3 Beyond the 2°C limit: Facing the economic and institutional challenges

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With very high risk of severe, widespread and irreversible impacts globally due to unabated anthropogenic climate change, we argue in this chapter that the 2°C limit can be justified by the synthesis of available scientific evidence as an application of the precautionary principle. In principle, the risks of mitigation differ fundamentally from the risks of climate change in terms of their nature, timescale, magnitude and persistence. Humankind has the technological means to solve the problem. However, the challenges of stringent mitigation action are enormous and have been increasing over the last decade because of the ongoing renaissance of coal, which does not allow for a decoupling of economic and population growth from emissions. Keeping a greater than 66% probability of staying below the 2°C limit, for example, would require current emission levels to be reduced by 40-70% by 2050, and emission levels of zero and below by the end of the 21st century. This requires a large-scale transformation in the way we produce and use energy, as well as how we use land. The most fundamental challenges are the oversupply of fossil fuels and the risks associated with negative emissions technologies, or high bioenergy deployment. A further delay in mitigation action substantially increases the difficulty of, and narrows the options for, this transformation. Delays are associated with a growing dependence on negative emissions technologies as well as higher mitigation costs in the long run. In the near term, a fundamental departure from the business-as-usual development is required. Therefore, triggering

short-term climate policy action is instrumental for any reasonable long-term climate goal. While the institutional challenges are tantamount, there are multiple rationales for pricing carbon and introducing complementary policies.

1 Dangerous climate change – the rationale of the 2°C limit

Faced with an increasing likelihood of "very high risk of severe, widespread and irreversible impacts globally" due to unabated anthropogenic climate change (IPCC 2014c), decision makers from all countries will meet at the 21st Conference of Parties (COP21) in Paris to work on a new international climate treaty. Climate policy is locked in a race against time, with greenhouse gas (GHG) emissions growing faster in the first decade of this century than in previous decades, despite a growing number of mitigation efforts. One of the most important drivers is the ongoing renaissance of coal, which does not allow for a decoupling of economic and population growth from GHG emissions (IPCC 2014a, Steckel et al. 2015). The oversupply of fossil fuels is one of the most fundamental challenges of climate policy. Understanding the technological and economic implications of limiting the disposal space of GHGs in the atmosphere (see Section 2) and triggering short-term mitigation action (see Section 3) is key to a workable and effective climate regime.

As highlighted in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the global mean temperature increase is an almost linear function of the cumulative release of CO_2 emissions to the atmosphere (see Figures SPM.10 and 12.45 in IPCC 2013; and Figure SPM.10 in IPCC 2014d). As carbon emissions accumulate in the atmosphere, the long-term temperature increase is determined in an irreversible way, unless technologies are available that allow for the net removal of carbon from the atmosphere, so-called 'negative emissions technologies'. While these may be necessary and useful within a portfolio of mitigation options, the required large-scale deployment of such technologies is associated with important risks (see Section 2) and is not able to prevent climate change within a reasonable time frame (IPCC 2013). These and other mitigation risks need to be weighed against the risks of climate impacts when determining a climate goal.

Economists have frequently tried to estimate the optimal balance between mitigation, adaptation and residual climate impacts. However, the underlying differences in methodological approaches and important gaps in knowledge make it challenging to carry out direct comparisons of these impacts in the form of cost-benefit calculations (Kunreuther et al. 2013, IPCC 2014e). More fundamentally, the identification of an optimal climate goal is based on many implicit value judgements and ethical considerations, which may be contested in pluralistic societies. Such judgements and considerations are fundamentally important, for example, when the damages from climate change, which are mainly incurred by future generations, are counted against the costs of mitigation, which are largely borne by today's generations (Kolstad et al. 2014). It therefore seems appropriate to take a risk management perspective that evaluates the risks of climate change (in terms of impacts and adaptation limits) and the risks of mitigation action (in terms of mitigation costs and potential adverse side-effects of mitigation technologies). This ultimately leaves the decision about the most desirable temperature level to policymakers and the public, who may base their discussions on the range of different risks, information about which is provided in the AR5 (Edenhofer and Kowarsch 2015).

