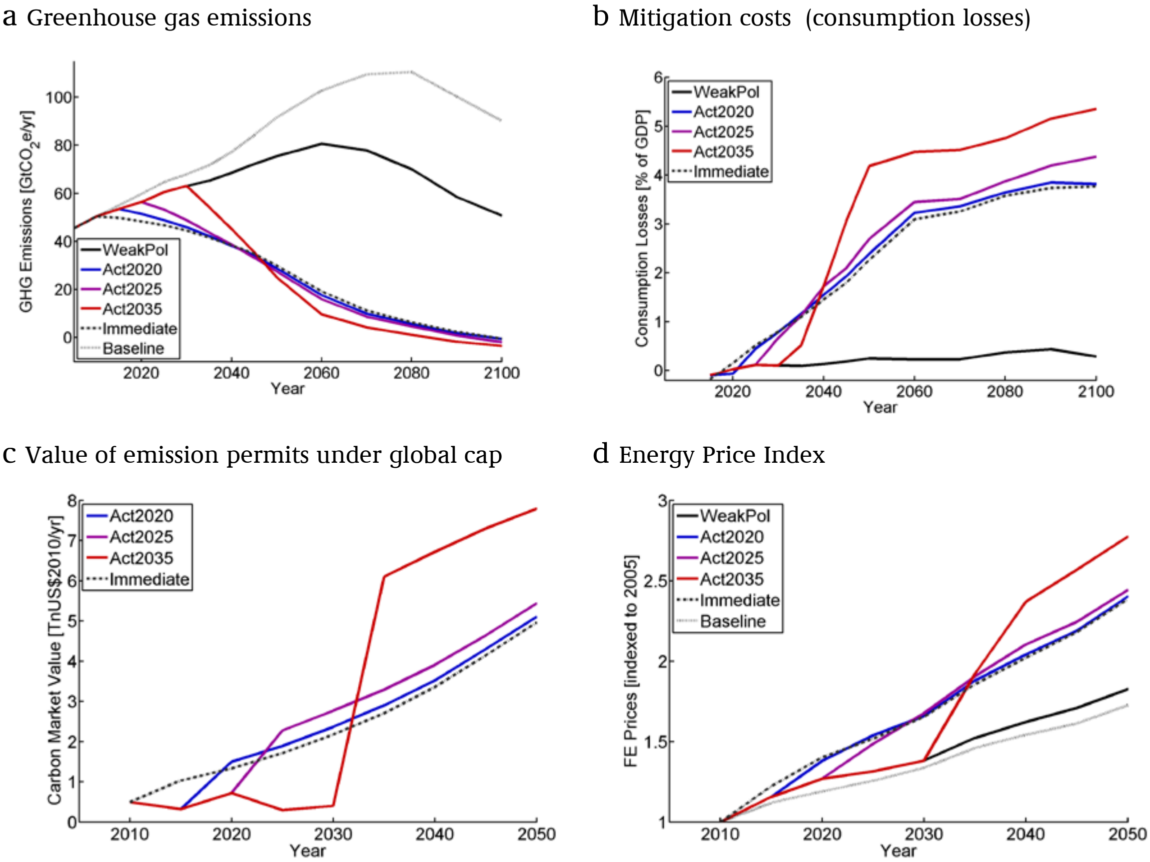


Figure 4.3: Development of global GHG emissions (a), consumptions losses (b), value of emission permits covered by carbon pricing (c), and final energy prices (c) for the reference scenario with weak polices *(WeakPol)*, as well as for stabilization scenarios with a cumulative emissions budget of 2500 $GtCO_2e$, with immediate *(Immediate)* or delayed implementation of comprehensive emissions reductions *(Act2020, Act2025, Act2035)*.

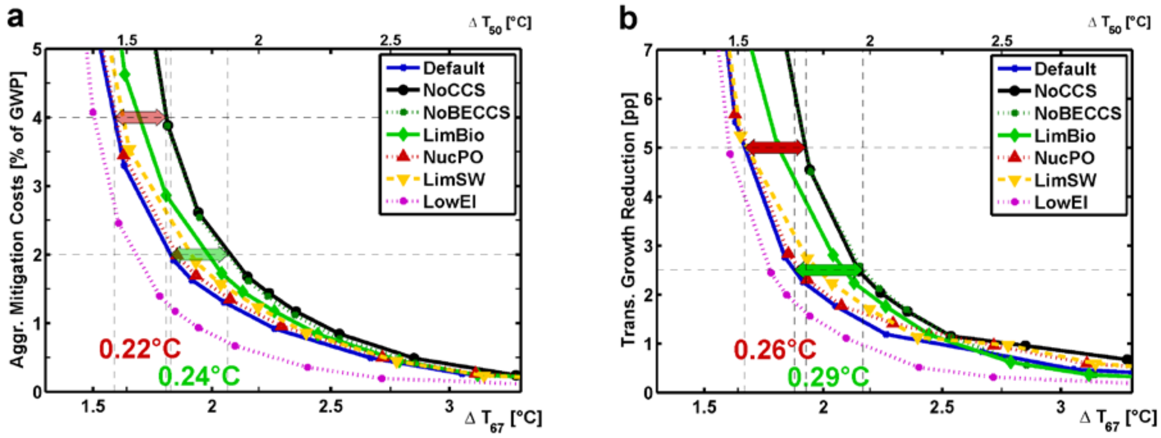


4.5 The role of technologies and energy demand

We focus the further discussion on aggregated mitigation costs and transitional growth reduction. We observe that the availability of CCS technologies has a particularly strong influence on target achievability. Lowest achievable mitigation targets increase by 0.2-0.3°C if CCS cannot be used. The similarity of the results of a) unavailability of BECCS and b) unavailability of both BECCS and fossil CCS underscores the importance of negative emissions, and suggest that BECCS is more crucial for low stabilization than fossil CCS. Limited bioenergy potential also results in a significant shift in the temperature-cost-trade-off curves. The relevance of bioenergy is two-fold: first, as described above, combining bioenergy with CCS allows generating negative emissions. Second, biomass can be used to provide non-electric energy, for example for the transport sector. Currently, non-electric energy supply accounts for about 60% of global emissions. While several options are available to provide low-carbon electricity, biomass, the switch to electricity and energy conservation are the only major options to reduce emissions from energy uses that are currently supplied with non-electric energy. The importance of biomass for low stabilization is at stark contrast to concerns about potential adverse effects of large-scale biomass production on food security and the environment (Chum et al. 2011; Creutzig et al. 2012).

Different decarbonization patterns of electric and non-electric energy supply do not only help to explain the value of biomass for the mitigation effort. They also elucidate the relative importance of technologies that are only used for power supply. Our results show that phasing out nuclear power (*NucPO scenario)* has no significant effect on the costs of achieving climate targets. This confirms findings from earlier studies (Edenhofer et al. 2010; Tavoni et al. 2012; Bauer et al. 2012b). The impact of limiting the contribution of solar and wind power to electricity supply (*LimSW* scenario) is more substantial, but still considerably lower than that of constraints on bioenergy and CCS technologies. Given the availability of a variety of technology options, reducing the option portfolio by excluding a subset of low-carbon electricity technologies can be readily compensated. This finding points to a certain degree of leeway in including broader sustainability consideration in the design of policies to induce emissions reductions in the power sector.

