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Road to Paris

Assessment of Low Emission Levels under World Action Integrating National Contributions

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Abstract
This report presents the modelling work quoted in the EC communication "The Paris Protocol - a blueprint for tackling global climate change beyond 2020" in the EU's Energy Union package. It examines the effects of a Baseline scenario where current trends continue beyond 2020, and of a Global Mitigation scenario in line with keeping global warming below 2°C. The analysis uses the POLES and GEM-E3 models in a framework where economic welfare is maximised while tackling climate change. In the Baseline, emissions trigger +3.5°C global warming. In the Global Mitigation scenario, all regions realise domestic emission cuts to stay below 2°C, with various profiles in 2020-2050 depending on their national characteristics. A significant transformation of the energy systems and non-energy measures enable regions at all levels of income to move to a low-emission growth pathway. Sectors linked (directly or indirectly) to carbon-intensive processes adjust their investments to be competitive in a low-emission environment. A significant number of regions draw economic benefits from shifting their expenditures on fossil energy imports to investments. GDP growth rates are marginally affected in most regions by global efforts to reduce emissions. Crucially, high growth rates are maintained in fast-growing low-income regions. Economic costs are reduced further when countries use emission permit auction revenues for other tax reductions. Delaying actions to stay below 2°C add large economic costs.

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1 Executive Summary

- The IPCC Fifth Assessment Report (AR5) shows that it is possible to limit global temperature rise to below 2°C but it will require strong, immediate and collective global effort.

- In 2013 at the COP19 in Warsaw, Ministers agreed to present intended nationally determined contributions (INDCs) to a possible new agreement well in advance of COP21 in Paris in 2015, and by the first quarter of 2015 for those countries in position to do so.

- In October 2014, the European Council EU leaders endorsed the 2030 Climate and Energy Policy Framework, with a binding headline domestic greenhouse gas emission reduction target of at least 40% compared to 1990.

- On 25 February 2015, the European Commission has set out the EU's vision for the new global climate change agreement due to be adopted in Paris in December 2015 with its Communication, "The Paris Protocol - a blueprint for tackling global climate change beyond 2020" in the EU's Energy Union package. The Communication highlights that the EU is seeking a transparent and dynamic legally binding agreement, containing fair and ambitious commitments from all Parties based on evolving global economic and geopolitical circumstances. The Communication also calls for commitments that collectively put the world on track to reduce global emissions by at least 60% below 2010 levels by 2050.

- The European Commission Staff Working Document accompanying the Communication 'The Paris Protocol – a blueprint for tackling global climate change beyond 2020' gives analytical results based on the latest available science. This report presents more details on the Baseline and Global Mitigation scenarios quoted in the Staff Working Document using the POLES and GEM-E3 models.

- The POLES and GEM-E3 models are used to explore possible ways to deliver global efforts to stay below 2°C through processes established in the run-up to Paris COP21. This report explores a combination of domestically determined mitigation targets for the period beyond 2020 respecting the below 2°C objective, differentiated according to national capabilities and based on the most recent estimates of the effects of the current pre-2020 pledges and policies. This report also explores how a framework of international collaboration could enhance further the domestic mitigation contributions.

- The modelling results confirm that all major economies and regions can define domestic mitigation goals in line with 2°C, based on their current policy experiences, and that the institutions and mechanisms put in place under the Climate Convention framework can be mobilised to deliver enhanced climate and economic benefits, especially for the countries with less capabilities.

- The modelling with POLES and GEM-E3 brings out a number of findings consistent with other recent model based analysis to support the preparation of the Paris agreement

  1. The scenario of Global Mitigation action in line with staying below 2°C requires a significant transformation across all global regions, and at global level they correspond to large-scale changes compared to the Baseline scenario. In particular, up-scaling of low-carbon energy supply, improvements in energy efficiency, and adopting low-emission technologies in all sectors are essential. Decoupling growth from emissions does not happen in the Baseline scenarios under the continuation of the current policies; only pro-active mitigation policies

by all countries can unlock the necessary changes in investment patterns and decoupling of growth from emissions.

2. Global Mitigation action is taking place in a context of various independent evolutions of global energy markets and under a persisting diversity across countries and regions. Climate action can be differentiated and tailored to these evolutions.

3. For each country, engaging in Global Mitigation action is a long-term structural challenge involving shifts in investments, trade flows, and key sectors of the economy. At the same time these changes are manageable compared to the pace of economic growth at global level and in each region. Integrating climate action in the framework of the national economic policy, and especially using the revenues of emission pricing to reduce other distortionary taxes, would benefit each and all regions.

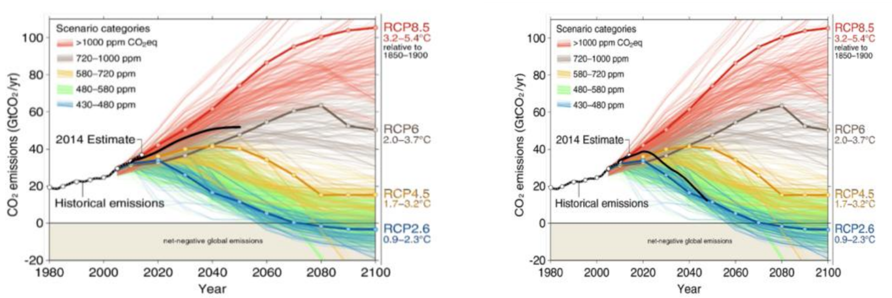
4. The efforts that countries are taking to engage in global climate action in line with 2°C are also delivering benefits in terms of improving energy security (reducing the burden of fossil fuel imports for net consumers, as well as diversifying the energy trade for some energy exporters); improving productivity and diversifying the economy (some sectors like equipment goods or services increase their weight and trade). There are further major benefits from global climate action that the toolbox of models have not represented in terms of health and air pollution reduction, innovation, food security, improved resilience, etc. Information barriers or split incentives are typically not represented in the models despite policies that can address them and thereby facilitate emission reductions.

5. The modelling framework that we used in this analysis concentrates on emissions from energy and industrial processes. While agriculture and land use are also included, mitigation trends and opportunities in this area rely on other studies which consider these sectors in greater detail. Hence the findings in this report related to the role of agriculture and land-use in the transition to a low-emission economy by 2050 must be seen together with these other reports. It is clear from other modelling frameworks that the emissions from the land use and agriculture sectors can be significantly reduced, and that enhanced sinks can compensate residual global emissions.