Increasing temperatures raise the likelihood of severe, widespread and irreversible impacts (IPCC 2014c). Without additional mitigation efforts, the global mean temperature will increase by about 4°C (3.7-4.8°C based on the median climate response) by the end of the 21st century and will lead to high to very high climate change risks even with adaptation (Clarke et al. 2014, IPCC 2014a, IPCC 2014e). These include inter alia the loss of the Arctic ice sheet, substantial species extinctions, consequential constraints for human activities and global and regional food insecurity (IPCC 2014c). Limiting warming to below 2°C would reduce these risks of climate change substantially compared to business as usual, particularly in the second half of the 21st century (IPCC 2014c, IPCC 2014d). The large differences in risk between a 4°C and a 2°C world were therefore clearly emphasised in the AR5, whilst the difficulties in understanding the differential climate impacts for small temperature changes – such as 1.5°C, 2°C, 2.5°C or 3°C – were also acknowledged. Even a temperature increase of 2°C and below is associated with some risks from climate damages irrespective of mitigation and adaptation efforts (IPCC 2014d).

In contrast to climate damages, the risks of mitigation are generally not irreversible (except, for example, nuclear accidents and biodiversity loss) because they allow for trial and error and therefore for a social learning process in climate policy implementation. Mitigation risks are thus seen as differing fundamentally from the risks of unabated climate change in terms of their "nature, timescale, magnitude and persistence" (IPCC 2014e). Mitigation risks, however, also differ across alternative mitigation pathways.[1] These differences mainly depend on the availability and choice of technologies as well as the stringency and timing of GHG emissions reductions (see Section 3) (Clarke et al. 2014, IPCC 2014a).

Once a certain temperature level has been exceeded, only two options remain to deal with climate change: adaptation and solar radiation management (SRM), the latter of which tries to intentionally modify the earth's radiative budget. Some environmental impacts of climate change, such as ocean acidification, cannot be addressed by SRM technologies. There may also be other adverse side-effects that need careful assessment (IPCC 2013). Given the inherent uncertainties of the impacts of these options and the future impacts of climate change, aiming for the 2°C limit can thus be seen as an application of the precautionary principle, which emerges from the synthesis of scientific evidence and the value judgements by experts of how to avoid dangerous climate change. Whilst the global mean temperature cannot be controlled directly, a carbon budget can be defined which allows the limitation of the global mean temperature with a specific probability (see Table SPM.1 in IPCC 2014b). However, the window of opportunity to stay below the 2°C limit is rapidly closing, as the next section shows.

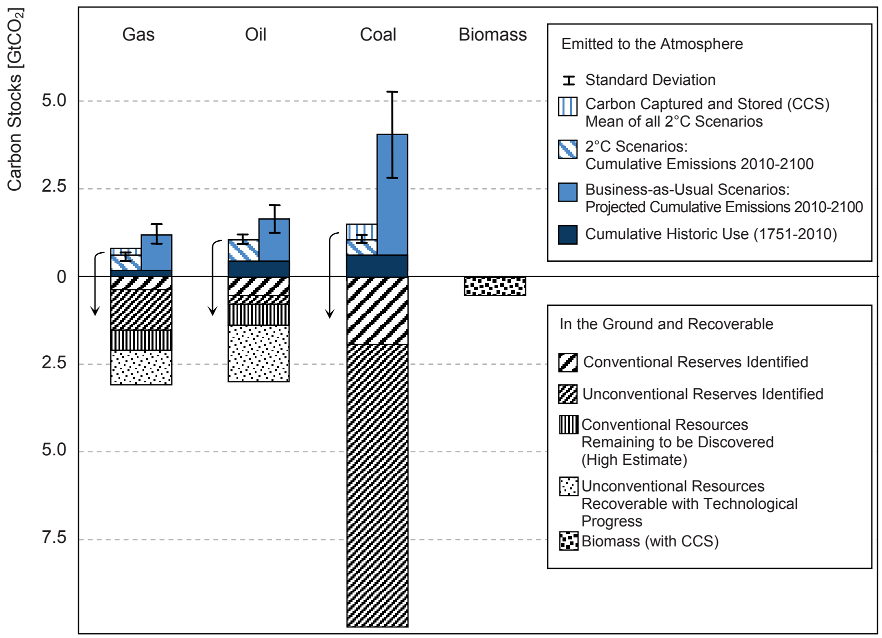
2 Technological and economic implications of the 2°C limit