Figure 4.4: Temperature-cost-tradeoff curves showing the effect of technology availability on (a) aggregated mitigation costs, and (b) transitional growth reduction (Act2020 scenario). Temperature targets (maximum 2010-2100 temperatures) reached with a 67% likelihood (lower axis) or 50% likelihood (upper axis) are shown. Numbers indicate shift in terms of ΔT_{67}.



The implementation of carbon pricing leads to an increase in energy prices, and is therefore bound to increase the return on energy efficiency investment by increasing the value of energy savings. This mechanism of demand responses to increasing energy prices is taken into account in our default climate policy scenarios and fully captured by the energy-economic modeling framework. However, due to market failures and implementation barriers, it is unlikely that carbon pricing alone is able to deliver the full cost-effective energy efficiency potential. Dedicated policies can help to remove barriers such as split incentives between landlords and residents, access to energy efficiency financing, and lacking information about appliance energy use. The energy intensity of economies can also substantially improve through behavioral changes that result in lower demand for final energy. Such behavior changes may not be directed but could be facilitated by policy.

In the *LowEI* scenario, we assume that in addition to carbon pricing a major policy effort is undertaken to overcome barriers, and to decrease energy use per unit of economic output at a much faster rate than historically observed. It results in a 25% lower energy intensity in 2050 than if historical trends continued. For this scenario, we observe that more leeway is created for affordable climate mitigation. For instance, the low-energy-intensity case shifts the lower limit of climate targets achievable at aggregated costs of 2% of GWP decreases by 0.14°C. For scenarios reaching the 2°C target with likely chance, aggregated mitigation decrease costs by more than a third if comprehensive climate policies start in 2020, and by more than 40% if policies start in 2035. Our analysis does not combine the low-energy-intensity case with cases in which mitigation technologies are limited, but it stands to reason that improved energy efficiency can also offset some of the mitigation cost impact of limited low-carbon energy supply options.

4.6 Temporary temperature overshoot and the achievability of the 1.5°C target

Assuming aggregated global mitigation costs of 4% of GWP, a short-term reduction of consumption growth of 5pp, an aggregated carbon trade volume of US$ 100 tn, and climate-policy-induced energy price increases of 100pp as critical thresholds of mitigation challenges, the lower limit of climate targets achievable with a two-thirds likelihood is ~1.7°C in terms of the maximum temperature over the 21st century—but only in case of a comprehensive climate agreement in 2015 inducing substantial mitigation action from 2020 onwards, and full technology availability. Without CCS, this lower limit increases by ~0.3°C. If comprehensive emissions reductions are delayed until 2035, the lowest achievable targets increase by ~0.4°C, chiefly because the transitional costs for the lower targets become prohibitively high. The combined analysis of policy frameworks and technology availability shows that limiting global warming to 2°C with a 67% likelihood essentially requires the adoption of a global climate regime in the coming ten years, and the deployment of CCS technologies. An acceleration of energy intensity improvements would provide some additional leeway but are insufficient to compensate for a prolonged further delay of action.

Figure 4.5: Overview of the combined effects of mitigation timing and technology availability on achievability of either not-to-exceed targets (upper panels), or 2100 temperature targets that allow for temporary overshoot (lower panels). Graphs show economic challenges (color shading) in terms of aggregated policy costs (left panels a,c), and transitional growth reduction (right panels b,d), as a function of maximum 2010-2100 temperature increase (a,b) or 2100 temperature increase (c,d). Dark grey areas at the base of bars indicate temperature target levels that were not achieved with the range of carbon price paths assumed.

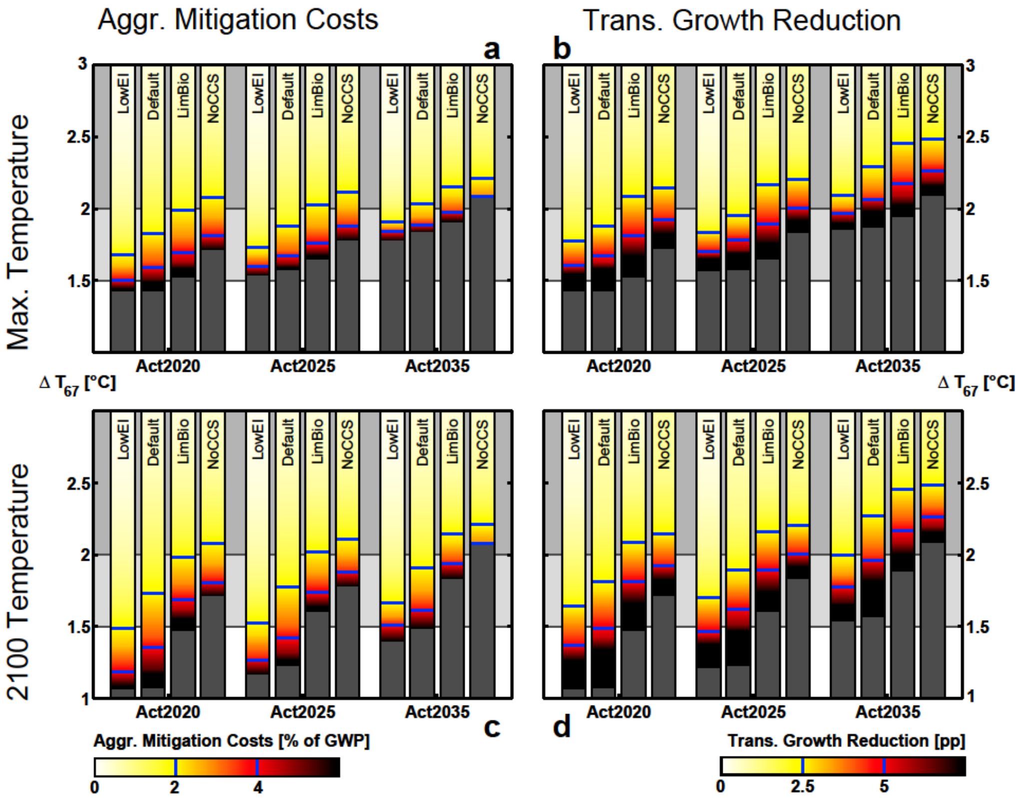
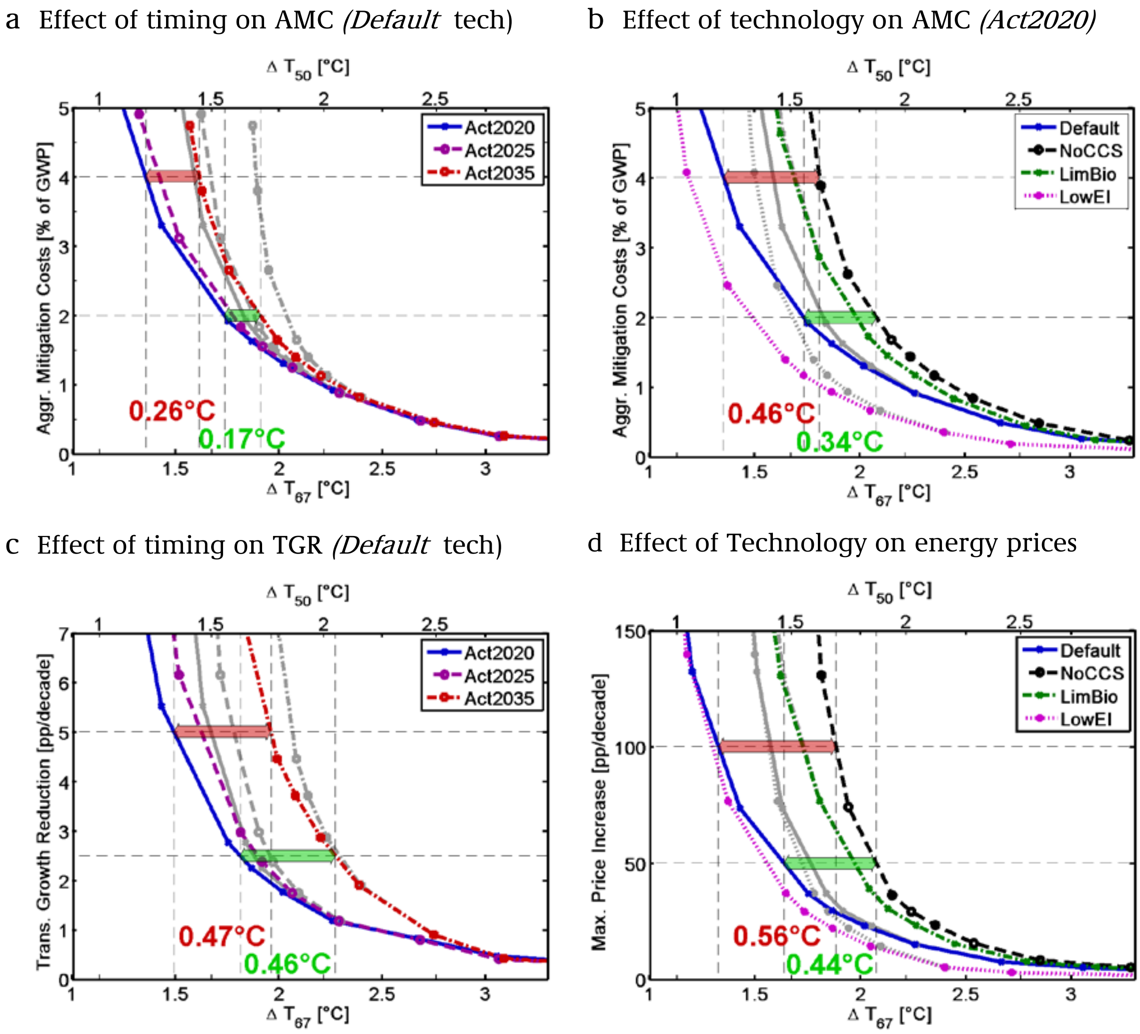