- Overall, the modelling with POLES and GEM-E3 encourages some specific policy developments at global level:

  1. *Creating a long-term, dynamic agreement, perceived as fair and effective by all* – To stay below 2°C will require substantial and sustained reductions in greenhouse gas emissions by all countries. The POLES results indicate that it is possible to peak by 2020 and halve global emissions by 2050 compared to 1990 levels (equivalent to 60% below 2010 levels), thereby securing likely chances to stay below 2°C with all regions participating with emission reductions by 2025, 2030, and 2050 corresponding to their past, current and evolving national circumstances (see Figure A).

Figure A: GHG emissions in baseline and Global Mitigation scenarios



Baseline scenario Global Mitigation scenario

2. *Creating the confidence needed for global investment and climate action* – The GEM-E3 results indicate that the global transition to low-emissions can be achieved without compromising growth and jobs. Furthermore, the POLES results indicate that delaying this transition will unnecessarily raise overall costs for realising this transition. By contrast, POLES and GEM-E3 results highlight that the introduction of ambitious mitigation policies and the related changes in the energy mix towards renewable sources representing 40% of primary energy in 2050 modify global investment patterns. These investments must be unlocked. Indeed, POLES and GEM-E3 results confirm that these investments may reduce other costs that would be required without climate action (notably fossil fuel imports), as well as creating new trade opportunities and improving competitiveness in parts of the global economy. Most importantly, there are multiple ways to facilitate these investments and yield economic benefits: with a global action framework, and choosing the right economic instruments in each region.

3. *Managing the transition in the period 2020-2030* – This modelling work takes conservative assumptions for the period up to 2020 factoring in the countries' efforts to implement their pre-2020 pledges and policies in place; countries could still deliver additional reductions through collaborations in specific sectors, like to reduce F-gases or additional policies. In this setting, to achieve low emissions by 2050 a significant change in emission trends across all sectors must happen in the period 2020-2030 compared to the Baseline. Reaping all mitigation options currently available, and at least-cost first, would let global emissions peak in 2020 and decline afterwards to 10% below 2010 levels by 2030.

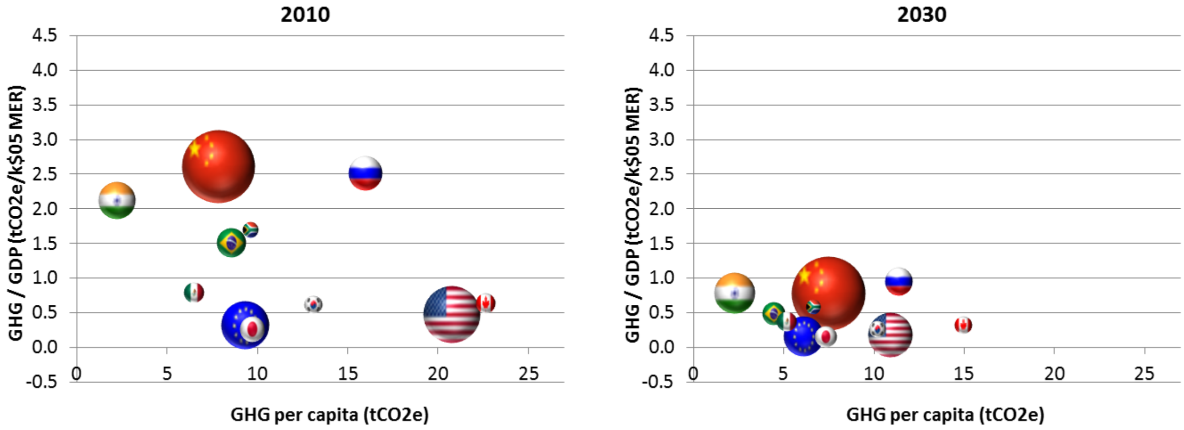
- Furthermore, the modelling with POLES and GEM-E3 encourages some specific policy developments at regional level:

1. Country-specific mitigation objectives, in all regions, should relate to the long-term global goal to stay below 2°C, to add up to the emission reductions needed at global level. This means in particular that all countries and regions have to aim for a significant progress in the level of ambition and scope of their mitigation goals compared to the objectives they set themselves in their pre-2020 pledges under the Cancun agreement or in their national climate and energy policies. Indeed, in the POLES Baseline scenarios, continuing with only current policies leads to an average temperature increase above 2°C.

2. Along country-specific pathways in the Global Mitigation scenario, multiple sectors realise emission cuts by 2020, 2025, 2030; and ultimately, by 2050 all sources of emissions contribute to mitigation. This is the key to minimise costs. Nonetheless, POLES and GEM-E3 take conservative assumptions: their results employ currently available technologies. In the real world innovation will enable further improvements of the emission intensity of the production of goods and services that would enable more or faster emission cuts.

3. Countries and regions have to aim for low levels of emissions and per capita emissions (to a global average of 4.5tCO_2e/cap by 2030 and below 2tCO_2e/cap by 2050). All countries have the potential to significantly improve their emission intensity over time, and to reach very low levels of emissions associated to higher levels of economic output by 2050, while unlocking co-benefits across regions. Even if countries and regions currently differ in their emission patterns; POLES and GEM-E3 analysis indicates there are country-specific responses to the mitigation challenges, relying on different technology options and on tailored-made policies that are apt for all countries and regions to converge over time to a low-emission future (see Figure B).

Figure B: Global Mitigation scenario, emission intensity vs. emission per capita



Source: JRC POLES model

4. By design, in the Global Mitigation scenario the countries with the highest responsibilities and capabilities need to deliver the most ambitious mitigation objectives, whereas countries with capacity constraints are not expected to contribute as much[1]. The results of the POLES/GEM-E3 modelling show that international cooperation on climate action taking into account national circumstances triggers benefits for countries and at global level.

5. The modelling by POLES highlights that under the Global Mitigation scenario, investments are shifting at large scale in the power sector and all countries diversify their energy mix in the period 2020-2030 with significant investment implications and associated benefits for energy security. This is consistent with other research findings. This should clearly encourage all countries to take steps to improve their enabling environments for attracting climate friendly investments. Moreover, the modelling with GEM-E3 shows that benefits are maximised when, at the same time, the countries improve their policy environment by reducing labour or indirect taxation.