Limiting climate risks by keeping global mean temperature increase below 2°C (with a greater than 66% probability) implies a remaining carbon budget of about 1,000 (750-1,400) $GtCO_2$ (IPCC 2014e). If current trends continue, this budget will be completely

1 Many mitigation technologies also entail co-benefits for non-climate policy objectives (von Stechow et al. 2015). These often accrue locally and may provide incentives for unilateral mitigation action; they are discussed in Section 3.

used up within the next 20-30 years. With more than 15,000 $GtCO_2$ in fossil fuel reserves and resources in the ground, it is clear that we will not run out of fossil fuels. Rather, it is the limited disposal space for waste GHGs of the atmosphere that constitutes the ultimate scarcity of the 21st century (see Figure 1).

Figure 1 Challenge for climate policy – there are more fossil fuels in the ground than disposal space for waste greenhouse gases remaining in the atmosphere for a 2°C limit



Notes: Columns below the zero line indicate the carbon contained in the estimated global reserves and resources of fossil fuels. The columns above the zero line are based on the scenario database used in the IPCC WGIII AR5 and indicate cumulative historical and projected emissions. For more details, see Edenhofer et al. (2015a).

Staying within this tight carbon budget implies that annual GHG emissions would need to be reduced by 40-70% by 2050 and decline towards zero and below thereafter. This requires rapid improvements in energy efficiency and a 3-4 fold increase in the share of zero- and low-carbon energy supply from renewables, nuclear energy and carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by 2050 (Clarke et al. 2014). The majority of scenarios with a greater than 66% probability of keeping average global temperature rise below 2°C can only stay within the carbon budget if the carbon debt is repaid through global net negative emissions towards the end of the 21st century. In other words, more CO_2 would need to be removed from the atmosphere through large-scale deployment of negative emission technologies, such as BECCS or afforestation, than is released by all human activities. These challenges can be alleviated to some extent through reductions in final energy demand in the near term, decreasing the amount of fossil fuels used and thus reducing the immediate pressure for decarbonising energy supply. This would also entail co-benefits that outweigh the few adverse side-effects of mitigation action in the transport, buildings, and industry sectors. On the energy supply side, the balance depends to a larger extent on the specific technology and implementation context (Clarke et al. 2014, von Stechow et al. 2015).

In addition to these technological challenges, staying within the remaining carbon budget would also imply a devaluation of coal, oil and gas assets.[2] Compared to business as usual (in the AR5 scenario database), 70% of coal reserves and resources would need to remain underground as well as 35% of oil and 32% of gas. As Figure 1 shows, this effect can be buffered to some extent by the deployment of BECCS, which has the potential to remove some of the emissions from the additional combustion of fossil fuels. If CCS is not available, however, this flexibility would be removed, calling for immediate GHG emissions reductions. This would have important implications for the allowed extraction rates and the above numbers would increase to 89%, 63% and 64%, respectively (Bauer et al. 2013, Jakob and Hilaire 2015).

One critical constraint on BECCS deployment is the large-scale availability of various bioenergy feedstocks (see the Chapter by Tavoni in this book). Deployment levels of total (modern) bioenergy in 2°C scenarios without delay and limits to technological availability are in the range of 10-245 EJ/yr by 2050 and 105-325 EJ/yr in 2100, increasing the share of bioenergy in total primary energy from 35% in 2050 to as much as 50% in 2100 (Creutzig et al. 2014, Smith et al. 2014). Whether or not these amounts of bioenergy can be supplied in a sustainable manner is highly contested, with some experts emphasising the large mitigation potential of bioenergy and others highlighting