Figure 4.6: Temperature-cost tradeoff curves considering 2100 temperature levels. Grey lines indicate corresponding trade-off curves that consider maximum 2000-2100 temperatures. The left column shows the effect of mitigation timing, the right column the effect of technology availability. (a), (b) show aggregated mitigation costs, (c) shows transitional growth reductions, and (d) shows the maximum climate-policy induced decadal energy price increase. Note that for the *NoCCS* and *LimBio* scenarios, maximal temperatures are reached in 2100, therefore colored lines (2100 temperature) lie on top of the grey lines (maximum 21st century temperature).



So far, we focused on climate outcomes in terms of maximum temperature increases over the 21st century. This is equivalent to formulating climate targets as not-to-exceed. Alternatively, 2100 temperature levels can be considered, equivalent to allowing for temporary overshooting of the long-term climate target. A well-established insight from the physical climate sciences is that the temperature change at any point in time mostly depends on the cumulative emissions of anthropogenic GHGs (Meinshausen et al. 2009; Allen et al. 2009; Matthews et al. 2009; Zickfeld et al. 2009). This means that a reversal of climate change essentially requires large-scale negative emissions. It is therefore not a surprise that achievable 2100 temperature levels depend to an even stronger extent on the availability of biomass and CCS technologies. For the high end of mitigation cost levels and under default technology assumptions, we observe that in terms of 2100 temperatures considerably lower climate targets can become achievable than in terms of maximal 2000-2100 temperatures (Figure 4.5 and Figure 4.6). In the Act2020 scenario with default technology assumptions, 2100 temperatures achievable with 67% likelihood at aggregated costs of 4% of GWP drop to 1.35°C, compared to 1.6°C in terms of maximum 2000-2100 temperatures. The results also show that technology availability has a greater influence on lowest achievable 2100 temperature levels than on maximum 21st century temperatures (Figure 4.5). This is because for trajectories with overshoot, the effects of technologies only come to bear in a limited time frame (until the maximum temperature is reached), while in case of 2100 temperatures the effects of technology cumulate over the entire century. This is particularly relevant for bioenergy and CCS, which are ramped up relatively slowly in the 1st half of the century, but become very significant after 2050, if available.

4.7 Conclusions

In view of the slow progress of international climate negotiations and emissions reduction efforts, the political achievability, and the technological and economic implications of limiting global warming to 2°C are debated controversially. Model-based scenarios of climate change mitigation pathways are crucial tools for assessing the implications of alternative policy choices. Our work maps out the trade-offs between the stringency of climate targets and economic mitigation challenges at a very high level of detail. It shows how a continuation of weak and fragmented climate policies reduces the option space for future climate policy, increasing mitigation challenges and the reliance on technologies for removing CO_2 from the atmosphere.

Under optimistic assumptions about the outcome of current climate negotiations—emissions reductions starting in 2020—and full technology availability, we estimate that economic mitigation challenges become prohibitively high for temperature stabilization targets below 1.7°C. This means that only very little leeway remains to reach the 2°C target. The results of our analysis suggest that a delay of comprehensive emissions reductions until 2035 shifts the frontier of climate targets by up to 0.4°C, in effect pushing the 2°C target out of reach.

A continuation of weak climate policies inevitably increases the risk of exceeding the 2°C. Returning to 2°C in such a scenario will be difficult, and require large-scale deployment of BECCS. Our results show that temperature levels reached in 2100 depend to a much higher extent than maximum 2010-2100 temperatures on the availability of technologies, with unavailability of CCS reducing achievable target levels by almost 0.5°C.

The results have important implications for climate policy. They show clear trade-offs between long-term climate targets and economic mitigation challenges. They also demonstrate that these trade-offs depend strongly on the start date of substantial emissions reductions and on the availability of certain technologies. The longer the international community delays the implementation of comprehensive climate policies, the more critical these trade-offs will be.