- Finally, the modelling with POLES and GEM-E3 encourages further development of the analytical framework to support the implementation of low-emission development strategies across regions and at global level.

[1] The human development index is used as a proxy for the economic, technological, administrative or social constraints that these countries face. Countries/regions with capacity constraints include Sub-Saharan Africa, India, Rest South Asia (Bangladesh, Pakistan, Afghanistan, Sri Lanka), Indonesia, and Central America (except Mexico).

2 Introduction

The IPCC shows it is possible to limit global temperature rise to below 2°C by year 2100 but it will require strong, immediate and collective global effort, enhancing the mitigation actions to be delivered by 2020.

As global emissions are standing at levels inconsistent with staying below 2°C, new climate action will be required beyond 2020. Parties are negotiating under the UN Framework Convention on Climate Change to conclude an agreement on global climate action in Paris in 2015.

This report contributes to the international debates, in the context of these negotiations, on the levels of emission reductions that the new climate agreement should encourage in order to stay below 2°C whilst maximising benefits for development.

The report presents a model-based analysis of several low-emission development pathways and achievable through globally coordinated action illustrating some of the economic challenges and opportunities for specific sectors, and key countries and regions.

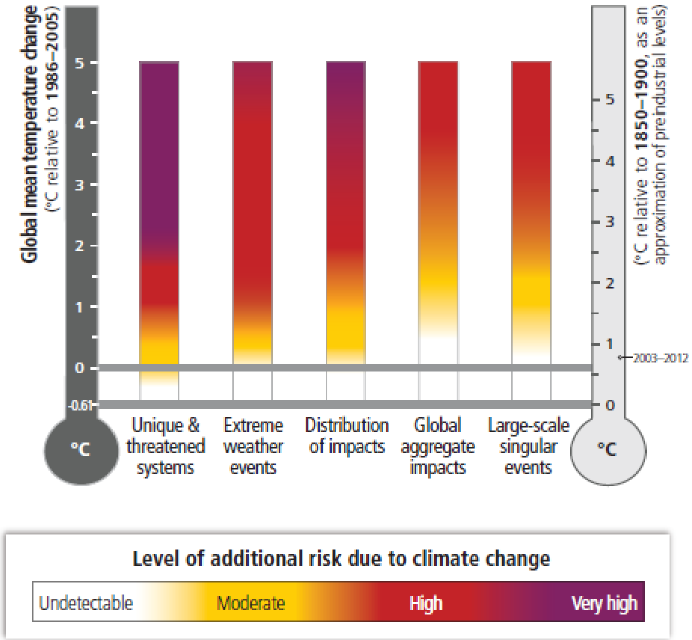
The report also details the Global Mitigation action, differentiated by countries and regions, that is required to stay below 2°C under these pathways. It also considers that countries may be willing to set up international emission trading mechanisms to realise early Global Mitigation efforts at the least possible cost. The report presents the assumptions underpinning each scenario and the results of analysis conducted using the global models POLES and GEM-E3.

2.1 Context

Under the UN Framework Convention on Climate Change (UNFCCC), 194 countries took decisions in Copenhagen, Cancun, Durban and Doha in 2009-2012 to act on climate change: notably, all agreed to aim for the common goal to limit global temperature rise to below 2°C compared to pre-industrial levels; more than 90 countries took mitigation commitments until 2020; the Green Climate Fund was established with developed countries agreeing to mobilise US$ 100 billion of private and public finance by 2020 for climate action.

At the same time as countries were embarking on implementing these decisions, new science warned that the current mitigation pledges will be insufficient, with a gap of 8 to 12 $GtCO_2e$ of additional mitigation to realise by 2020 in order to be on a path to stay below 2°C (equivalent to 1 – 2 ½ years of EU emissions). The Intergovernmental Panel for Climate Change (IPCC) confirmed in its latest report (IPCC 2014) that without further climate action global temperatures will increase by 3.7 - 4.8°C compared to pre-industrial levels, or five to six times the current increase (0.8°C). The IPCC also showed that significant, immediate and collective action to reduce global emissions of greenhouse gases (GHGs) would help to avoid the most severe impacts of climate change and decrease the likelihood of persistent and irreversible impacts (Figure 1). Such action is vital to protect sustainable development and growth worldwide, and to protect the most vulnerable populations.

Figure 1. Global perspective on climate-related risks



Source: IPCC AR5, WG II, Summary for Policymakers, Fig1 p13 (IPCC 2014)

In 2011, all countries agreed to start afresh with a new negotiation round under the UNFCCC, recognising the urgency of the need for further action at global level to stay below 2°C. Under this new "Durban platform" of negotiations, parties to the UNFCCC work to enhance collective mitigation ambition by 2020 and to establish a new framework for international climate action beyond 2020. The parties aim to agree, in the Paris COP[2]21 in 2015, on the design of the new global climate regime, which should be applicable to all.

At the Warsaw COP19 in 2013, countries agreed that all should put forward their 'intended nationally determined contributions' (INDCs). All the major economies, and many more countries, have started to prepare their planned contributions for reducing GHG emissions, and this in the context of their national priorities and policies. For instance, a large number of countries presented these plans and priorities at the UN Secretary General Climate Summit in September 2014. On February 27 2015, Switzerland was the first Party to communicate its INDCs, the EU communicated its INDC on March 6. Many more parties will present information on their INDCs including estimates or quantifiable information about the emission reductions expected from their contributions. And many other parties may, like Switzerland or EU, provide a long-term perspective to their mitigation efforts and/or elaborate on why they consider these contributions fair and ambitious.

Furthermore, a number of parties are aiming for a new climate agreement that includes a process of regular reviews, which would enable or require countries to raise the level of ambition of individual and collective mitigation commitments to the levels required by science to stay below 2°C. Parties are negotiating on this issue under the Durban Platform, and parties have been elaborating specific proposals for such processes that are now included in the official draft negotiation text serving as basis for the Paris agreement (see EC 2015a; UNFCCC 2015).

[2] Conference Of the Parties of the UNFCCC

2.2 Objectives

Low-emission development pathways will be an important element of the discussions between parties and stakeholders on the road towards the new climate agreement and during its implementation. This report is meant to inform these discussions by presenting the levels of emissions and the key mitigation options that are consistent with a below 2°C objective.

