Transitioning from short-term policies to long-term targets: cost-effectively limiting temperature increases to 2 degrees

R. Dellink[1,*] , J. Chateau[1], B. Magné[1], V. Marchal[1], J. van Vliet[2] and D. van Vuuren[2]

[1] Organisation for Economic Co-operation and Development (OECD), Environment Directorate, Paris, France

[2] PBL Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands

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Abstract

This paper aims to investigate the economic and environmental consequences of climate change mitigation policies aimed at limiting long-term average global temperature increase to 2 °C, and contrasting that with the business-as-usual baseline projection. A combination of the ENV-Linkages economic model and the IMAGE biophyisical model is used to assess different emissions pathways to reach the long-term goal. To explore the feasibility and implications of achieving this target, three different scenarios for stabilising concentrations at 450 ppm by the end of the 21st century have been modelled. The main results of this analysis include:

- Without more ambitious policies, the *Baseline* projects that atmospheric concentration of GHG would reach almost 685 ppm CO_2e by 2050.
- Emissions must peak before 2020 to reverse emission trends in order to stabilise GHG concentrations at 450 ppm CO_2e and have at least a medium chance of limiting temperature increase to 2°C.
- The analysis suggests that achieving the 2 °C goal would require establishing carbon prices that increase over time to 325 \$/tCO_2e by 2050. The cost of reaching the 2°C goal would slow global GDP growth from 3.5 to 3.3% per year on average, costing roughly 5.5% of global GDP in 2050. Given the huge scale of the problem it is essential that cost-effective policies are implemented.
- Keeping future technology options open is important as reliance on a single unproven techniology such as BECCS can be very risky, both in terms of costs as well as the chances of reaching the temperature goal.
- Delayed or insufficient action up to 2020 as resulting from the Copenhagen pledges could lead to 50% higher costs in 2050 compared to timely action, and potentially entail higher environmental risk.

[*] Corresponding author; 2 rue André-Pascal, 75775 Paris, France; r.dellink@oecd.org.

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1 Introduction

Climate change is a serious global systemic risk that threatens life and the economy. Observations of increases in global average temperatures, widespread melting of snow and ice, and a rising global average sea level indicate that the climate is already warming (IPCC, 2007a). If greenhouse gas (GHG) emissions continue to grow, this could result in a wide range of adverse impacts and potentially trigger large-scale, irreversible and catastrophic changes (IPCC, 2007b) that will exceed the adaptive capacity of natural and social systems. The environmental, social and economic costs of inaction are likely to be significant. Agreements reached in Cancún, Mexico, at the 2010 United Nations Climate Change Conference recognised the need for deep cuts in global greenhouse gas emissions in order to limit the global average temperature increase to 2 degrees Celsius (2 °C) above pre-industrial levels (UNFCCC, 2011a). A temperature increase of more than 2 °C is likely to push components of the Earth's climate system past critical thresholds, or "tipping points" (EEA, 2010a).

Most countries have begun to respond through actions at the international, national and local levels, drawing on a mix of policy instruments that include carbon pricing, other energy efficiency policies, information-based approaches and innovation. Some progress can be noted, but much more needs to be done to achieve the 2 °C goal.

This paper aims to investigate the economic and environmental consequences of climate change mitigation policies aimed at limiting long-term average global temperature increase to 2 °C, and contractsting that with the business-as-usual baseline projection. A combination of OECD's dynamic CGE model ENV-Linkages model for economic projections and PBL's IMAGE for climate system projections is used to assess different emissions pathways to reach the long-term goal. Further details on the links between both models, the baseline developments and the specification of the climate policies are provided in OECD (2012).

This paper is organised as follows. Section 2 describes the modelling framework used. Section 3 describes the baseline projection while Section 4 compares three policy scenarios that avoid the worst environmental impacts of the baseline projection by stabilising GHG concentrations at 450 ppm. Section 5 concludes.

2 The modelling framework

The analysis in this paper are made possible by combining a general equilibrium economic modelling framework (the OECD's ENV-Linkages model) with a comprehensive environmental modelling framework (the IMAGE suite of models of the PBL Netherlands Environmental Assessment Agency). Further details on the ENV-Linkages and the IMAGE suite of models, as well as information and data sources, are provided in Chateau et al. (2012) and Kram et al. (2012), respectively. Here, only the main features of these models are briefly explained.

The **ENV-Linkages** model developed by the OECD Environment Directorate is a global dynamic computable general equilibrium (CGE) model that describes how economic activities are linked to each other between sectors and across regions. It also links economic activity to environmental pressure, specifically to emissions of greenhouse gases (GHGs). These links between economic activities and emissions are projected several decades into the future, and thus shed light on the impacts of environmental policies for the medium- and long-term future. This model was used to make projections of key socioeconomic drivers such as demographic developments, economic growth and developments in economic sectors.

The **IMAGE** (Integrated Model to Assess the Global Environment) suite of models run by the PBL is a dynamic integrated assessment framework to model global change. The IMAGE suite is underpinned by modelling of global land allocation and emissions, mapped onto a geospatial 0.5 x 0.5 degree[1] grid of the world (thus results for small areas or specific countries are less robust than for larger countries and regions). The IMAGE suite comprises models that also appear in the literature as models in their own right, and it has been used for other key global environmental assessments such as the *Global Environmental Outlooks* (GEOs) by the United Nations Environment Programme (UNEP).

The key socioeconomic trends to 2050 emerging from the ENV-Linkages model were fed into the IMAGE models to make projections of biophysical environmental consequences. In this way, the economy and the environment were connected through energy, agriculture and land use. Modelling of land and energy use provides the key connections between the economic and biophysical models. The biophysical projections from IMAGE are then used in ENV-Linkages to specify climate policies and assess their economic implications. The data flows between ENV-Linkages and the IMAGE suite were used to develop the *Baseline* projections as well as the policy simulations which are discussed below.

3 A baseline projection

A baseline projection is not a prediction of future developments. Instead it constructs expected future trends for several key economic and environmental variables based on current trends and a number of assumptions about the future. The Baseline assumes no new policies for environmental issues, but implicitly includes other government policies that are included in the projected trends for the key variables. It thus provides a benchmark against which policy scenarios aimed at improving environmental quality for the issues under investigation can be assessed.

3.1. An economic baseline projection

Baseline economic scenarios underlying global environmental economic projections – such as those developed for the Intergovernmental Panel on Climate Change (IPCC) – typically assume that there will be some gradual convergence of income levels towards those of most developed economies. A similar approach is taken here, but special emphasis is put on integrating some of the current theoretical and empirical knowledge on long-term economic growth, and making transparent assumptions about the drivers of GDP growth over the projection period (for discussion of assumptions, detailed results and data sources, see Duval and De la Maisonneuve, 2010).