Our study provides arguably the most comprehensive and fine-grained analysis of mitigation pathways consistent with low-stabilization targets, and their implications in terms of economic impacts to date. However, studying the long-term evolution of the global energy-economy climate system is a monumental challenge. Integrated assessment models are valuable tools for developing scenarios, an important caveat is that they inevitably represent many of the relevant processes and interactions in an aggregated way.

In order to further improve our understanding of the option space of climate change mitigation policies, we see the following issues as areas where additional research efforts are particularly important:

- **Bottlenecks and sustainability constraints:** Reaching the 2°C target requires a fundamental transformation of global energy systems. The longer climate policies remain weak, the faster new low-carbon technologies need to be up-scaled. At the same time, existing fossil capacities need to be replaced. Further research should be directed at improving the understanding of the dynamics of this transition process. The low-carbon transformation relies on a broad portfolio of mitigation technologies. In particular, our work shows that bioenergy and CCS are crucial technology options for low stabilization. CCS is controversial, because of concerns of leakage, and since it exhausts an ultimately limited geological storage potential. Large-scale bioenergy competes with food production and can adversely affect biodiversity. More research is required to explore the sustainability implications of such pathways.
- **The role of energy efficiency improvements***:* Bottom-up studies suggest substantial potential for energy efficiency improvements. Our results indicate that the mitigation challenge becomes significantly smaller in scenarios with lower energy demand. Many drivers of energy demand are only represented in a stylized way. Further research is required for an improved assessment of energy efficiency potentials in IAMs, and the analysis to what extent higher energy efficiency decreases the pressure for low-carbon technology deployment on the supply side.
- **Co-benefits of climate change mitigation***:* Climate change mitigation can have considerable co-benefits with other political objectives. For example, a recent study found that ambitious climate policies greatly facilitate the reduction of air pollution, and increase energy security (McCollum et al. 2011). The current expenditures for air pollution control are sizable, yet air pollution continues to have strong adverse effects on humans and nature in industrialized and developing countries alike. Further research is needed to understand to what extent the co-benefits reduce the effective costs of mitigation policies.
- **Distributional implications of climate policies***:* Most climate economic studies have focused on the aggregated long-term economic costs of climate policies. Our research shows that the effects on short-term consumption growth and energy prices as well as the redistribution of wealth induced by CO_2 pricing are crucial challenges of mitigation pathways consistent with 2°C. This finding points to potentially strong distributional effects of climate policies, which increase strongly if comprehensive climate policies are

delayed further. Additional work is needed to further corroborate these findings and to analyze policy instruments and institutional requirements to ensure that the burden of climate change mitigation is distributed across countries and societal groups in an equitable way.

5 The achievements and future role of the UNFCCC

5.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 with the ultimate objective to “prevent dangerous anthropogenic interference with the climate system” (UNFCCC 1992). Since its adoption, the international community has developed not only a comprehensive institutional structure, but also common rules for international cooperation on climate change. Nevertheless, global greenhouse gas emissions have increased by around 25% since then (EDGAR 2011), while they are supposed to peak and decline to a low level to stabilize the climate in the long term.

So what has the UNFCCC process achieved if it has not yet actually achieved haltinggrowth in global greenhouse gas emissions?

To answer this question we comprehensively evaluated the effect and achievements of the UNFCCC process along a set of objectives of international cooperation on climate change. So far such comprehensive analysis is missing, as earlier assessments usually consider individual aspects of the UN process (Manne and Richels 2004; Michaelowa et al. 2005; Aldy and Stavins 2009) or only analyze its impact on national policy making (Tompkins and Amundsen 2008; Baettig et al. 2008).

The basic characteristics of the UN-led process are important for the assessment: The UNFCCC process has almost universal participation, with 195 countries that are party to the agreement. All decisions have to be adopted by consensus, meaning that no single country may object. As a consequence, decisions are developed in a lengthy yet inclusive process. It results in a negotiated compromise among all countries. Thus, the decisions may include some “constructive ambiguity” leaving room for different interpretations to allow them to be acceptable to all. Decisions once taken, however, represent a worldwide consensus and as such have very high legitimacy and are rarely reversed.

Countries commit to any action under the UNFCCC voluntarily. Once a country joins, the implementation of the commitments is subject to a review procedure. The Kyoto Protocol, agreed in 1997 under the UNFCCC, established stringent compliance rules, by which a committee assesses whether the commitments are met and decides on penalties if they are not met, e.g. in the form of additional emission reduction requirements in the future. This is exceptional for environmental treaties. On the other hand, if a country decides to leave the treaty, it cannot be stopped. An example is the announcement of Canada not to adhere to its targets under the Kyoto Protocol for 2008 to 2012, and its subsequent complete withdrawal from the Kyoto Protocol.

5.2 Method

The objective of this paper is to provide an overview of the impact of the UNFCCC process along different objectives. For the analysis we first defined objectives of international cooperation on climate change drawing from the political science literature (compare literature review in the introduction) on the general elements of international treaties.

We identified the following basic objectives, in order of a possible time sequence:

- **Raising awareness**: International cooperation can raise global awareness of the problem through public and political attention.
- **Agreeing on principles and general goals**: The international community can agree on acknowledging the problem, on general principles and on general goals, without yet specifying concrete actions of countries.
- **Preparing for emission reductions: GHG inventories, projections, strategies**: International cooperation can incentivise countries to prepare for action by providing guidance on how to establish national greenhouse gas inventories, projections of emissions and climate strategies.
- **Sharing information on policies, technologies, institutions and actions by different actors:** International cooperation can be a forum to exchange information on actions, polices, technologies and institutions that (groups of) countries or other actors have implemented to tackle climate change.
- **Defining measurable GHG emission reduction targets / commitments / actions:** International cooperation can define and enforce measurable greenhouse gas emission reduction targets.
- **Developing international policy instruments to jointly achieve goals:** International cooperation can support the development of policy instruments, such as international emissions trading, to jointly achieve common goals.
- **Incentivising national polices:** International cooperation can incentivise the implementation of national policies to reduce emissions.
- **Monitoring action by countries or other actors to increase transparency and to assess if in total sufficient:** International cooperation allows for processes to review if the aggregated action of countries and other actors is sufficient to meet its jointly agreed goals.
- **Providing international assistance:** Countries can cooperate to help each other to adapt to climate change and to reduce greenhouse gas emissions based on their common but differentiated responsibilities and respective capabilities.

In as a second step we assessed three aspects of each objective:

- **Achievements of the UNFCCC in relation to the abovementioned objectives:** Analysing the decisions of the UNFCCC to assess which elements of the objectives are covered
- **Issues that are still to be achieved in the future:** Highlighting the parts of the objectives that are not yet covered by the UNFCCC process

- **Role of future international cooperation:** Describing the necessary and possible future means of international cooperation to fully achieve the objectives

The analysis was supported by an initial literature review and a subsequent expert survey. We interviewed eight experts that are very familiar with the UNFCCC process and provided diverse inputs to the outcome of the analysis. The selection criteria for the interviewee group included:

- At least 10 years of experience with the UNFCCC process
- Exercise of a specific function within the UNFCCC process (chairperson, delegation member etc.)
- A balanced mix of government representatives, consultants and NGOs, as well as experts from 5 continents.