This report aims to support the INDC formulation process by presenting specific scenarios of global action that could unlock low-emission development pathways. These scenarios are presented globally and for individual countries and sectors. The principles and approaches taken into account by the scenarios are documented clearly. Projected emission levels in 2030 and 2050 are also highlighted, in order to illustrate the deviation from business-as-usual trends that is required to deliver global action in line with staying below 2°C. The report also provides insights into possible shifts in investment patterns in the energy sector, in economic activity across sectors, and in trade flows associated with a scenario of global action to stay below 2°C. It is beyond the scope of this paper to consider the other investments in research and innovation, in delivering access to energy for the poor, or in building a climate-resilient economy protected from climate impacts. Other modelling tools have to be used to provide in-depth analysis on these issues (see IEA 2014a).

2.3 Structure of the report

The report is organised as follows:

Part 3 describes the Baseline case: key macro assumptions on population and GDP growth considered in the projections, the current policies considered and the resulting energy prices, demand and GHG emissions. These assumptions have been considered by the two models used for the analysis: the world energy system model POLES (see Annex 5) and the global CGE model GEM-E3 (see Annex 6).

Part 4 describes a Global Mitigation scenario that aims at respecting the long-term 2°C target with a high probability, implying very rapid action in line with the recommendations of the IPCC AR5 report. Part 4.1 provides detailed results from POLES on the evolution of energy markets under the Global Mitigation scenario, and describes the global trends in GHG emissions and drivers of emission reductions across regions. Part 4.2 goes more in-depth in the macro-economic implications of the Global Mitigation scenario. Part 4.3 briefly compares the Global Mitigation scenario with variants where countries would put in place with delay the necessary mitigation policies; and tests the sensitivity of the modelling to the assumptions about fossil fuel price developments.

Part 5 provide country factsheets describing the main drivers and options of emission reductions taken up by specific countries or regions along the Global Mitigation scenario. This part also indicates some effects on investment patterns and on the economic development of some sectors associated with the Global Mitigation scenario modelling for specific countries or regions.

The annexes give a description of the POLES and GEM-E3 models; background information on the socio-economic assumptions used in the modelling; an overview of countries mitigation pledges and policies for the period up to 2020 as this information was used to define the Baseline scenario; and a comparison of the modelling results presented here with other recent model-based analysis of comparable Global Mitigation scenarios. For a more in-depth analysis of the emission reductions in the agriculture and land-use sectors and the associated environmental, economic and social co-benefits please refer to additional material beyond this report.

3 Baseline scenario

The Baseline scenario represents the effects of the current pre-2020 mitigation pledges on global emission levels up to 2050, without new additional policies by 2020 or beyond.

The Baseline scenario represents the evolution of the energy markets, as driven by its own dynamic of production, supply and demand. This representation is consistent with other international energy projections.

In the absence of new policies, economic and emission growth are not decoupled. Large-scale additional investments are required to cope with the growing energy demand, as the energy sources are not used very efficiently.

In this Baseline scenario, global emissions would increase to unsustainable levels: by more than 10% above 2010 levels by 2020, by at least 30% above 2010 levels by 2030, and around 50% above 2010 levels by 2050. Along such trajectories, the world is at risk to experience a global temperature increase of +4°C, with sizeable impacts on sustainable growth and on vulnerable groups in all regions.

3.1 Macro assumptions

To be consistent with modelling approaches used by the international community of experts and policy makers, our modelling framework is based on independent projections of population and economic growth.

These projections do not consider the impact on growth from unabated climate change.

According to these common macro-economic assumptions, growth is sustained in all regions and the average GDP per capita triples in the period 2010-2050. The strong growth in countries with low-income levels in 2010 enables them to join middle-income levels by 2050.

3.1.1 Population

Population estimates are from UN (2013) for all world countries and regions except for the EU which are taken from EC (2013a).

Table 1 gives the evolution for the main economies. The World will see important changes in population distribution: while population growth in OECD slows down (to decrease to 15% of world population by 2050), the population in Africa has the highest growth rate by far, with its population more than doubling in 40 years. Asia sees its population stabilising by 2050 at around 4.5 billion inhabitants, with India becoming the single most populated country.

Table 1. Population

Region	Million inhabitants			Yearly average growth rate (%)	
	2010	*2030*	*2050*	*2010-30*	*2030-50*
EU28	507	519	513	0.1	-0.1
USA	312	363	401	0.8	0.5
Canada	34	41	45	0.9	0.5
Japan	127	121	108	-0.3	-0.5
Other OECD	278	345	385	1.1	0.5
Russia	144	134	121	-0.4	-0.5
Other CIS	134	143	144	0.3	0.0
China	1360	1454	1386	0.3	-0.2
India	1206	1476	1620	1.0	0.5
Rest Asia	1056	1302	1439	1.1	0.5
Mexico	118	144	156	1.0	0.4
Brazil	195	223	231	0.7	0.2
Rest Latin America	283	350	394	1.1	0.6
Africa	1031	1634	2393	2.3	1.9
Middle-East	216	299	361	1.6	0.9
OECD	**1225**	**1348**	**1408**	**0.5**	**0.2**
Non-OECD	**5691**	**7077**	**8143**	**1.1**	**0.7**
World	**6916**	**8425**	**9551**	**1.0**	**0.6**
Source: UN (2013), EC (2013a)					

3.1.2 GDP per capita

Table 2 (and Figure 153 in Annex 1) show that non-OECD regions will benefit from a higher economic growth rate than OECD by 2050, in the line with the 1990-2010 developments. OECD yearly growth rate remains lower by 1-2 points than the world average by 2050.

However this differential in growth rates is insufficient to induce a catch-up of GDP per capita in non-OECD regions, even when expressed in purchasing power parity (PPP[3]), as Figure 2 shows. Furthermore, by 2050 a clear distinction is projected in GDP per capita between the Least Developed Countries (LDCs) and other non-OECD countries.

The countries' level of income[4] remains differentiated:

[3] Expressed in market exchange rate (MER) $2005, non-OECD GDP per capita remains much lower than OECD by 2050: China still leads non-OECD, but with a GDP per capita of 18 k$2005 only, ahead of Latin America and Middle East at around 15 k$ and CIS at 13 k$. India and Other Asia are around 7 k$, and Africa at 4 k$ per capita.