The "conditional convergence" hypothesis is incorporated into the projections. GDP per capita is first decomposed as follows:

$$Y_t \; / Pop_t = (K_t \; / Y_t \;)^{\alpha/(1-\alpha)} A_t \, h_t \; (L_t \, / \, Pop_t \;)$$

where Y_t/Pop_t, K_t/Y_t, A_t, h_t, and L_t/Pop_t denote the level of GDP per capita (using PPP exchange rates to convert national GDPs into a common currency), the capital/output ratio, total factor productivity (TFP), human capital per worker and the employment rate, respectively; α is the capital share in aggregate output.

Based on this, long-term projections are then made for each of the four components so as to project the future path of GDP per capita:

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1 Degrees in terms of latitude and longitude on the Earth's surface.

- Long-term annual TFP growth at the "frontier", i.e. for best performers, defined here as the average of the "high-TFP" OECD countries, is 1.5%. The other countries converge to that frontier gradually.
- In countries where it is currently highest, the human capital of the 25-29 age group is assumed to level off, based on historical trends. The speed at which other countries converge to that frontier is assumed to tend gradually towards a world average between 1960 and 2000. The human capital of the working-age population is then projected by age cohorts.
- Capital/output ratios in all countries gradually converge to the level of the United States,
- Employment projections combine population, age structure, participation and unemployment scenarios and correspond to the 2008 revision of the United Nations medium population projections. In those OECD countries where participation is currently highest, future retirement ages are partially indexed to life expectancy. Elsewhere, participation rates gradually converge to the average level in "frontier" countries. Unemployment rates converge slowly to their structural level.
- For countries where energy resources comprise a large part of GDP, the above methodology is adapted and GDP projections are made using long-term projections for energy prices and energy demand (which in turn are influenced by the GDP projections of the other countries).

The full economic baseline methodology and resulting projections are described in detail in Chateau et al. (2011); a few key characteristics of the baseline projection are:

- **World gross domestic product (GDP)** is projected to nearly quadruple over the coming four decades, in line with the past 40 years. By 2050, the OECD's share of the global economy is projected to decline from 54% in 2010 to less than 32%, while the share of Brazil, Russia, India, Indonesia, China and South Africa (the BRIICS) is projected to grow to more than 40%. The US economy, which has been the largest in the world, as measured by GDP and expressed in purchasing power parity exchange rates (PPPs), is projected to be overtaken by China around 2012. India's GDP is projected to surpass that of the United States before 2040. Today's global "engines of growth" – China and India – could see their average GDP growth rates slow down to 2050, while remaining well above the average growth rate of the OECD region. The *Baseline* projects that Africa will experience high economic growth rates between 2030 and 2050, but will remain the poorest continent.
- There are significant differences in demographic developments across regions and countries. By 2050, the **world population** is projected to grow by another 2.2 billion people, reaching almost 9.2 billion. Most of this growth will occur in South Asia, the Middle East and especially Africa. The population profiles of all regions are ageing, especially China and the OECD countries. Populations are becoming increasingly **urbanised**. By 2050, 2.8 billion more people than today are projected to be living in urban areas, which will contain nearly 70% of the world's population. The rural population is projected to decrease by 0.6 billion. This urbanisation has pros and cons – while a concentrated population might make it generally easier to supply with modern energy and water infrastructure, levels of exposure to outdoor air pollution will be higher and could worsen environmental conditions in slums with serious consequences for human health.

- Under the *Baseline* scenario, world **energy** demand in 2050 is projected to be about 80% higher than today. The 2050 global (commercial) energy mix is not projected to differ significantly from today's, with fossil fuels still providing about 85%, renewable sources (including biofuels, but not traditional biomass) providing just above 10%, and the remainder provided by nuclear. Of fossil fuels, it is uncertain whether coal or gas will be the main source of increased energy supply.
- Globally, the area of agricultural **land** is projected to expand in the next decade to match the increase in food demand from a growing population, intensifying competition for land. Agricultural land is expected to peak before 2030 and decline thereafter, as population growth slows down and yield improvements continue. Deforestation rates are already declining, and this trend is projected to continue, especially after 2030 when demand for more agricultural land eases.

3.2. Baseline trends for emissions and climate change impacts

Global GHG emissions have doubled since the early 1970s, driven mainly by economic growth and increasing fossil-energy use in developing countries. Historically, OECD countries emitted the bulk of GHG emissions, but the share of Brazil, Russia, India, Indonesia, China and South Africa (the BRIICS countries) in global GHG emissions has increased to 40%, from 30% in the 1970s. Today CO_2 emissions account for around 75% of global GHG emissions. While global CO_2 emissions decreased in 2009 – by 1.5% – due to the economic slowdown, trends varied depending on the country context: developing countries (non-Annex I) emissions continued to grow by 3%, led by China and India, while emissions from developed countries fell sharply – by 6.5% (IEA, 2011a). Most CO_2 emissions come from energy production, with fossil fuel combustion representing two-thirds of global CO_2 emissions. Indications of trends for 2010 suggest that energy-related CO_2 emissions have rebounded to reach their highest ever level at 30.6 gigatonnes ($GtCO_2$), a 5% increase from the previous record year of 2008.[2] A slow-down in OECD emissions has been more than compensated for by increased emissions in non-OECD countries, mainly China – the country with the largest energy-related GHG emissions since 2007 (IEA, 2011a). Overall, the global average concentrations of various GHGs in the atmosphere have been continuously increasing since records began. In 2008, the concentration of all GHGs regulated in the Kyoto Protocol was 438 parts per million (ppm) CO_2-equivalent (CO_2e). This was 58% higher than the pre-industrial level (EEA, 2010b). It is coming very close to the 450 ppm threshold, the level associated with a 50% chance of exceeding of the 2 °C global average temperature change goal.

Any projection of future emissions is subject to fundamentally uncertain factors, such as demographic growth, productivity gains, fossil fuels prices and energy efficiency gains. The baseline projection suggests that GHG emissions will continue to grow to 2050. Despite sizeable energy-efficiency gains, energy and industry-related emissions are projected to more than double to 2050 compared to 1990 levels. Meanwhile, net emissions from land-use change are projected to decrease rapidly.[3] Emissions from BRIICS countries are projected to

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2 See *www.iea.org/index_info.asp?id=1959*.