5.3 Analysis

5.3.1 Raising awareness

The UNFCCC process has significantly raised international awareness for necessary action on climate change in three aspects that are further described below: putting the issue of climate change high on the political agenda, putting (public) pressure on countries to form a position and creating "climate trade fairs".

The meetings under the UNFCCC, the so-called Conferences of the Parties (COPs) that take place annually since 1992, have placed the topic of climate change very high on the political agenda. Over the last 20 years, climate change has become a cross-cutting topic that is broadly covered in the media and can be found on the agendas of all relevant stakeholders within governments, businesses and civil society groups. The UNFCCC process attracted unprecedented attention at the end of 2009 when the conference in Copenhagen was to agree on a new international climate treaty. Over 100 heads of state, in total 40 000 participants came together, more than ever for any environmental conference.

The high level of attention forced heads of state to follow and to contribute to the negotiations. All governments had to form political positions on climate change and the detailed issues negotiated under the UNFCCC, which in turn has had impacts on in-country institutional set-ups (e.g. climate change units, advisory boards, funds or ministries).

The annual meetings also create a "trade fair" atmosphere in addition to the formal negotiations. A great number of institutions active in the area of climate change mitigation and adaptation come together and exchange information to further learn from each other.

The raising of attention and the high-level political discussions on climate change can be attributed to the UNFCCC and is extraordinary compared to other UN processes. All interviewees agreed that the UNFCCC process significantly accelerated the public awareness of climate change.

5.3.2 Agreeing on principles and general goals

We identified three main achievements of the UNFCCC in this category: agreement on "preventing dangerous anthropogenic interference with the climate system", agreement on "common but differentiated responsibilities and respective capabilities" and agreement "reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius".

The text of the UNFCCC, includes an agreement on fundamental goals and principles. For example, it defined as its ultimate objective to “prevent dangerous anthropogenic interference with the climate system” (Article 2). It provides the basis for any future work, even if the word “dangerous” is open to interpretation. A further specification of the term was discussed over several years. Proposals included defining a global or regional emission limit, a global greenhouse gas concentration limit or a temperature limit. The Copenhagen Accord of 2009, which was “taken note” of by most countries, stated the intent to “reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius”. In 2010, the Cancun Agreements (a decision agreed to by all countries) included the same text (For a discussion on the impact of the 2°C limit on national action see Chapter 3.6.).

One of the principles stipulated under the UNFCCC is that of “common but differentiated responsibilities and respective capabilities” (UNFCCC 1992, Article 3). The text of the UNFCCC in the next sentence specifies that developed countries need to take the lead in reducing greenhouse gas emissions. This responsibility is expressed in an annex to the UNFCCC (Annex I) that lists those developed countries with particular commitments related to emission reductions, provision of financial resources and technology transfer. This principle has shaped the structure of commitments and actions by countries that were agreed subsequently.

Overall, all interviewees agreed that the UNFCCC has made substantial progress on principles and goals, with some areas still to be specified. The universal membership of the UNFCCC provides the basis for such agreement with very broad scope and legitimacy. In fact only a UN body is able to provide such level of legitimacy.

5.3.3 Preparing for emission reductions: GHG inventories, projections, strategies

The UNFCCC has created a comprehensive reporting and review system on these items: reporting is split by “national greenhouse gas inventories”, with estimates of recent national emissions, and national communications, with more information such as projections of greenhouse gas emissions and actions.

Developed countries report national greenhouse gas inventories annually, estimated or measured according to common guidelines (IPCC 2006 guidelines) and reviewed by experts annually Developing countries have also agreed to report annual greenhouse gas emission inventories every two years as of 2013 (a decision taken within the Cancun Agreements in 2010).

Developed countries report national communications in intervals of roughly 5 years on projections of greenhouse gas emissions and actions to mitigate climate change. Since 2010 they also have to provide biannual updates. These national communications and update reports are also reviewed. Developing countries have to report on their actions also on a biannual basis, but less comprehensively compared to developed countries. All countries are also encouraged to prepare low carbon development strategies (Cancun Agreements).

However, some shortcomings remain. Currently few developing countries report greenhouse gas inventories. Some countries need support for the preparation while others are reluctant to report, as they fear to be pushed to commit to additional actions. The national strategies reported by countries focus in their majority on the short term and in many cases lack necessary ambition.

In sum, the UNFCCC has made substantial progress to encourage countries to prepare for emission reductions with the preparation of consistent, comparable and reviewed national greenhouse gas inventories, actions and strategies. Such comprehensive information would not exist without the UNFCCC process. Due to its universal member ship, the UNFCCC was able to install such an internationally consistent system.

5.3.4 Sharing information on policies, technologies, institutions and actions by other actors

An additional function of international cooperation is the sharing of information on actual activities that countries and other actors undertake to reduce emissions and to adapt to climate change. This goes beyond preparatory work mentioned above, but is short of a formal commitment to undertake action.

Reporting of this information within the UNFCCC process is quite comprehensive. Developed countries need to provide information on emission mitigation policies in relevant sectors ("Policies and Measures" chapter of the national communications) around every 5 years. These national communications also include information on financial support, but in a less comprehensive manner. Since 2010, developing countries also need to report on their actions more regularly. Some have voluntarily submitted "nationally appropriate mitigation actions, NAMAs".

However, the UNFCCC stimulates discussion on policies, lessons learned and good practices only to a limited extent: under the heading of "Policies and Measures" for developed, and under "NAMAs" for developing countries. A number of developed countries did not want to engage in this discussion, claiming that national action is within their sovereignty. Hence, the topic of "policies and measures" never became a meaningful agenda item in the negotiations. Some developing countries on the other hand did not want to discuss their NAMAs in detail, as they feared this could lead them into binding commitments. An example of this tendency is that workshops on clarifying submitted NAMAs were agreed to be held only after a long debate and only on limited occasions.

The UNFCCC process has also stimulated exchange of information from actors other than national governments. The Bali Action Plan agreed in 2007 requested countries to negotiate on "ways to strengthen the catalytic role of the Convention in encouraging multilateral bodies, the public and private sectors and civil society, building on synergies among activities and processes, as a means to support mitigation in a coherent and integrated manner" (UNFCCC 2008 paragraphs 1b7, similar for adaptation in 1c5). Certain activities by the UNFCCC secretariat allow such actors to make their action visible. However, a comprehensive treatment and exchange of information on these activities does not take place.

Additional information sharing is already happening outside of the UNFCCC, where committed countries organize exchanges of experience, e.g. under the Cartagena Dialogue, the Mitigation and MRV Partnership of the German, South African and Korean governments or informal dialogues on NAMAs.

5.3.5 Defining measurable GHG reduction targets / commitments / actions

The impact or success of the UNFCCC process is often solely defined on the basis of its ability to set greenhouse gas mitigation targets, commitments or action. Clearly, this is an important objective of international climate change cooperation, but it is only one of many interconnected objectives to support the multilateral approach to mitigation and adaptation.