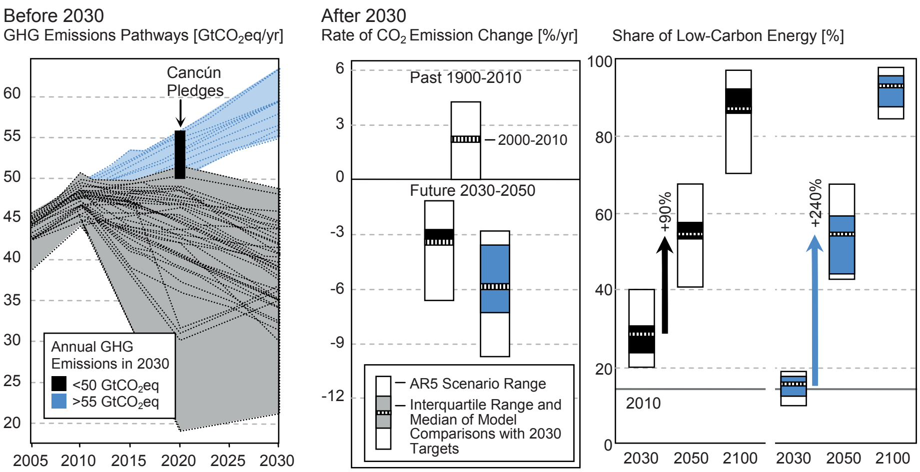
2 By reducing the disposal space for waste GHGs in the atmosphere, climate policy not only reduces the resource rents of the owners of coal, oil and gas assets, but it also creates a 'climate rent'. These revenues from carbon pricing overcompensate the loss in resource rents (Bauer et al. 2013); they are discussed in more detail in Section 3.

the risks associated with such high bioenergy deployment levels (Creutzig et al. 2012a, 2012b). The main adverse side-effects discussed relate to possible reductions of land-carbon stocks, as well as negative impacts on ecosystems, biodiversity, food security and livelihoods. The sustainable technical bioenergy potential is estimated to be around 100 EJ/yr in 2050, with high agreement in the literature, and up to 300 EJ/yr with medium agreement (Creutzig et al. 2014, Smith et al. 2014).

The technological challenges and adverse side-effects of staying below the 2°C limit increase further as stringent emissions reductions are delayed. This results from the faster timescales over which the required technologies need to be implemented. Figure 2 highlights that unless GHG emissions are reduced below current levels in 2030, the technological challenges of the 2°C limit increase substantially – particularly between 2030 and 2050 (Bertram et al. 2015, Riahi et al. 2015). Using a larger share of today's tight emissions budget also reduces the flexibility of technology choice, as staying below the temperature limit increasingly depends on the availability of potentially risky negative emissions technologies. Overall, the ability to hedge against the risks of mitigation across a broad technology portfolio becomes more and more constrained with increasing delays.

Mitigation costs increase with growing mitigation ambition, but are characterised by large uncertainties. Staying below the 2°C limit with a greater than 66% probability would imply reducing global consumption levels relative to business as usual by 5% (3%-11%) by 2100. Staying below a 2.5°C and 3°C limit would imply decreasing consumption levels by 4% (1%-7%) and 2% (1%-4%), respectively. For comparison, business-as-usual consumption itself grows between 300% to more than 900% over this period (IPCC 2014a). While these reductions in consumption levels are by no means negligible, they seem comparatively moderate. They also hinge on the assumption of effective global institutions and the establishment of a global, uniform carbon price.

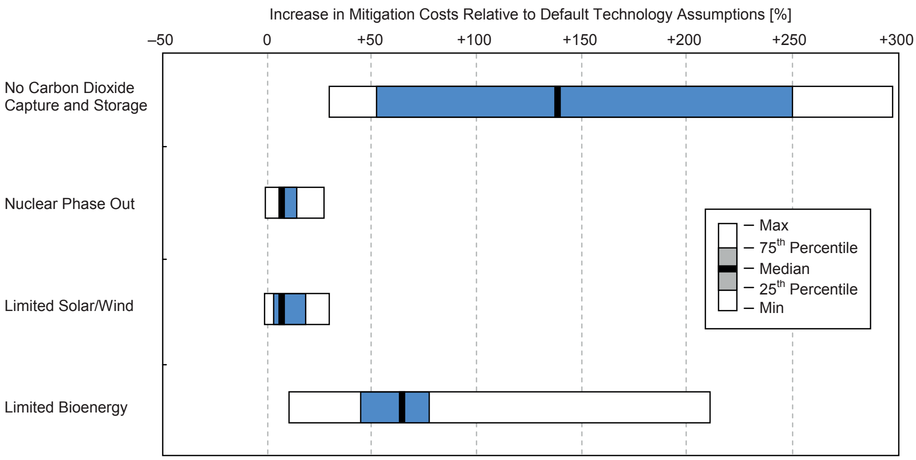
Figure 2 Increasing technological challenges associated with the energy system transformation in delayed relative to immediate mitigation scenarios consistent with staying below the 2°C limit with a roughly 50% probability