[4] Expressed as World Bank income group level classification: low-income economies are defined as those with a Gross National Income (GNI) per capita, calculated using the *World Bank Atlas* method, of $1,045 or less in 2013; middle-income economies are those with a GNI per capita of more than $1,045 but less than $12,746; high-income economies are those with a GNI per capita of $12,746 or more. Lower-middle-income and upper-middle-income economies are separated at a GNI per capita of $4,125.

- North America remains the wealthiest region in the high income countries; followed by other high-income countries: Pacific ("Other OECD" in Table 2 and Figure 2) and EU;

- emerging economies which are already upper-middle income countries, like China (which reaches the highest non-OECD per capita level in 2050: 40 k$2005 PPP), Latin America (Brazil, Mexico) or high-income countries like Middle-East further increase their income levels;

- countries with currently lower-middle income or low-income levels, in which half the world population is located, GDP per capita remains comparatively lower than in other regions: i.e. developing Asia (20 k$ per capita) and Africa (less than 10k$);

To reflect these differences, the 2°C policy scenario differentiates the effort undertaken by LDCs on the one hand and by other regions on the other hand.

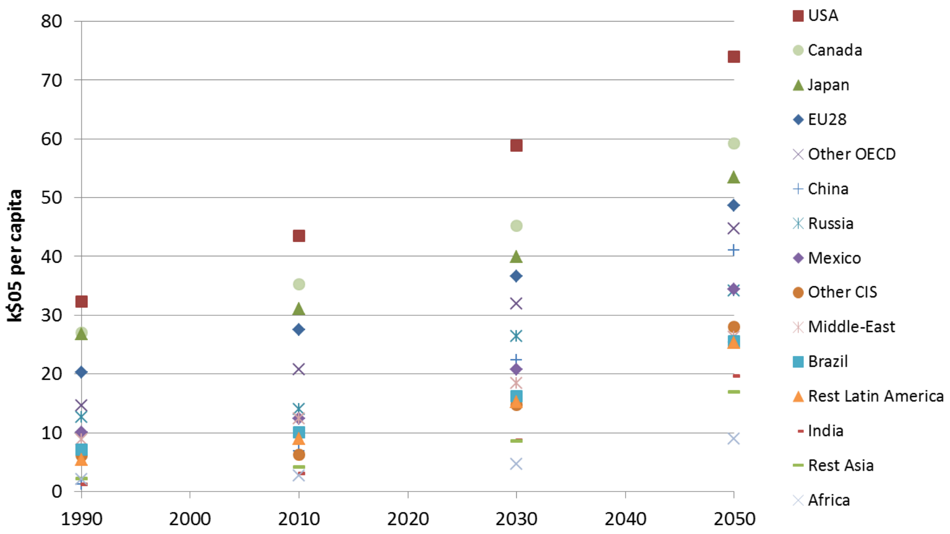
Table 2. Yearly average growth rate of GDP (left) and GDP per capita (right) ($05 MER)[5]

Region	GDP			GDP per capita		
	1990-2010	*2010-30*	*2030-50*	*1990-2010*	*2010-30*	*2030-50*
EU28	1.8	1.5	1.4	1.5	1.4	1.5
USA	2.5	2.3	1.7	1.5	1.5	1.1
Canada	2.4	2.1	1.9	1.3	1.3	1.4
Japan	0.9	1.0	0.9	0.7	1.3	1.5
Other OECD	3.4	3.4	2.2	1.8	2.2	1.7
Russia	0.4	2.8	0.8	0.5	3.2	1.3
Other CIS	0.6	4.8	3.3	0.3	4.5	3.3
China	9.8	6.4	2.8	9.0	6.0	3.1
India	6.6	6.3	4.6	4.8	5.2	4.2
Rest Asia	4.9	4.5	3.7	3.2	3.5	3.2
Mexico	2.7	3.6	3.0	1.1	2.6	2.6
Brazil	3.1	3.1	2.5	1.7	2.4	2.3
Rest Latin America	3.9	3.8	3.2	2.3	2.7	2.6
Africa	3.6	5.2	5.2	1.0	2.8	3.2
Middle-East	4.3	3.7	2.8	1.8	2.1	1.8
OECD	**2.1**	**2.0**	**1.6**	**1.4**	**1.5**	**1.4**
Non-OECD	**4.7**	**5.0**	**3.4**	**3.2**	**3.9**	**2.7**
World	**2.7**	**3.0**	**2.4**	**1.3**	**2.0**	**1.7**

Source: JRC POLES model

[5] See Annex 1 for details on the sources used.

Figure 2. Regional GDP per capita ($05[6], PPP)



3.2 Policies considered

Table 3 summarises the policies considered in the Baseline scenario in 2020. This scenario considers that without additional measures in the coming years, countries will implement only the lower end (or part) of their pledges. The GHG objectives are reached through the use of a "carbon value" (CV) that can represent either the carbon price formed on a carbon market associated with sectoral emission entitlements (like the EU ETS), the taxation of GHG emissions (expressed in CO_2-equivalent[7]) or the cost per tonne of GHG emission associated to abatement-related regulation and standards. The CV modifies the relative competitiveness of fuels and technologies and leads to a reduction of GHG emissions (expressed in CO_2-equivalent terms). Non-GHG objectives are reached through sector-specific measures like financial support to technology development or mandatory standards for vehicles. In the case of the EU, the CV evolution 2005-2015 reflects the past evolution of the ETS price (see EEA 2014[8]). The EC is putting in place the measures to ensure that the ETS sends the correct signal to the economic actors, which should help a slow recovery of the price in the years to come: postponing of the auctioning of allowances in the period up to 2020[9], followed later by the implementation of a "market stability reserve" (MSR[10]).