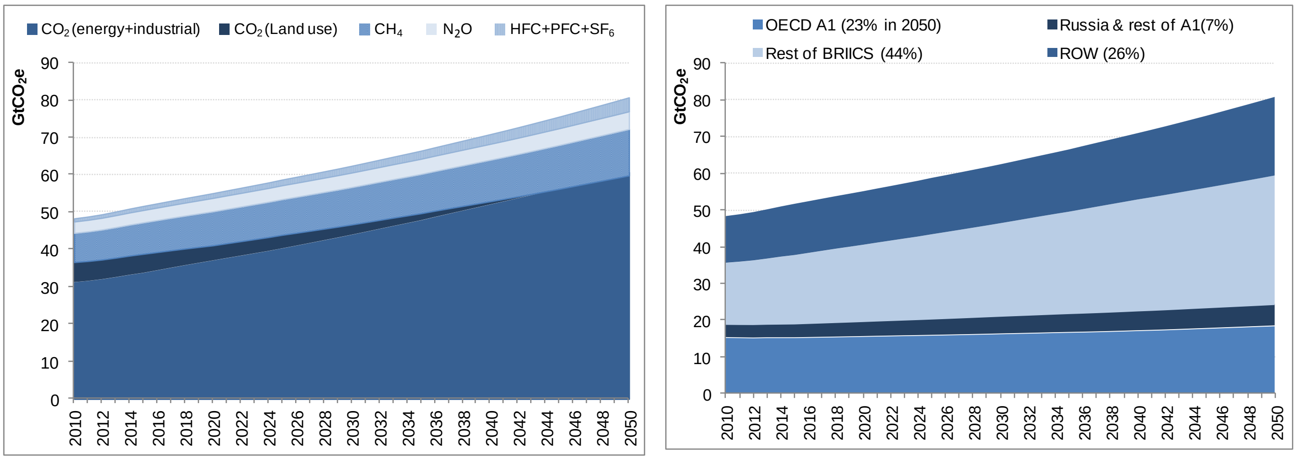
[3] Historically, global net-CO_2 emissions from land-use change (mainly deforestation driven by the expansion of agricultural land) have been in the order of 4-8 $GtCO_2$ a year. Other factors also contribute to land-use related emissions, *e.g.* forest degradation and urbanisation. In the *Baseline* scenario, the global agricultural land area is projected to expand until 2030, and to decline thereafter, due to a number of underlying factors such as demographics and agricultural yield improvements (see Chapter 2 for detailed discussions). However, the projected trends in agricultural land area differ tremendously across regions. In OECD countries, a slight decrease (2%) to 2050 is projected. For the BRIICS as a whole, the projected decrease is more than 17%,

account for most of the increase (Figure 1). This is driven by growth in population and GDP per capita, leading to growing per-capita GHG emissions. In the OECD, emissions are projected to grow at a slower pace, partly reflecting demographic decline and slower economic growth, as well as existing climate policies. Overall, the contribution of OECD countries to global GHG emissions is projected to drop to 23%, but OECD countries will continue to have the highest emissions per capita.

Figure 1. GHG emissions: *Baseline*, 2010-2050

a. By gases

b. By regions



3.3. The Baseline is not a viable policy option

The Baseline projection presented in this paper implies severe environmental pressures. These pressures pose important risks and expected costs, which could erode the natural capital base upon which economic growth is built. For this reason, the Baseline cannot be considered to be a viable pathway for future development. Although the nature of these impacts is beset with uncertainty, the implication of not taking action to address the environmental pressures, and failing to account for the environmental consequences of economic activities, are potentially very large. OECD (2008a) provides an overview of the cost of inaction on key environmental challenges, including climate change, water pollution and environment-related health issues. If the costs of taking no action to address the key environmental challenges were fully included in this assessment, future GDP would be lower than projected under the Baseline discussed here. By the same token, the benefits of environmental actions may be underestimated. In terms of the physical consequences of inaction, the links between the

reflecting in particular the declining population in Russia and China (from 2035). At least for the coming decades, a further expansion in agricultural area is still projected in the rest of the world, where population is still growing and the transition towards a higher calorie and more meat-based diet is likely to continue. These agricultural developments are among the main drivers of land-use change, and consequently of developments in GHG emissions from land use (Figure 3.8). From about 2045 onwards, a net reforestation trend is projected – with CO_2 emissions from land use becoming negative.However, there is large uncertainty over these projections, because of annual variations and data limitations on land-use trends and the exact size of various carbon stocks. To date, the key driver of agricultural production has been yield increases (80%), while only 20% of the increase has come from an expansion in agricultural area (Smith *et al.*, 2011). If agricultural yield improvements turn out to be less than anticipated, global agricultural land area might not decline, but could stabilise or grow slowly instead.

environmental pressures and impacts for the different environmental issues have been included in the analysis. For example, changes in temperature and precipitation patterns induced by climate change affect agricultural productivity. This in turn increases agricultural land requirements and pressures to deforest, which may aggravate biodiversity losses. Continuing business-as-usual under the Baseline scenario risks exceeding biophysical limits or tipping points, and causing other non-linear large-scale (systemic) irreversible damages.

4 Three pathways for 2 degrees

4.1. Translating 2 degrees into 450ppm scenarios

Research shows that if the world could stabilise GHG concentrations[4] at 450 ppm CO_2e, the chance of keeping the global temperature increase under 2 °C would be between 40% and 60% (Meinshausen *et al*., 2006; 2009).[5,] To explore the feasibility and implications of achieving this target, three different scenarios for stabilising concentrations at 450 ppm by the end of the 21st century have been modelled. The 2 °C pathways presented in this paper assume an optimal allocation of mitigation efforts across different sources and gases. These stylised optimisation scenarios temporarily allow the targeted concentration level (450 ppm) to be exceeded or overshot in the middle of the century, before falling to reach the target concentration by the end of the century. Compared with the "no new policies" *Baseline* projection, all three 450 ppm scenarios would have significantly lower climate impacts, and offer at least a medium chance of limiting global average temperature increase in 2100 to 2 °C.[6] Precipitation patterns would also change less in the 450 scenarios than in the *Baseline*. However, the mitigation efforts undertaken in the 450 ppm scenarios will not avoid all climate impacts. Thus, adaptation to remaining impacts will still be required.

The ***450 Core*** pathway assumes full flexibility in the timing of emission reductions and the use of mitigation options, including biomass energy with CCS known as "BECCS"[7] (see also Box 3.13). It further assumes that global co-operation is achieved for tackling climate change, and thus the pathway is implemented through a fully harmonised carbon market that encompasses all regions, sectors and gases. Achieving this pathway thus depends on: (i) acting now to put a price on carbon, and immediately tapping into the cheap mitigation options in all sectors, regions and gases; (ii) gradually transforming the energy system to become a low-carbon sector; and (iii) using the large opportunities for low-cost advanced technologies – including BECCS – that are stimulated by the carbon price. As all least-cost mitigation options are included in the analysis, this scenario acts as the cost-effective reference point against which to compare the other scenarios.

The *450 Core* scenario assumes that there can be negative emissions in some regions in the latter half of the century by using BECCS. This allows this pathway to be achieved despite

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4 The different GHGs have been aggregated using CO_2-equivalents (CO_2e).