Notes: Technological challenges are represented in terms of the average annual rate of carbon emissions reductions (2030-2050, middle panel) and low-carbon energy upscaling (2030-2050/2100, right panel). Left panel shows GHG emission pathways between 2005 and 2030. Compared to immediate mitigation scenarios (grey, GHG emissions <50 Gt CO_2-equivalent in 2030), delayed mitigation scenarios (blue, GHG emissions >55 Gt CO_2-equivalent) are characterised by much faster emissions reductions and much faster upscaling of low-carbon energy technologies between 2030 and 2050. The black bar shows the uncertainty range of GHG emissions implied by the Cancún Pledges. For more details, see IPCC (2014b).

Limiting the availability of key mitigation technologies such as CCS and bioenergy might reduce some of the adverse side-effects of these technologies, but would increase discounted mitigation costs by approximately 140% (30-300%) and 60% (40-80%) by the end of the century, respectively (Figure 3). Delaying emissions reductions further increases the costs of reaching specific climate goals. A delay would protect the rents of fossil fuel owners, today's cost savings would thus be eclipsed by future cost increases. For example, delaying stringent mitigation through 2030 could raise the aggregate costs of mitigation by 30-40% (2-80%) by 2050 and by 15-40% (5-80%) by 2100 (in scenarios with a roughly 50% probability of staying below the 2°C limit) (Clarke et al. 2014).

Figure 3 The impacts of a limited mitigation technology portfolio on the relative increase in mitigation costs compared to a scenario with full availability of technologies in mitigation scenarios consistent with staying below the 2°C limit with a roughly 50% probability



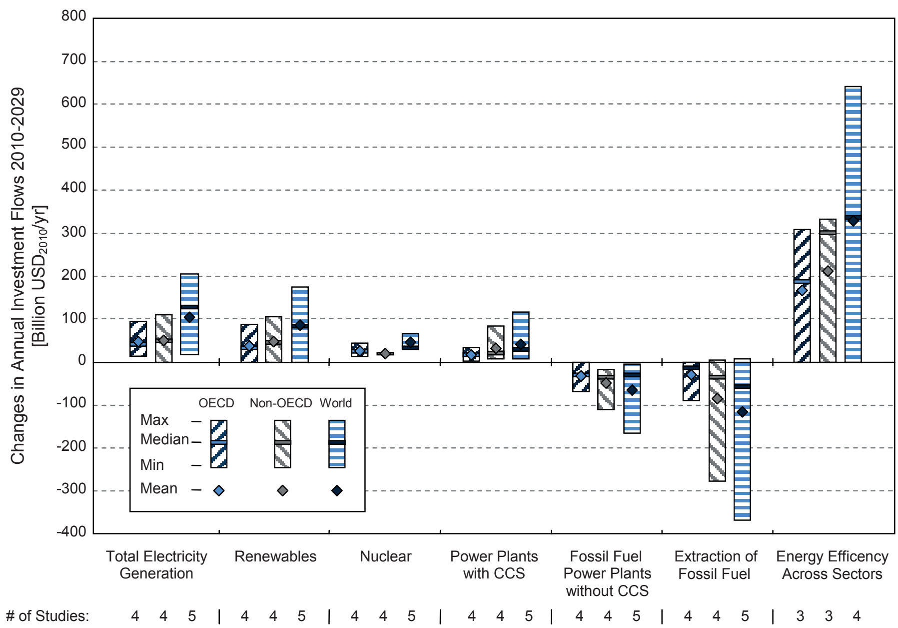
Notes: The cumulative mitigation costs (2015-2100) are presented as net present value, discounted at 5% per year. Nuclear phase out = No addition of nuclear power plants beyond those under construction and existing plants operating until the end of their lifetime; Limited Solar / Wind = a maximum of 20 % of global annual electricity supply from solar and wind; Limited Bioenergy = a maximum of 100 EJ/yr modern bioenergy supply globally. For more details, see Clarke et al. (2014).