The UNFCCC process set several such targets. The first commitment set out in Article 4.2 (a) and (b) of the UNFCCC (UNFCCC 1992), stipulates that developed countries should implement national policies “with the aim of returning individually or jointly to their 1990 level by the turn of the century”. It is an indicative target, which was actually met.

As a next step, the Kyoto Protocol established economy-wide binding targets for developed countries to collectively reduce their greenhouse gas emissions by 5.2% below 1990 levels in the period from 2008 to 2012. The agreement of concrete reduction targets of legally binding nature, together with a compliance procedure and possible penalties are unprecedented in international environmental law.

However, some countries dropped out of the agreement. The at the time largest emitter, the USA, decided after signing the Kyoto Protocol in 1997, not to ratify it. Canada did ratify, but in December 2011 announced not to implement the reduction target, and to withdraw from the Protocol completely. A second commitment period from 2013 to 2020 was agreed in 2012, including emission reduction targets only for a limited number of developed countries. The accounting framework and the institutions under the Kyoto Protocol will be continued. Some of the largest developing country emitters are still reluctant to join, e.g. USA, Canada, Japan and Russia.

In the run up to the Copenhagen conference in December 2009 and shortly thereafter all major countries submitted emission reduction proposals and actions for 2020. These proposals and actions were recorded and acknowledged in the Cancun Agreements adopted in December 2010, but do not have a legally binding nature. Still, all major developing countries actually submitted quantitative GHG emission reduction targets for 2020. This is remarkable, because until 2007 all of these countries had constantly resisted formulating any quantitative targets for themselves.

The 2°C limit has been an important benchmark for many countries when setting their national emission reduction target. For developed countries, the often mentioned range that is compatible with 2°C is 25% to 40% below 1990 in 2020 (den Elzen and Höhne 2008; Den Elzen and Höhne 2010). Countries like Japan (-25%) and Norway (-30% to -40%) seem to be influenced by this range. For developing countries the comparable range is -15% to -30% below a business as usual scenario in 2020 (den Elzen and Höhne 2008, 2010). Countries like Mexico (-30% from previously -20%), South Korea (-30%), South Africa (-34%), Brazil (36% to 39%) and Indonesia (-26% to 41%) seem to be guided by these ranges.

While the pledges show a general willingness of countries to act, they are in total not yet sufficient to limit global average temperature increase to 2°C (UNEP 2010, 2011b). Several of the proposed actions for 2020 are conditional to action by others. The pledges of all major countries have essentially not changed since December 2009, although it has been known and accepted since then that, in aggregate, they are not sufficient to limit global temperature increase to 2°C. Only a few countries have made reduction proposals beyond 2020.

Some argue that the decision on an Annex I with a fixed list of countries has blocked faster action. For example, it proved difficult that countries join this Annex (Kazakhstan) or leave this Annex (Turkey). In addition, it was a long standing position of the group of developing countries that first Annex I countries have to take on new binding commitments before developing countries take on such commitments. The pledges of all countries now acknowledged in the Cancun Agreements and the agreement to develop a new internationally legally binding agreement applicable to all countries by 2015 essentially has overcome this divide.

So in effect, the UNFCCC has installed a system of actions and targets for all countries, even though a legally binding agreement was not achieved in 2009 and 2010 as planned. It also has initiated a process to increase the ambition level before 2020, with results to be expected during 2014. The pledges can be the basis for a new legally binding agreement.

5.3.6 Developing international policy instruments to jointly achieve goals

The UNFCCC has been very successful in developing policy instruments and institutional structures to assist each other to jointly achieve common goals: It introduced International Emissions Trading, Joint Implementation and the Clean Development Mechanism. These mechanisms are fully operational and served as the basis for national policy instruments, such as national emission trading schemes or voluntary offset mechanisms.

Further mechanisms are under development, including the mechanism for Reducing Emissions from Deforestation and Forest Degradation (REDD+), the Technology Mechanism which is to facilitate enhanced technology transfer and development, as well as institutional structure for financing NAMAs, which could also use a “registry” for matching proposed actions by developing countries with donors from developed countries.

In our analysis and during discussions with the interviewees, there was broad agreement that the UNFCCC has enabled the development of innovative policy instruments for the joint achievement of common goals.

5.3.7 Incentivising national polices

A major question is whether the preparatory work of the UNFCCC has indeed incentivised the implementation of national government policies to reduce greenhouse gas emissions.

There are traceable examples showing that the preparatory work and the target setting of the UNFCCC process has directly led to national policies that reduced GHG emissions and that clearly would not have happened otherwise, as explained below:

- National climate laws: several countries recently implemented national climate laws that make the international pledge for 2020 nationally binding. Mexico for example set a national GHG target of 20% below business as usual emissions in 2020 and later increased it to 30%. This target is now national law. South Korea also adopted a target of 30% below BAU and has agreed to implement an emission trading scheme to achieve the target. Brazil included its international pledge of 36% to 39% below BAU in its national law. Australia implemented a clean energy future plan that is designed to meet its international pledge. Countries would not have had these targets without the UNFCCC process.

- Emission trading schemes: Various countries introduced national emission trading systems designed to implement commitments under the Kyoto Protocol or to be compatible with the Kyoto Protocol’s mechanisms. These include, for example, the EU, Australia, New Zealand, Switzerland and Kazakhstan. Systems in California, Quebec, Regional Greenhouse Gas initiative (Northeastern USA) and very recently also in some Chinese jurisdictions and at the national level in South Korea were encouraged by these emerging national systems.

- Policies on hydrofluorocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF6): Because they were included in the basket of controlled GHG gases of the Kyoto Protocol, many countries implemented policies that cover HFCs, PFCs and SF6, additional to CO_2 reduction policies. Before the adoption of the Kyoto Protocol, these gases were not controlled and not recognised as a problem.

In addition, countries are implementing national energy efficiency and renewable energy policies, triggered also in part by the UNFCCC process: Many countries, including the USA and China, are currently implementing national policies for energy efficiency and renewable energy, such as efficiency standards for cars and power plants or renewable standards by states (USA) or renewable energy and efficiency targets and emission trading schemes (China) in line to reach their international targets.

In summary, the UNFCCC has actively and quite successfully incentivised national policies to reduce greenhouse gas emissions.

5.3.8 Monitoring action by countries or other actors to increase transparency and assess if in total sufficient

Under the UNFCCC, reported information on country actions is reviewed to varying degree (see Chapter 3.3). For developed countries the review is explicitly limited to check whether the reporting guidelines were followed, not to assess if the action is comprehensive or sufficient to meet the targets. The details of the review of developing countries' actions is yet to be defined and implemented.

An assessment whether the national actions by countries are sufficient to meet the 2°C limit is currently performed by other organisations without a specific mandate from the UNFCCC (UNEP 2010, 2011b, 2012).

The UNFCCC process does also not check the effects of activities of actors other than national governments such as cities, provinces, companies and individuals. Such action should in principle be covered by national reporting, but the real coverage is unclear. The UNFCCC could in the future mandate this analysis or undertake it itself. A decision to review of appropriateness of action was not possible in the past due to opposition of large emitters such as USA and China, who fear that such assessment could lead to increased pressure for further commitments for themselves.