5 Rogelj *et al*. (forthcoming) estimate that a 450oppm pathway will have a around a 60% chance of exceeding 2°C in the long-term (in equilibrium), with a 15% chance of exceeding 3°C and a 5% chance of exceeding 4°C.

6 The long-term equilibrium temperature increase will be lower than 2° C, as by the end of the century the declining concentrations of GHGs are already projected to lead to less radiative forcing.

7 BECCS combine bioenergy in power and in hydrogen production with carbon capture and storage (CCS) to create a technology which could actually remove emissions from the atmosphere: CO_2 is absorbed during the growth phase of the biomass, and then captured and stored when the biomass is converted to power or hydrogen (Azar *et al*., 2010; Read and Lermit, 2005). Several studies have identified BECCS as an attractive mitigation option later in the century (Van Vuuren and Riahi, 2011).

relatively high emission levels in the first half of the century. However, experience with bioenergy and CCS technologies is currently limited. Both face challenges related to climate policy uncertainty, public acceptance, first-of-a-kind technology risks, and high costs relative to other technologies (especially CCS). Bioenergy can also have harmful side-effects through indirect land-use change, potentially leading to higher emissions and biodiversity losses. Thus, uncertainty about the costs and effectiveness of the BECCS technology remains considerable. If BECCS turns out not to fulfill its promise of negative emissions, the world runs the risk of being locked into higher temperature increases. Thus, an optimal pathway for the coming decade should balance the long-term climate risks, short-term costs and mitigation potentials and expectations about technology development.

By contrast, the ***450 Accelerated Action*** scenario assumes greater mitigation effort in the first half of the century, and less reliance on unproven emissions technologies (like BECCS) in later decades. Additionally, this scenario would offer greater potential for achieving more ambitious long-term temperature stabilisation targets, such as 1.5 °C, although opportunities are limited to speed up emission reductions beyond the pathway shown here.

On the other hand, the ***450 Delayed Action*** scenario starts from the premise that it may not be realistic to expect large emission reductions in the coming decade.[8] It reflects the current situation in that it models the high end of the pledges made in the Copenhagen Accord and Cancún Agreements (with strict land-use accounting rules and no use of surplus emission credits from the current Kyoto Protocol commitment period). It also assumes that the various domestic carbon markets are not linked to each other until 2020. If this scenario comes to pass, by 2020, emissions would be outside the 41-48 $GtCO_2e$ range that UNEP (2010) suggests is necessary for least-cost pathways to have at least a medium chance of limiting average global temperature to 2 °C. The *450 Delayed Action* scenario assumes that significant additional efforts will have to be made after 2020 to “catch up” and very rapid rates of emission reduction will be required to give a 50% chance of meeting the 2 °C goal. Postponing compensation for the higher short-term emissions until after 2050 would increase the chance of exceeding the temperature limit and increase the risks of negative environmental consequences caused by a 10% higher annual temperature increase in the coming decades than under the *450 Core* scenario. Moreover, it relies heavily on (i) unlocking the global energy system from its current high-carbon reliance; and (ii) the ability to rapidly transform the energy system later in the century. This goes against the current trend, in which the world is in fact locking itself into high-carbon systems more strongly every year (IEA, 2011b).

Figure 2 shows how these different pathways affect the growth of global emission levels over time and compares it to the range of pathways presented in UNEP (2010). All three 450 ppm scenarios show emissions peaking before 2020. The *450 Delayed Action* scenario shows a short delay before global emission levels start reducing, implying that after 2025 there would need to be a rapid reversal of current trends to still achieve the 2 °C target.

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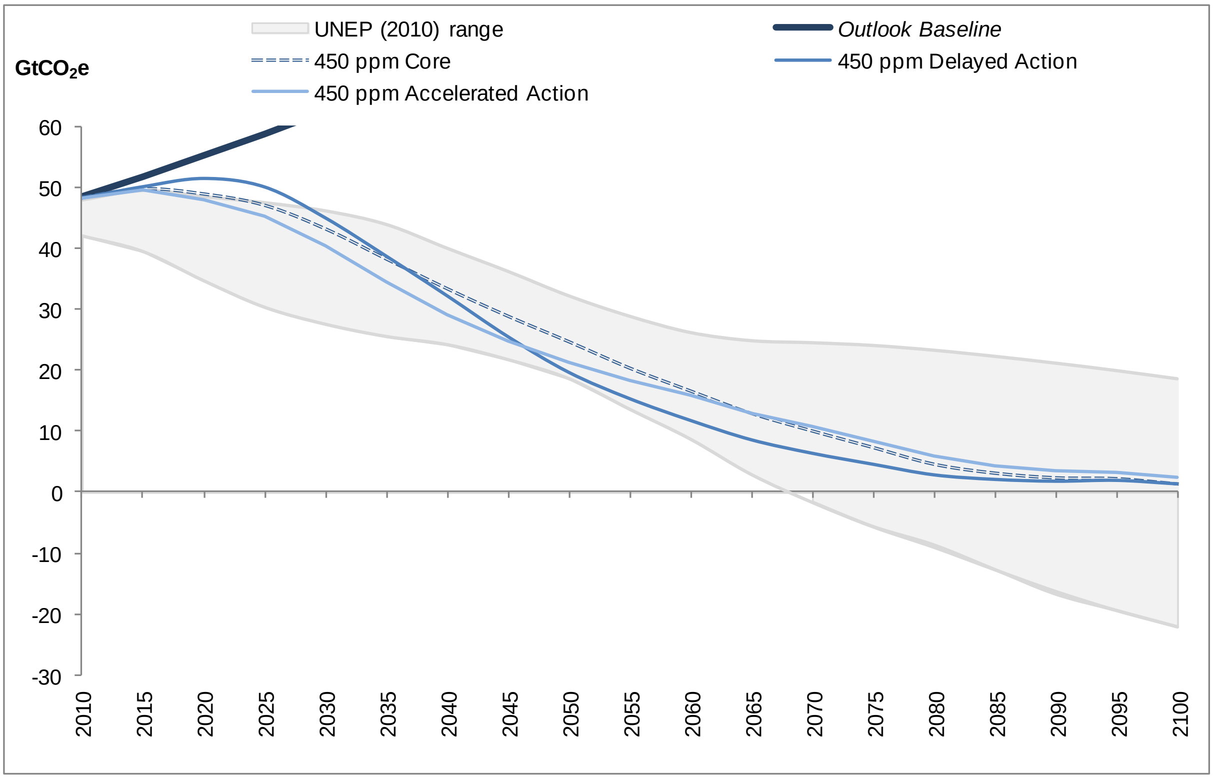
8 The label “delayed action” does not imply that all action is delayed, but rather that in the coming decades less mitigation takes place than in the other scenarios.