3 Triggering short-term mitigation action

A fundamental departure from business-as-usual development is required to leave the window of opportunity open to stay below the 2°C limit. Triggering short-term climate policy action is instrumental to achieving any reasonable long-term climate goal – short-term action reduces the risks of increasing future mitigation costs and the risks of relying on negative emissions technologies with potentially large adverse-side-effects.

As discussed by Sterner and Kohlin and Stavins in their chapters in this volume, the necessity for introducing a clear price signal through carbon taxes or emissions trading becomes evident when considering the required changes in the different sectors and looking at the required reallocation of investment flows. In the energy sector, for example, new investment strategies away from fossil fuel extraction and use towards energy efficiency and low-carbon technologies for energy generation are urgently needed (Figure 4). But despite its necessity, carbon pricing is perceived as extremely demanding. The feasibility of an optimal global carbon price is currently limited as free-rider incentives seem to undermine the willingness of parties to participate in an ambitious international climate agreement (Carraro 2014, Cramton et al. 2015). It is therefore even more remarkable that a number of countries – including the majority of the world's 20 largest emitters – have started implementing GHG emissions reduction policies on their own accord.

Figure 4 Change in annual energy sector investment flows towards low-carbon energy technologies in mitigation scenarios consistent with staying below the 2°C limit with a roughly 50% probability relative to the average business-as-usual level (2010–2029)



Notes: Results are based on a limited number of model studies and model comparisons (numbers in the bottom row) highlighting that investment needs are an evolving area of research. The extent to which the investment needs in one region translate into regional mitigation costs depends on the effort-sharing regime, which has important effects on the relative cost burden (Tavoni et al. 2013, Höhne et al. 2014). For more details, see Gupta et al. (2014).

Several unilateral and often short-term incentives for introducing climate policies and establishing GHG emissions pricing schemes exist: i) the efficient generation of additional revenues for government budgets; ii) the use of carbon-pricing revenues for the provision of public goods or infrastructure investments in welfare-enhancing ways; iii) the introduction of Pigouvian carbon pricing to internalise national climate impacts;

and iv) the realisation of co-benefits from GHG emissions reductions (Edenhofer et al. 2015b). Interestingly, all of these unilateral incentives for domestic carbon prices are particularly relevant for developing countries.

1. Carbon pricing helps to broaden the often thin tax base in countries with large informal sectors (Bento and Jacobsen 2007, Bento et al. 2013, Markandya et al. 2013). With the possibility to recycle these additional carbon price revenues, potentially regressive effects may be compensated and/or existing distortionary taxes (that particularly affect low-income groups) may be reduced. Carbon pricing can therefore enhance economic growth without adverse distributive effects (Casillas and Kammen 2010, Goulder 2013, Somanathan et al. 2014). As a recent IMF report shows, however, one ton of carbon emissions receives, on average, more than 150 US$ in subsidies. The removal of all such subsidies, accompanied by an appropriate price on carbon, would benefit especially developing countries (Coady et al. 2015).
2. Carbon-pricing revenues could reduce the large investment gap in public infrastructure that provides access to basic needs, such as universal access to water, sanitation, and clean energy (Edenhofer et al. 2015b). For example, the investment needs for energy efficiency and low-carbon technologies (see Figure 4), universal energy and water access and sanitation access in non-OECD countries are well within expected revenues from climate policy (Hutton 2012, Pachauri et al. 2013, Jakob et al. 2015a). It is worth noting that the removal of fossil fuel subsidies also has a remarkable potential to raise revenues. If these subsidies of approximately US$550 billion were to be redirected to investments in basic infrastructure over the next 15 years, substantial improvements could be made in reducing poverty. This includes universal access to clean water in about 70 countries, improved sanitation in about 60 countries, and access to electricity in about 50 countries (out of roughly 80 countries that do not yet have universal access). Such investments would also increase the long-term growth prospects of poor economies (Jakob et al. 2015b). Additionally, the removal of these subsidies would cut global carbon emissions by more than 20%, and reduce pre-mature deaths related to air pollution by more than half (Coady et al. 2015).