The soft review of actions is a result of the specific characteristics of the UNFCCC. Within the intergovernmental process, sovereign nations only reluctantly subscribe to a strict review process of their actions, fearing it could lead to increased pressure to undertake further commitments.

5.3.9 Provide international assistance

The UNFCCC has stimulated direct climate financing from developed to developing countries. The Global Environment Facility of the World Bank was defined as the financial mechanism under the UNFCCC. It supports emission reductions projects, adaptation and preparation of GHG inventories and national reports.

The level of financing was significantly increased through the agreement in Copenhagen in 2009 on “fast start financing” of US$ 10 billion per year from 2010 to 2012 to be provided by developed countries following the principle of common but differentiated responsibilities. The establishment of the Green Climate Fund was agreed in 2010, which will be one of the main international climate finance channels. Countries agreed to mobilize US$ 100 billion per year by 2020, leaving unclear if this is public or private financing and which share is for mitigation and adaptation. In addition, many bilateral and multilateral development banks are financing climate change mitigation and adaptation activities.

The UNFCCC provides international assistance also through its newly developed international policy instruments, e.g. jointly reducing emissions through the Clean Development Mechanism and Joint Implementation and the emerging REDD+ and Technology Mechanisms.

However, the scale of financing is criticized as too low and too slow. Due to the lack of common rules, some governments label already existing flows as additional. A further criticism is that there is no equitable access to the resources (Michaelowa et al. 2011). Many had hoped that in 2012, new financial goals would be agreed for the period 2013 to 2019, to provide a strategy on how to reach the US$100bn.

For the future the interviewees agreed that the UNFCCC is the appropriate institution to have an overview function over international funds on climate change. In addition, as currently practiced, other organizations provide and should further provide additional multilateral/ bilateral support. It was however controversial, if the UNFCCC should also directly decide on the majority of the funds, e.g. through the green climate fund, or whether most of the funding should be channelled through separate institutions.

5.4 Conclusions and Outlook

We find that the UNFCCC process has made substantial achievements in the ground work for action and is well placed and well on track to further advance these objectives:

- **Raising awareness:** In particular, the annual meetings under the UNFCCC regularly place the topic of climate change very high on the political agenda. The UNFCCC process attracted unprecedented attention at the end of 2009 when the conference in Copenhagen was to agree on a new international climate treaty. Over 100 heads of state, in total 40 000 participants came together, more than ever for any environmental conference. It forced country governments to form a position and formulate strategies on climate change.

- **Agreeing on principles and common goals:** The UN process agreed on globally accepted goals that guide action. The common goal agreed in 1992 to “preventing dangerous anthropogenic interference with the climate system” was specified in 2010/11 as the intent to “reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius”. The principle of “common but differentiated responsibilities and respective capabilities” of countries included in the text of 1992 has shaped the structure of commitments and actions by countries agreed subsequently. The universal membership of the UNFCCC provides the basis for such agreement with very broad scope and legitimacy. In fact only a UN body is able to provide such level of legitimacy.

- **Preparing for emission reductions - GHG inventories, projections, strategies:** The UNFCCC process has made substantial progress to encourage countries to prepare consistent, comparable and reviewed national greenhouse gas inventories, actions and strategies, which are now reported biannually. Such comprehensive information would not exist without the UNFCCC process. It is internationally consistent due to the universal membership to the process.

- **Developing international policy instruments to jointly achieve goals:** The UNFCCC process introduced carbon market mechanisms such as International Emissions Trading, Joint Implementation and the Clean Development Mechanism. These mechanisms are fully operational and served as the basis for national policy instruments, such as national emission trading schemes or voluntary offset mechanisms. Further mechanisms are under development, e.g. on reducing emissions from deforestation and degradation.

We also find that UNFCCC process has played a major role in other objectives of international cooperation, but these elements could still be further enhanced compared to the potential:

- **Sharing information on policies, technologies, institutions and actions by other actors:** The UN process established regularly reporting of national actions on climate change. A comprehensive discussion of this information is still limited. Countries within the UNFCCC process could work toward engaging in significantly more comprehensive analysis and discussion of best practices, positive examples and lessons learned from national policies and action, in addition to only reporting on them. This could be a future focus of the UNFCCC, eventually as important as setting GHG reduction targets.

- **Monitoring action by countries or other actors to increase transparency and assess if in total sufficient:** Actions by countries are currently reviewed only to a limited extent. For developed countries the review is explicitly limited to check whether the reporting guidelines were followed, not to assess if the action is comprehensive or sufficient to meet the targets. The details of the review of developing countries' actions is yet to be defined and implemented. The comprehensive information sharing could be supplemented by a stringent but facilitative review of progress of national actions. The enhanced reviews under the UNFCCC could aim to demonstrate that they are to the benefit of those that are reviewed. For example one could install voluntary pilot reviews for those countries that wish to be reviewed to build trust and help to develop review guidelines for the future. This could be complemented by independent additional review at the global level, currently performed by other organisations without a specific mandate from the UNFCCC (UNEP 2010, 2011, 2012; Höhne et al. 2011).

- **Incentivising national policies:** There are traceable examples showing that the preparatory work and the target setting of the UNFCCC process has directly led to national policies that reduced GHG emissions and that clearly would not have happened otherwise. Several countries recently implemented national climate laws that make their international emission reduction proposal for 2020 nationally binding. Mexico, Brazil and South Korea for example transformed the internationally proposed GHG target into national law. Australia implemented a clean energy future plan that is designed to meet its international pledge. Countries would not have had these targets without the UNFCCC process. In addition, various countries introduced national emission trading systems designed to implement commitments under the Kyoto Protocol or to be compatible with the Kyoto Protocol's mechanisms. These include, for example, the EU, Australia, New Zealand, Switzerland and Kazakhstan. Systems in California, Quebec, Regional Greenhouse Gas initiative (Northwest of the USA) and very recently also South Korea and China were encouraged by these emerging national systems.

- **Providing international assistance:** The UNFCCC has stimulated financial flows from developed to developing countries on climate change. The level of financing was significantly increased through the agreement in Copenhagen in 2009 on "fast start financing" of US$ 10 billion per year from 2010 to 2012 to be provided by developed countries following the principle of common but differentiated responsibilities. The establishment of the Green Climate Fund was agreed in 2010, which will be one of the main international climate finance channels. Countries agreed to mobilize US$ 100 billion per year by 2020. However, the scale of financing is criticized as too low and too slow. Due to the lack of common rules, some governments label already existing flows as additional. A further criticism is that there is no equitable access to the resources (Axel Michaelowa and Katharina Michaelowa 2011).