Figure 2. Alternative emission pathways, 2010-2100

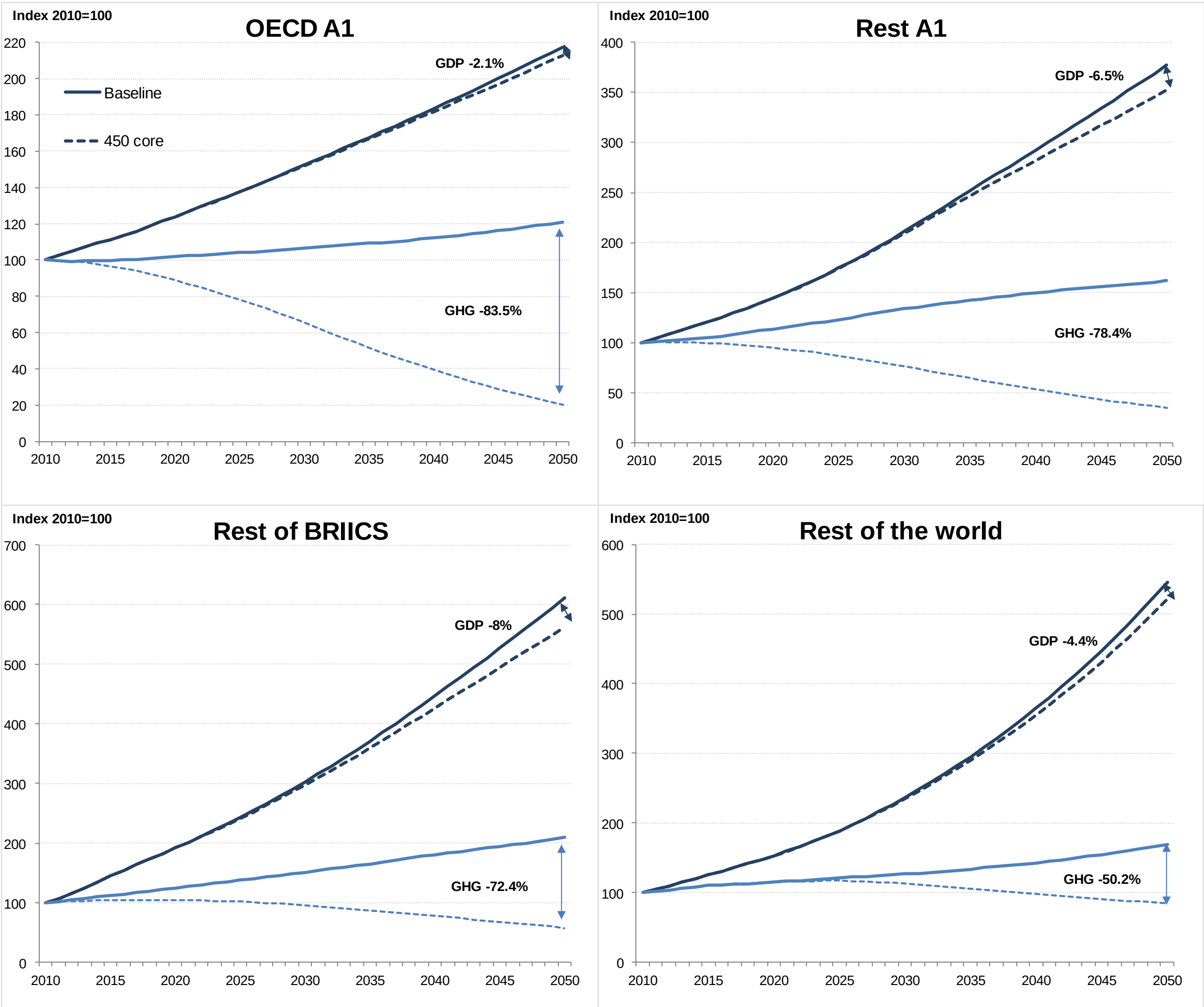
Annual net emissions of all Kyoto gases in $GtCO_2e$



4.2. Reaching the 2 degree target at least cost (featuring the 450 core scenario)

Figure 3 indicates that to achieve the 450 ppm stabilisation target, global emission reductions of 12% will be needed by 2020 and 70% by 2050 compared to the *Baseline* (for 2050 this means 52% below 2005 levels, and 42% below 1990 levels). Emissions would therefore have to decrease at an average rate of 1.7% per year between 2010 and 2050, compared to the increase of +1.3% projected under the *Baseline*. Reduced CO_2 emissions from fossil fuel combustion would account for 75% of the global reduction by 2050. For emissions from land-use change the situation is reversed: the *450 Core* scenario would require additional land for growing bioenergy crops. Thus there would be a less rapid reduction of emissions from land-use change compared to the *Baseline*, and lower levels of net CO_2 uptake in the later decades (the difference is 1.2 $GtCO_2e$ in 2050). In order to achieve the 450 ppm target these additional emissions (and reduced uptake) would have to be compensated for by greater emission reductions by energy and industry.

Figure 3. *450 Core* scenario: emissions and cost of mitigation, 2010-2050



Notes: Emission projections are before permit trading, *i.e.* they reflect emission allowances.

"OECD AI" stands for the group of OECD countries that are also part of Annex I of the Kyoto Protocol; "Rest AI" stands for the other Annex I parties, including Russia; "Rest of BRIICS" are the BRIICS countries excluding Russia, and "Rest of the World" represent all other regions distinguished in the ENV-Linkages model.

GDP figures do not include the costs of inaction.

The scenario assumes that carbon pricing is used to give incentives for mitigation efforts in all parts of the economy. A relatively large portion of emission reductions could be achieved relatively cheaply and quickly by limiting emissions of non-CO_2 gases from industries (*e.g.* coal mining, oil and gas processing and shipping, acid production) and the agricultural sector (*e.g.* changing rice cultivation patterns and nutrient management); and improving waste handling (waste recycling and methane capture from landfills). Curbing global emissions beyond 2020 would require a rapidly increasing carbon price (to USD 325/tCO_2e in 2050) to discourage intensive reliance on carbon-based energy sources. Only a strong and lasting carbon price signal will achieve the major transition required in carbon-intensive sectors, and those with large-scale infrastructural investments.

This scenario implies that world GDP growth would slow down between 2010 and 2050 as a result of lower energy consumption and the shift in supply options driven by higher energy prices. The average growth rate decreases from 3.5% per year in the *Baseline* to 3.3% per year in the *450 ppm Core* scenario, giving a world GDP that is 5.5% lower in 2050 than under the *Baseline* scenario. However, it should be stressed that a major limitation of all the results presented here is that they do not factor in any benefits of the mitigation action. The economic impacts therefore reflect purely the cost of action, not the net costs or benefits.