[6] All monetary units are expressed in $05 since most data (income, energy prices) are available at country level in that unit. To convert in €2010 one has to multiply by 0.88.
[7] Using the IPCC SAR GWP (mentioned in IPCC 2007).
[8] See in particular Figure 3.8 p41 (EEA 2014)
[9] See the "Commission regulation (EU) No 176/2014 of 25 February 2014 amending Regulation (EU) No 1031/2010 in particular to determine the volumes of greenhouse gas emission allowances to be auctioned in 2013-20" Available on (25-03-2014): http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0176&from=EN
[10] See the COM(2014) 20/2 "Proposal for a decision of the European Parliament and of the Council concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC" Available on (25-03-2015): http://ec.europa.eu/clima/policies/ets/reform/docs/com_2014_20_en.pdf

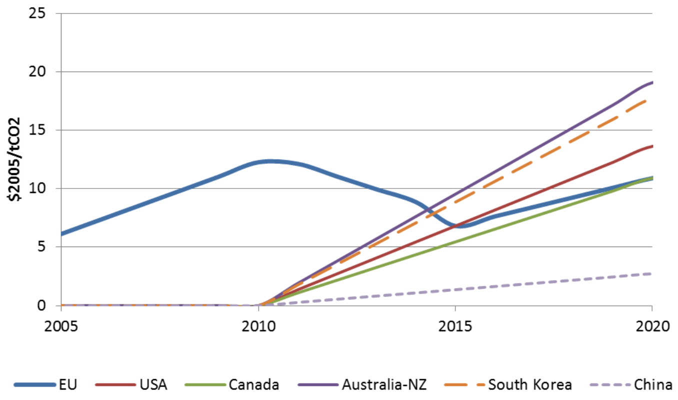
Table 3. 2020 pledges and policies implemented in the Baseline case

	2020 pledge	Policies implemented	Binding Emission constraint?	Other policy instruments
AUS	GHG 5%-25% below 2000	GHG 5% below 2000	Yes	
NZL	10% to 20% below 2000 incl. land management	aggregated with AUS	Yes	
BRA	GHG 36% - 39% below national BAU by 2020	GHG do not exceed 2000 $MtCO_2e$ including Land Use, Land-use Change & Forestry (LULUCF)	No	
CAN	GHG 17% below 2005, incl. 12% from domestic action; standards in transport	GHG at 2005 level	Yes	Fuel standard for new vehicles (44 mpg)
CHE	GHG 20%-30% below 1990	Joins the EU ETS	Yes	
CHN	CO_2 emission/GDP -40–45% vs. 2005; 15% share of non-fossil fuel in primary energy consumption by 2020; increased forest coverage/stock volume	CO_2 emission/GDP -40% vs. 2005 levels	Yes	
EU28	GHG 20% below 1990, 30% conditional; standards in transport	GHG 20% below 1990	Yes	Fuel standard for new vehicles (95 gCO_2/km)
IDN	GHG 26% below national BAU by 2020	GHG 78% above 2010 (68% excl. LULUCF)	No	
IND	GHG/GDP (except agriculture) -20–25% vs. 2005; Share or RES in electricity 15%, wind and solar capacity target	GHG (except agriculture) per unit of GDP -20% vs. 2005 levels	No	
JPN	GHG 3.8% below 2005; RES targets 2022: Wind (38 GW), Solar (20 GW) Solar thermal capacity (14 GW)	GHG 3.8% below 2005 levels	No	
KOR	GHG 30% below national BAU by 2020; 6% share RES in primary energy	GHG 3% above 2010 level	Yes	
MEX	GHG 30% below national BAU; non-CO_2 electricity share 35% in 2024	halfway: GHG 24% above 2010 level	No	
NOR	GHG 30%-40% below 1990 (2/3 domestic)	Joins the EU ETS	Yes	
RUS	GHG 15-25% below 1990; RES target (5% share of electricity)	GHG 25% below 1990 levels	No	
USA	GHG 17% below 2005; standards in transport, share RES of electricity 14%	GHG 12% below 2005 levels	Yes	Fuel standard for new vehicles (44 mpg)
ZAF	GHG 34% to 42% below national BAU by 2020; RES capacity target (25 GW 2030)	BAU Trend	No	

Note 1: Pledges expressed as a reduction from national BAU in 2020 have led an estimate of emission levels in 2020 and translated into objectives expressed in % of historical emissions (example: Korea, Rep. KOR).
Note 2: Countries have no carbon price when the emission constraint is not binding according to the Baseline scenario projections.
Source: Den Elzen et al. (2015)

As a result of the assumptions described Table 3 about how a carbon value represents the countries' pre-2020 mitigation pledges and climate and energy policies, most OECD countries face a carbon value (CV) by 2020 in the range 10-20 $/tCO_2$, while China implements a fairly low CV by 2020 (less than 5 $/tCO_2$) to respect its objective of CO_2 intensity of GDP (-40% compared to 2005).

Figure 3. Baseline carbon value by 2020

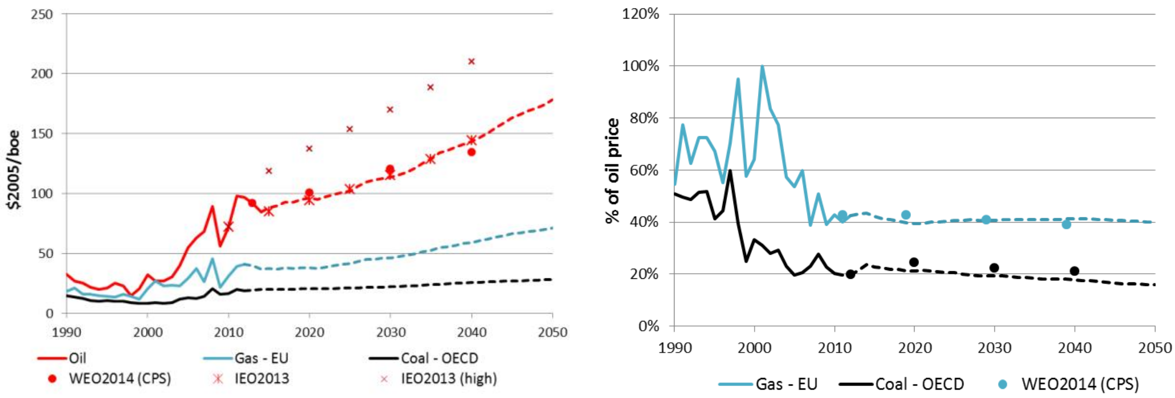


Source: JRC POLES model

3.3 Energy prices

Figure 4 shows the evolution of fossil fuel prices in the Baseline case. After a stabilisation in the coming years due to a reduction of the utilisation rate of spare capacity in the Gulf region[11], the oil price resumes its upside trend experienced over the last 10 years. It remains close to other international projections (the World Energy Outlook 2014, from IEA 2014a, and the International Energy Outlook 2013 from EIA 2013). It should be noted that oil price projections do not take into consideration the recent drop in prices, which is presented as a sensitivity analysis conducted with POLES model in Section 4.4.