- **Defining measurable GHG reduction targets / commitments / actions:** Substantial progress has been made with the setting of emission reduction targets / pledges for all major emitters. The first commitment set out in Article 4.2 (a) and (b) of the UNFCCC (UNFCCC 1992), stipulates that developed countries should implement national policies "with the aim of returning individually or jointly to their 1990 level by the turn of the century". This indicative target was actually met. As a next step, the Kyoto Protocol established economy-wide binding targets for developed countries to collectively reduce their greenhouse gas emissions by 5.2% below 1990 levels in the period from 2008 to 2012. The agreement of concrete reduction targets of legally binding nature, together with a compliance procedure and possible penalties are unprecedented in international environmental law. After having signed the Protocol in 1997, the USA refrained to ratify it. Canada did ratify, but in December 2011 announced not to implement the reduction target and to withdraw from the Protocol completely. A second commitment period from 2013 to 2020 was agreed in 2012, including emission reduction targets for a limited number of developed countries. Some of the largest developed country emitters are still reluctant to join, e.g. USA, Canada, Japan and Russia.

In the run up to the Copenhagen conference in December 2009 and shortly thereafter all major countries submitted emission reduction proposals and actions for 2020. These proposals and actions were recorded and acknowledged in the Cancun Agreements adopted in December 2010, but do not have a legally binding nature. Still, all major developing countries actually submitted quantitative GHG emission reduction targets for 2020. This is remarkable, because until 2007 all of these countries had constantly resisted formulating any quantitative targets for themselves.

The 2°C limit has been an important benchmark for many countries when setting their national emission reduction target. For developed countries, the often mentioned range that is compatible with 2°C is 25% to 40% below 1990 in 2020 (Gupta et al. 2007; den Elzen and Höhne 2008; Den Elzen and Höhne 2010) (Gupta et al. 2007; den Elzen and Höhne 2008, 2010). Countries like Japan (-25%) and Norway (-30% to -40%) seem to be influenced by this range. For developing countries the comparable range is -15% to -30% below a business as usual scenario in 2020 (den Elzen and Höhne 2008, 2010). Countries like Mexico (-30% from previously -20%), South Korea (-30%), South Africa (-34%), Brazil (-36% to -39%) and Indonesia (-26% to 41%) seem to be guided by these ranges.

Although not legally binding and in sum insufficient to limit temperature increase to below 2°C (Höhne et al. 2012; UNEP 2012), they constitute a major achievement and incentivise national policies to reduce emissions. It essentially also has overcome the formerly rigid divide between developed and developing countries. The general reluctance of countries to be bound internationally by measurable and ambitious targets is unlikely to be solved by any other process or institution.

Table 1: Objectives that have been achieved

Objectives of international cooperation in climate change	Achievements of UNFCCC	Issues to be achieved in the future (or barriers to overcome)
Raising awareness	Putting the issue of climate change high on the political agenda on an annual basis Forcing countries to meet and form a position and to develop a voice Create "Climate trade fairs"	Keep it high on the agenda against other competing topics
Agreeing on principles and general goals	"Prevent dangerous interference with the climate system" "Common but differentiated responsibility and respective capability" 2°C limit is internationally agreed and guides reduction efforts	Further specifying the agreed principles Specify 2°C limit with probability and date Agree limits from GHG concentrations or global emissions
Preparing for emission reductions: GHG inventories, projections, strategies	All countries should report GHG inventories and projections All countries are encouraged to prepare low carbon development strategies	Reporting of inventories scarce for developing countries, some need support, some are reluctant National strategies are mostly short term and not ambitious enough for 2°C
Developing international policy instruments to jointly achieve goals	International Emissions Trading Joint Implementation Clean Development Mechanism REDD+ Technology Mechanism Nationally Appropriate Mitigation Actions	Coordination of rules of carbon markets Specification of emerging mechanisms

Table 2: Objectives that have been partly achieved

Objectives of international cooperation in climate change	Achievements of UNFCCC	Issues to be achieved in the future (or barriers to overcome)
Sharing information on policies, technologies, institutions and actions by other actors	Countries regularly report policies Initial exchange of information between actors other than national governments	UNFCCC stimulates exchange of information and discussion on policies only to a limited extent, also because of reluctance of some to talk about it Improve reporting on climate finance
Monitoring action by countries or other actors to increase transparency and assess if in total sufficient	Reporting and review requirements Review for developed countries currently only checks if elements are reported, not if they are sufficient	Review for developing countries yet to be implemented No checking if national action is sufficient to meet 2°C limit No checking if action of non-state action is significant

Incentivising national policies	National climate laws (EU, Mexico, Brazil, South Korea) Emission trading schemes (EU, Australia, New Zealand, Switzerland, Kasakhstan, California, Quebec, RGGI, South Korea, China)	Scale of incentivised action still insufficient
Providing international assistance	Climate finance (UNFCCC funds, NAMAs, REDD+, GEF, MDBs, bilateral banks) – fast start finance of US$ 30bln is significantly higher than previous support through GEF Carbon markets (Clean Development Mechanism, Joint Implementation) Technology mechanism	Scale of financing criticized as too low and too slow, not additional, no equitable access/ transparence
Defining measurable GHG reduction targets / commitments / actions	Reduction targets for developed countries until 2012 (Kyoto Protocol) and new commitment period approved Reduction targets and action (NAMAs) by all countries until 2020, some inspired by the 2°C limit, some conditional Countries implement national policies as a result of these pledges	Proposed actions only until 2020 In sum not ambitious enough for 2°C Agree on action for all countries from 2020

What next?

Based on the list of achievements, the UNFCCC process could further develop along a gradual approach taking many small steps instead of a few large ones. Countries have agreed to develop a new international legally binding agreement applicable to all countries by 2015. Such an agreement would be another major step forward. Elements of it could be specified already before and also after 2015 in separate decisions.

The greenhouse gas reduction targets proposed by countries for 2020 or possible new ones for e.g. 2030 could be viewed as a “floor” of ambition that can be increased or overachieved in the future. This is essentially the situation for the targets agreed under the second commitment period of the Kyoto Protocol. The UNFCCC process would continuously review if the aggregated stringency is sufficient and agree on concrete points in time where targets and actions are to be strengthened. Such strengthened targets would be used in the legally binding treaty.

However, any future system would have to ensure that the raising of ambition does not result in unintended consequences. For example, it would have to be agreed upfront that overachieving the targets would not result in surplus allowances that will water down the ambition at a later date.

In support of stricter targets, complementary initiatives outside of the UNFCCC process with proactive national, regional and local governments, companies, sectors and individuals could help raise global ambition (Blok et al. 2012). The UNFCCC could further encourage such activities and provide a forum for them, following its mandate to catalyse such action.

In addition, the UNFCCC process could focus much more on sharing experiences of successes and failures in efforts to reduce greenhouse gas emissions through dedicated dialogues and stringent but facilitative review.

The advantages of the above recommendations include that the UNFCCC process would focus on the positive achievements to date, would further catalyse action and would be motivated by the possible successes. It would amplify its significant effect even before an all-encompassing treaty is accepted.

Such a facilitative, positive approach has already incentivised countries to implement national actions underneath the pledges, and they could be encouraged to do even more to scale up action sufficient to meet the 2°C limit.

Solving climate change is a global challenge. Our analysis showed that the UNFCCC process plays an essential role in solving this global challenge by facilitating and framing the international cooperation and has significant scope to enhance this role in the future.

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