Energy use grows between 2010 and 2020 in both the *Baseline* projection and the *450 Core* scenario (although at a slower pace in the latter). After 2020, emissions would be reduced primarily by energy-efficiency improvements and strong supply changes. The ENV-Linkages simulations find that energy-efficiency improvements are the main driver (especially producers substituting more expensive energy with labour and capital, such as more expensive but energy-efficient machines), leading to a sharp drop in emissions by 2050.[9] A vast decarbonisation is required in the power generation and transport sector, as well as replacing existing dirty energy use by consumers (*e.g.* use of cooking fuels) with more efficient electricity-based technologies. This all involves a drastic restructuring of the energy sector.

The costs shown in Figure 3 result from a regional permit allocation rule where regional emission allowances evolve over time towards equal per-capita allowances. This so-called "contraction and convergence" allocation rule is not meant as a policy recommendation, but is used here purely for illustrative purposes. Alternative permit allocation rules lead to similar global costs, at least when full permit trading is allowed, but the allocation of these costs across the regions can vary significantly. When allowing full emission permit trading, GHG emission reduction pathways are similar across all regions (ranging from 67% to 71% reduction by 2050 compared to the *Baseline*), as the stringency of the *450 Core* target calls for action in all regions. Nonetheless, mitigation strategies will differ depending on the level of economic development and growth perspectives. Switching rapidly to low-carbon technologies allows OECD economies to be partially decarbonised, while energy-efficiency measures are the main mitigation option in BRIICS countries.[10] Energy intensity, defined as the ratio of energy use to GDP, is projected to decrease by 3.2% annually in OECD countries (close to the world average), while this ratio will reach 3.9% and 4.5% per year in BRIICS and RoW countries respectively. There is more potential for improvement in energy efficiency in these regions as their carbon intensity is on average higher than in OECD countries (IEA, 2009b).[11]

Given the "contraction and convergence" distribution of emission permits under the *450 Core* scenario, the OECD region is the main buyer of permits, implying that they achieve part of their required emission reductions abroad. The developing countries in the RoW group are the main suppliers of permits. The related costs to the economies vary more widely among regions. The relatively high GDP losses in the BRIICS are largely concentrated in (i) Russia – which is negatively affected by the reduced demand for fossil fuels; and (ii) China, where emission growth is much more rapid than population growth, implying that in the later decades China would have to buy substantial amounts of emission permits on the international market.

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9 The IMAGE suite of models assume that a larger share would come from fuel switching, and have more conservative estimates on energy efficiency improvements.

10 However, energy efficiency also plays a role in the OECD region – energy efficiency improvements are an essential part of a cost-effective mix of mitigation options.

11 Average energy intensity also differs across regions due to national circumstances, including climate.

4.3. On the importance of keeping technology options open (featuring the Accelerated action scenario)

Both the *450 Accelerated Action* and the *450 Core* scenarios reduce the projected *Baseline* emissions by more than 75% by 2050. The main difference between the two scenarios is the timing of global mitigation efforts in the next two decades. These result in differences in which gases are reduced most (or which fuel in the case of energy-related CO_2 emissions), as well as different regional and sectoral mitigation choices. These elements are illustrated in the four panels of Figure 4. Of course, the larger mitigation efforts in the *450 Accelerated Action* scenario imply lower environmental risks but higher costs than the *450 Core* scenario. By 2030 carbon prices would be about 50% higher in the *450 Accelerated Action* scenario than in the *450 Core*.

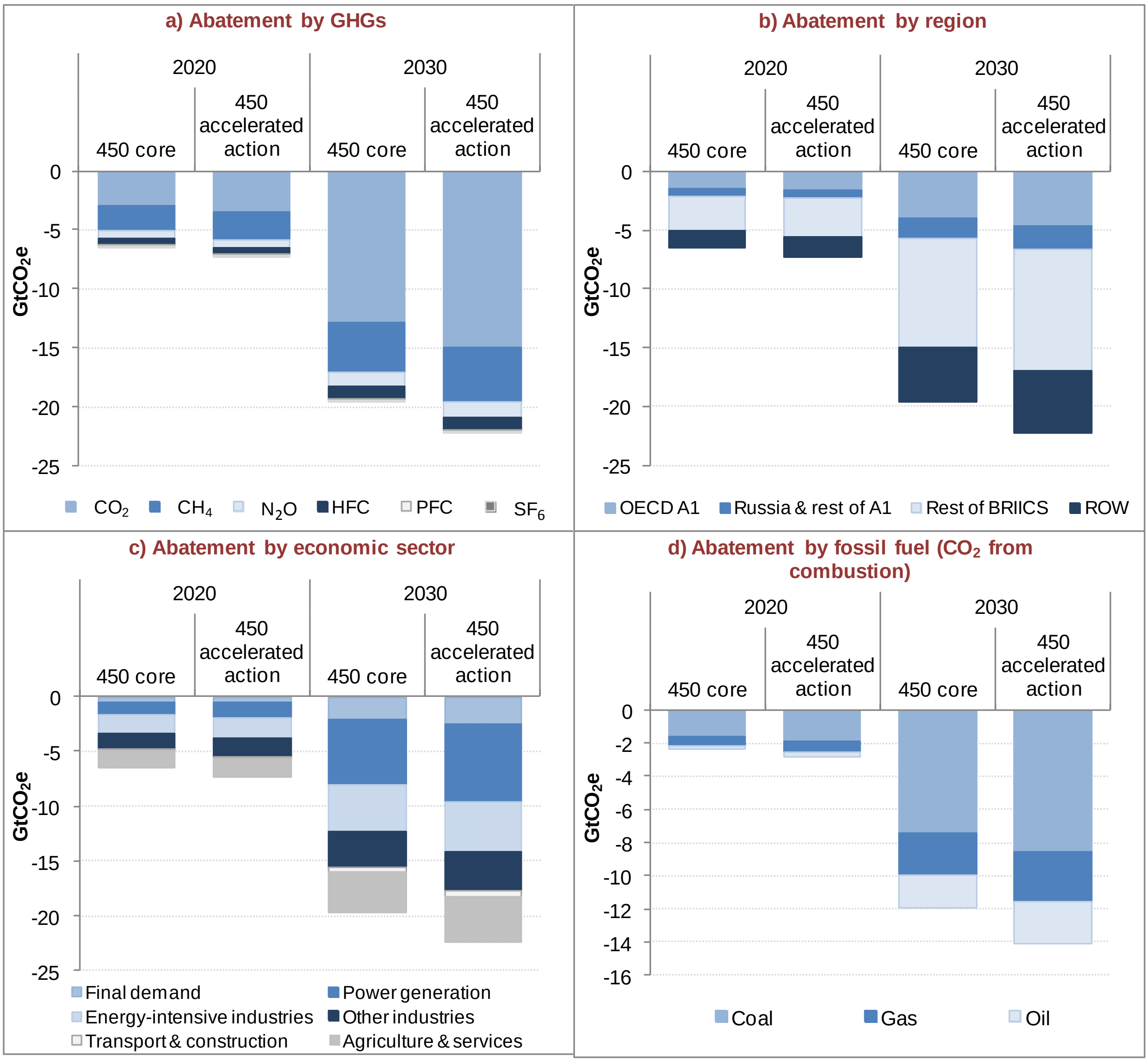
In aggregate terms, both scenarios lead to very similar emission reduction patterns across regions, given the shared permit allocation rule. BRIICS countries account for about half of the total mitigation effort, the other half being split evenly between OECD and RoW countries. However, the analysis of country details reveals larger differences across scenarios: China and the Middle East account respectively for about one-third and 7% of total mitigation in the *450 Accelerated Action* scenario, and are more sensitive to the targeted emission level in 2020. In other countries, such as India, mitigation efforts depend less on the scenario architecture because the mitigation potentials in these countries are less sensitive to the carbon price level around the years 2020 and 2030.