Figure 4. Baseline fossil fuel prices (left) and ratio of coal & gas to oil price (right), 1990-2050

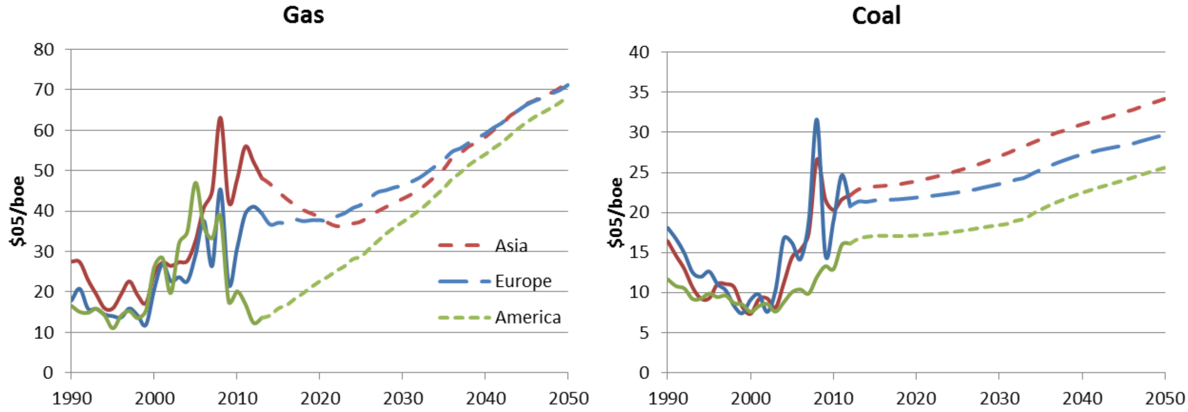


Note: WEO2014 and IEO2013 are expressed originally in $2013 and $2011 respectively. In this figure they have been normalised to POLES prices expressed in $2005; WEO2013 CPS: Current Policy Scenario, IEO2013 "high": high oil price scenario. Source: JRC POLES model

The decoupling between oil and other fossil fuels prices observed since the early 2000s continues in the future for coal, while the ratio of gas to oil price remains fairly stable. The decrease for coal infers an increasing competitiveness of coal, most notably compared to gas with which it competes in the power sector.

[11] This scenario considers a progressive recovery of production capacity in Iraq, and did not try to capture possible new turmoil in the region. For an analysis on this specific aspect see Kitous et al. (2013).

Figure 5. Average regional prices for coal (left) and gas (right) in the Baseline



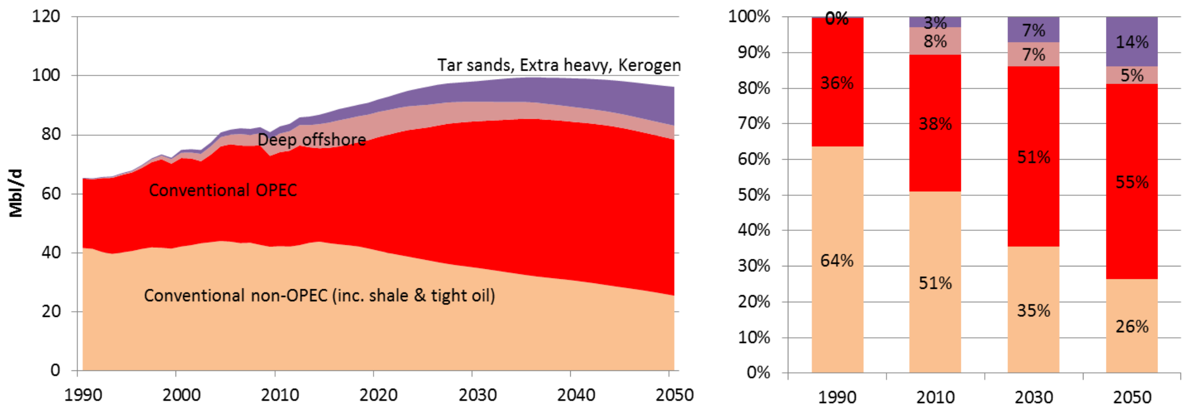
Source: JRC POLES model

Gas prices will keep increasing over the next 10 years, while retaining regional differentials reflecting supply patterns and transport costs. However convergence will gradually take place with the development of international LNG trade[12] and the further integration of Asian and European markets via Russian supply[13]. Coal price should follow a moderate upwards trend, driven by transport costs and, in the long term, by increasing mining costs.

3.4 Oil production

The main driver of the future oil price is the growing scarcity of conventional oil resources[14] and consequent increasing market power of OPEC. This upward evolution of price is also sustained by the progressive substitution of conventional resources for expensive energy-intensive liquid fuels: tar sands, extra heavy oil and kerogen / oil shale represent together almost 15% of the total production in 2050.

Figure 6. World oil production, Baseline scenario



Note: includes crude, LNG production and non-conventional oil; does not include liquid biofuels, Coal-To-Liquids, Gas-To-Liquids nor processing gains. Source: JRC POLES model

[12] LNG could represent about 60% of total international gas trade by 2035

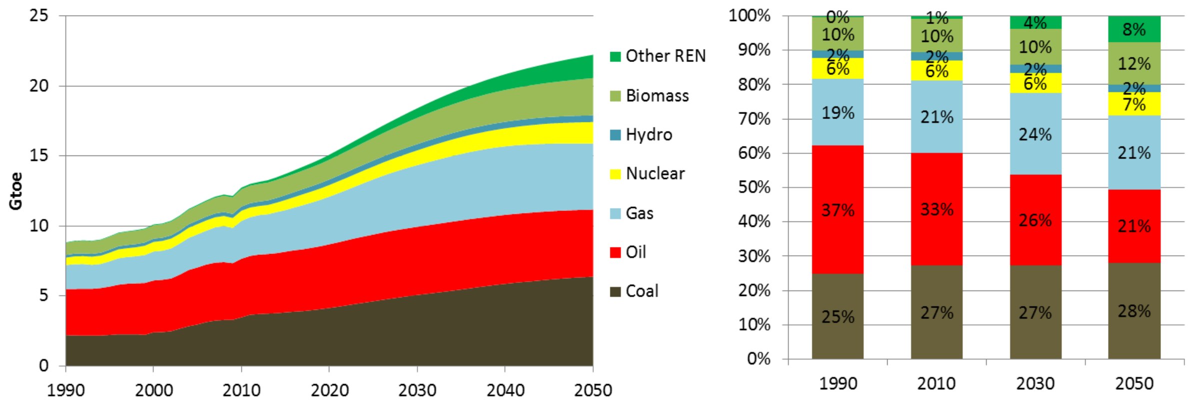
[13] Export of Russian gas towards China should start in the coming years, after the signature in May 2014of a 30-year supply agreement between both countries.