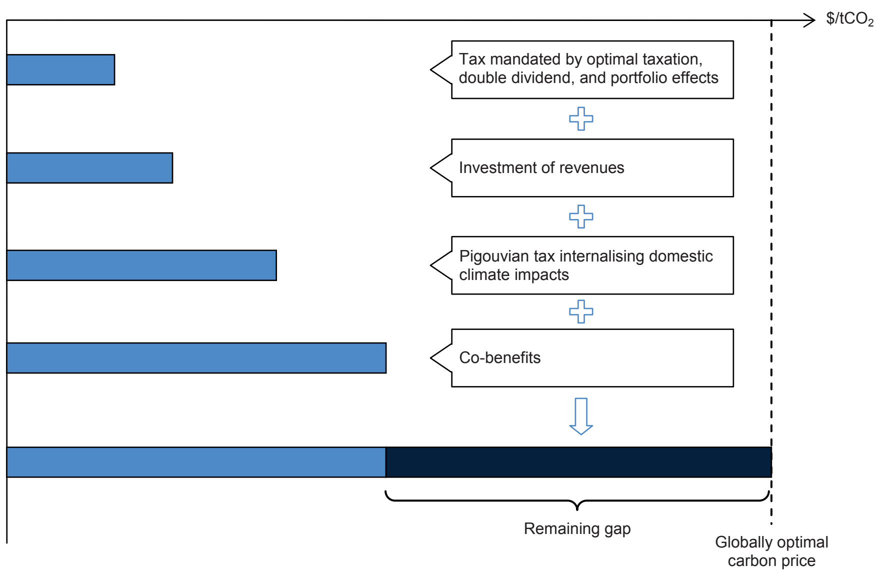
3. A substantial share of optimal carbon prices (with maximum values of 10-40%) could internalise the expected domestic damages from climate change in developing regions (Figure 3 in Edenhofer et al. 2015b).
4. Co-benefits, for example those related to reducing the health and environmental externalities from currently high air pollution, further increase the incentives to trigger short-term mitigation action in developing countries (Nemet et al. 2010, West et al. 2013).

Most of the aforementioned unilateral incentives to introduce climate policies are also particularly relevant for industrialised countries. The introduction of a carbon price provides the flexibility to reduce existing distortionary taxes and thus increase the overall efficiency of the economy. In addition, a tax on fixed production factors such as fossil fuels could stimulate the redirection of investments towards producible capital (Edenhofer et al. 2015b). The revenues from carbon pricing could also provide ample funds for the investments required in the energy sector (see Figure 4), or for addressing investments needs in the transport sector and existing market failures in technology R&D. Finally, revenues may be used for financing adaptation needs resulting from the unavoidable impacts from climate change (Malik and Smith 2012), which may range between US$25-100 billion per year by 2015-2030 (Fankhauser 2010).

These unilateral incentives show that finance ministers might be interested in carbon pricing even though they are not primarily interested in emissions reductions (Franks et al. 2014). Still, mitigation efforts that are purely motivated by national interests are not expected to achieve the globally optimal carbon price. They could nonetheless contribute towards closing the 'emission price gap', i.e. the difference between the level of current GHG prices and a globally optimal carbon price (see Figure 5, Edenhofer et al. 2015b). The crucial question remaining is to what extent unilateral action by some countries, regions or industries can promote collective action and can facilitate cooperation on the international level (Ostrom 2010, Urpelainen 2013, Cramton et al. 2015).

It has been shown above that the prospects of carbon pricing are less bleak when the investment gap in public infrastructure is financed by carbon-pricing revenues, co-benefits can be realised, and the removal of distortionary taxes is taken into account. This will not lead automatically to international cooperation and to a global carbon price. However, should domestic carbon pricing no longer be perceived as committing political suicide, the remaining carbon price gap will be easier to close by international agreements. Admittedly, the challenge of international cooperation remains and innovative proposals are needed to solve this globally pressing problem (e.g. Cramton et al. 2015, Barrett and Dannenberg 2012, and the contributions by Stewart, Keohane and Victor, and Stavins in this volume). However, the potential for domestic carbon pricing as a short-term entry point to a longer-term solution has been widely underestimated. It would open up new perspectives for tackling the climate problem if finance ministers were to become much closer allies of environmental ministers, working together to close the emission price gap and thus triggering short-term mitigation action.

Figure 5 Incentives for unilateral introduction of carbon prices and their role in closing the emission price gap.



Note: For more details, see Edenhofer et al. (2015b).

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