In both simulations, the lowest cost mitigation options are mobilised in the early stages of action, irrespective of the carbon price level. The level of ambition then determines the optimal mix of reduction measures. Non-CO_2 GHGs (methane, nitrous oxide and fluorinated or “F gases”, such as HFCs, PFCs and sulphur hexafluoride – SF_6) have sizeable mitigation potential and reductions can be achieved at moderate cost. These potentials could be tapped into even under modest carbon prices. For example, easily adjusted industrial activities and changes in agricultural practices are projected to help reduce large volumes of methane efficiently (*e.g.* in coal mining, oil and gas processing and shipping; waste recycling and methane capture from landfills). Methane mitigation alone accounts for more than 60% of the total reduction of non-CO_2 gases by 2020. The reduction of nitrous oxide arising from changes in rice cultivation patterns, acid production or nutrient management, covers another 20%.

Accelerated action would require a quicker decarbonisation of electricity production, while a more gradual response to climate change would require relatively more effort from energy intensive industries, services and agriculture. In both scenarios, oil is the fossil fuel affected the most over the coming decade. Coal use is particularly discouraged for power generation and even moderate carbon prices are enough to trigger efficiency improvements in coal-based electricity generation and to favour a switch towards gas-based production capacity that is less carbon-intensive, notably in China and India. Natural gas is affected evenly in both scenarios and represents about 20% of total reduction in 2020 and 2030. In both scenarios, gas acts as a bridging fuel until lower carbon technologies become available on a large scale. Nuclear energy is projected to supply almost two-thirds of low-carbon electricity in 2020 and only half of it by 2030 in both cases. The share of hydro electricity tends to diminish over time as wind, solar and other non-hydro renewables take over. However, the carbon price differential between the two scenarios is not significant enough to drive notable changes in the mix of renewable technologies by 2030. Finally, fossil fuel based electricity generation with CCS plays a significant role later in the projection period.

Figure 4. GHG abatements in the *450 Core Accelerated Action* and *450 Core* scenarios compared to the *Baseline*, 2020 and 2030

(a) by GHG, (b) by aggregate region, (c) by economic activity and (d) by fossil fuel



4.4. On the extra costs resulting from combining short-term realism with long-term ambition (featuring the Delayed Action scenario)

As discussed above, the *450 Delayed Action* scenario assumes that until 2020 mitigation efforts will aim to achieve the high end of the pledges made in the Copenhagen Accord and Cancún Agreements (Table 1). A large number of countries have submitted reduction targets or national mitigation plans as part of the 2009 Copenhagen Accord – these were subsequently incorporated into the 2010 UNFCCC Cancún Agreements. Almost all developed countries have pledged to meet quantified economy-wide emission targets by 2020, and 44 developing countries have pledged mitigation actions.[12] Table 1 summarises the quantitative

12 Information from UNFCCC website (*www.unfccc.int*), accessed August 2011.

targets and actions, and also translates these pledges into quantified GHG emission reductions compared with 1990 (for Annex I Parties) and 2020 *Baseline* (for non-Annex I) emission levels in the modelling simulations.[13] Many Annex I Parties have not detailed their policies on the use of offsets; therefore, this information is only added for a few regions, and a default assumption that a maximum of 20% of the reduction targets is used in all other cases. Annex I Parties could potentially use land use, land-use change and forestry (LULUCF) credits to meet their pledged target; the extent to which this is assumed in the simulation is provided in the last column (see OECD, 2012, for further details).

Although up until 2020 the emission reductions in the *450 Delayed Action* scenario are smaller than in the *450 Core* scenario, real income losses are larger for most regions, because of the fragmentation of the carbon market (Figure 5). Carbon prices vary between regions in *Delayed Action*, ranging from zero for regions that do not have a binding pledge (including the Middle East and North Africa and rest of the world countries) to more than USD 50/tCO_2e for the combined Japan and Korea region. These results depend on a number of crucial but uncertain assumptions about the interpretation of the pledges (see also Dellink et al., 2011).

As by assumption until 2020 international permit trading is not allowed in the *450 Delayed Actio*n scenario, many low-cost mitigation options remain unexploited until 2020, driving up global costs. Figure 5 clearly illustrates that domestic policies are not the only, and sometimes not even the main, determinant of the macroeconomic costs of the policies. Fossil fuel exporters, such as Russia and the Middle East region, are projected to have higher income losses, despite having hardly or no costs from domestic mitigation efforts. Panel A of Figure 5 also shows how international financing of mitigation action (assumed to take place in South Africa, Brazil and Mexico) can help to limit the costs of domestic action. Combined with the opportunity to sell credits on the offset market, the “Rest of BRIICS” group have only very small income losses in the *450 Delayed Action* scenario.

In the longer run (2050), the *450 Delayed Action* scenario requires more ambitious mitigation efforts to bring concentration levels back down to the 450 ppm target before the end of the century. As these efforts occur later than in the *450 Core* scenario, it is not surprising that income losses are again higher in the *450 Delayed Action* scenario (Figure 5, Panel B). By 2050 in both the *450 Core* and *Delayed Action* scenarios a global carbon market has formed with permit allocations based on population; thus the larger income losses reflect the additional costs resulting from inadequate mitigation efforts in the earlier decades. There is both a direct effect – stemming from the increased mitigation efforts required in 2050 to limit concentrations – and an indirect effect from the lack of structural reform in the energy sector in the earlier decades.

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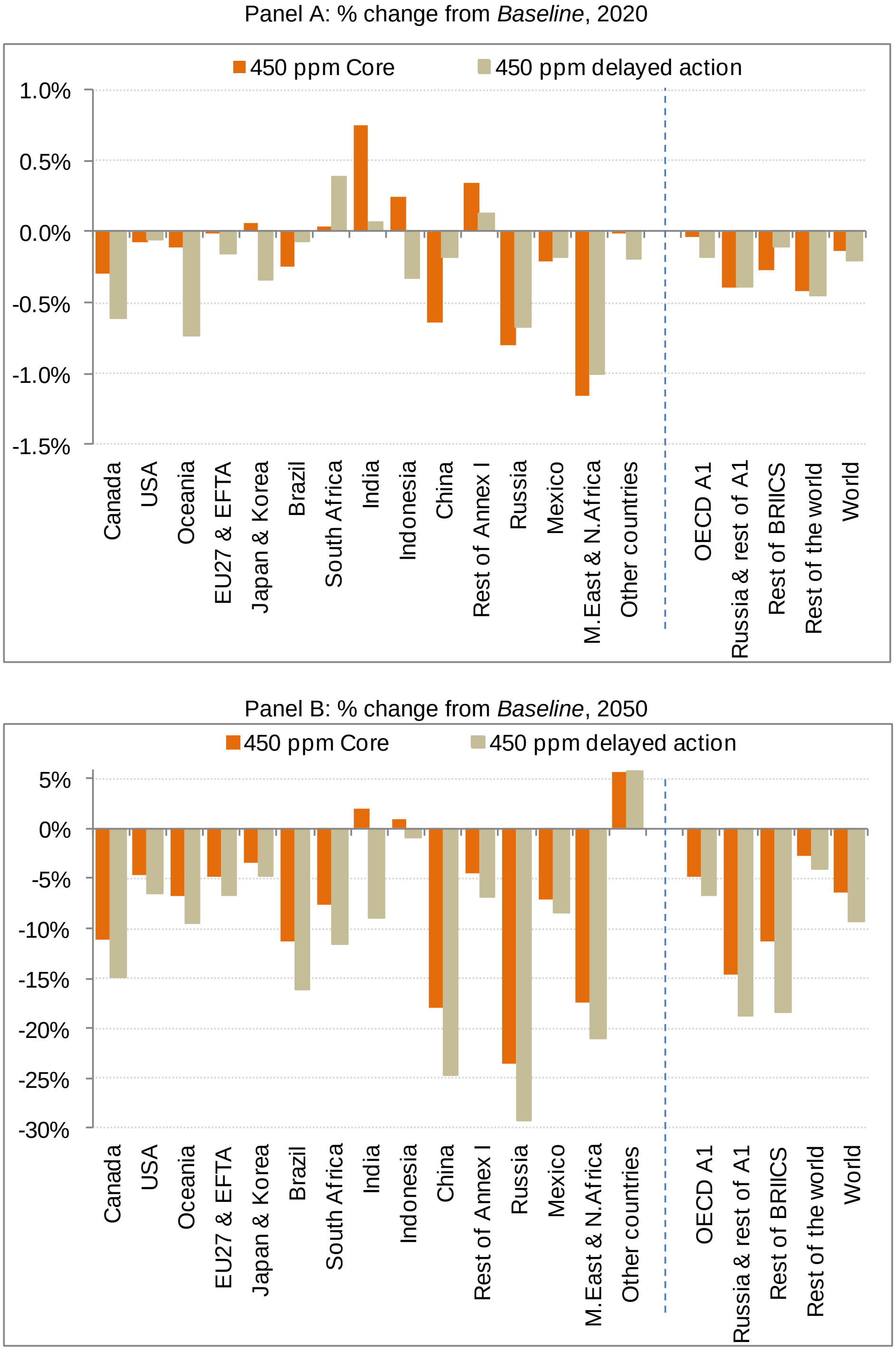
13 The calculations are based on the methodology described in Den Elzen *et al*. (2011), but revised to reflect our Baseline projections. More information on the assumptions behind the assessment of the pledges is given in OECD (2012).

Table 1. How targets and actions pledged under the Copenhagen Accord and Cancún Agreements are interpreted as emission changes under the *450 Delayed Action* scenario: 2020 compared to 1990

Region	Declared country emissions targets and actions	Emissions under *450 Delayed Action* scenario
Canada	-17% from 2005; no credits from international offsets currently assumed	+2.5% from 1990 (5 $MtCO_2e$ LULUCF credits)
Japan & Korea	Japan -25% from 1990; Korea -30% from business as usual (BAU)	-16% from 1990 (35 $MtCO_2e$ LULUCF credits)
Oceania	Australia -5% to -25% from 2000; New Zealand -10% to -20% from 1990	-12% from 1990 (0 $MtCO_2e$ LULUCF credits)
Russia	-15% to -25% from 1990	-25% from 1990 (0 $MtCO_2e$ LULUCF credits)
United States	-17% from 2005	-3.5% from 1990 (150 $MtCO_2e$ LULUCF credits)
EU27 & EFTA	EU27, Liechtenstein and Switzerland -20% to -30% from 1990; Norway -30% to -40% from 1990; Iceland and Monaco -30% from 1990; max. 4 percentage-points credits from international offsets; no LULUCF credits for low pledge	-30% from 1990 (195 $MtCO_2e$ LULUCF credits)
Rest of Europe	Ukraine -20% from 1990; Belarus -5% to -10% from 1990; Croatia -5% from 1990; emissions for other countries in this group without a pledge (incl. Turkey) are assumed to remain at BAU level.	-19.5% from 1990 (25 $MtCO_2e$ LULUCF credits)
Brazil	-36% to -39% from BAU	-39% from BAU (incl. 775 $MtCO_2e$ REDD)
China	Carbon intensity -40% to -45% from 2005; share of non-fossil fuels in primary energy consumption 15%; forest coverage +40 mln ha & volume +1.3 bln m3	-4% from BAU
Indonesia	Indonesia -26% from BAU	-26% from BAU (incl. 200 $MtCO_2e$ REDD)
India	Carbon intensity -20% to -25% from 2005	-2% from BAU
Middle East & Northern Africa	Israel -20% from BAU; no pledge for other countries in this group	No restriction on emissions
Mexico	Mexico -30% from BAU	-30% from BAU (incl. 115 $MtCO_2e$ REDD)
South Africa	South Africa -34% from BAU	-25% from BAU*
Rest of the world	Pledges have been made by some countries in this group (incl. Costa Rica, Maldives, Marshall Islands) but not by the major emitters in this group.	No restriction on emissions

Notes:
* The domestic BAU projection used by South Africa has substantially higher emissions than the OECD *Baseline* projection; therefore the target for South Africa has been adjusted for this difference.
The pledges presented here are an interpretation of their main quantitative aspects for the purpose of establishing a stylised modelling scenario. Many countries have provided additional details and nuances in their submissions to the UNFCCC, and often conditions are stated. For full details on the pledges see FCCC/SB/2011/INF.1/Rev.1 and FCCC/AWGLA/2011/INF.1 at *www.unfccc.int*.

Figure 5. Regional real income impacts, *450 Core versus 450 Delayed Action scenarios*



5 Conclusions

[to be added]

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