[14] Fossil fuel resources comes primarily from BGR (2013) and USGS (USGS 2013 and Schenk, C.J., 2012).

3.5 Energy demand

Primary energy demand[15] in the Baseline scenario increases from 13 Gtoe in 2010, to 18 Gtoe in 2030 and 22 Gtoe in 2050. This reflects increasing population and energy needs per capita, even though it is compensated by the steady decline of the energy intensity of GDP (see Table 4). The structure of demand by fuel evolves with each fuel's relative scarcity (the share of oil is progressively declining, gas maintains a fairly constant share, coal's contribution increases to a third of the total energy supply in 2050) and the growing role of new technologies, with renewable forms of energy representing 22% of the total mix in 2050 vs. 13% in 2010.

Figure 7. World energy demand, Baseline scenario



Source: JRC POLES model

World final consumption per sector remains fairly constant over time: industry represents around 40% of the total, transport 25-30% and buildings 30-35% (see Figure 20).

3.6 Resulting GHG emissions

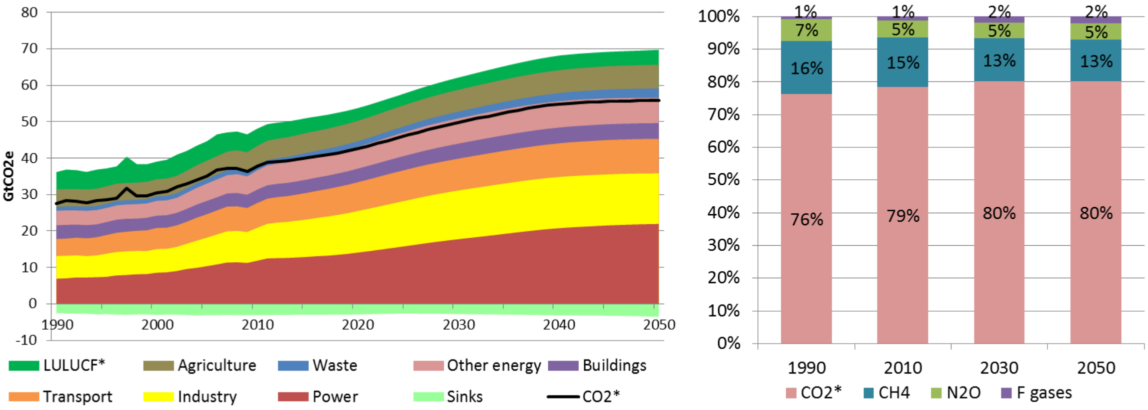
Figure 8 gives the evolution of total GHG emissions at World level in the Baseline scenario. Emissions excluding sinks increase by 2050 to 70 $GtCO_2e$ (from 48 $GtCO_2e$ in 2010 and 62 $GtCO_2e$ in 2030), with power generation staying the dominant source, ahead of industry and transport, followed by "other" energy sectors (primary supply, transformation), agriculture[16], buildings and waste GHG emissions. Emissions related to Land Use, Land-use Change and Forestry in the graph (LULUCF[16]) exclude sinks[17]. Sinks from afforestation and forest management could represent 3 $GtCO_2$ in 2010 and about 3.5 $GtCO_2$ in 2050, but the uncertainty on the estimates of the historical role of sinks on global emissions is significant and the modelling of the future role of sinks to contribute to projected global emission reductions goes beyond the scope of this paper; in the remainder of the paper, the focus is on analysing the projected evolutions of the emissions from all sources, excluding sinks.

[15] Primary energy demand is calculated using the IEA conversion factors – see Annex 2

[16] Projected CH_4 and N_2O agriculture emissions and CO_2 land-use emissions are derived from the GLOBIOM model (Global Biosphere Management Model*)* which has been linked to the POLES model – for more information on the GLOBIOM model see IIASA (2015) and Havlík P. et al. (2014).

[17] Sinks are defined as negative CO_2 emissions from land-use related activities.

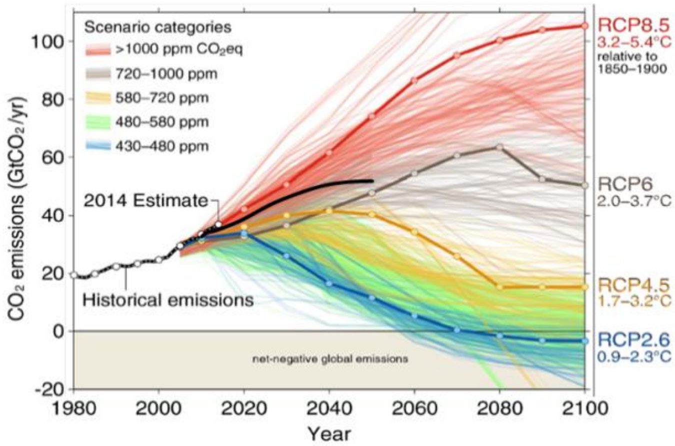
Figure 8. World GHG emissions in the Baseline scenario, by sector (left) and by gas (right)



Note: Historical data: CO_2 emissions from combustion are derived from national and regional energy balances (most update: 2012); CO_2 from industrial processes, CH_4 and N_2O come from UNFCCC (Annex 1 / 2012, source: UNFCCC 2014) and EDGAR (Non-Annex 1 / 2010, source: EC JRC 2014); CO_2 LULUCF come from UNFCCC (Annex 1 / 2012), FAO-Stat (source: FAO 2014) and EDGAR (non-Annex 1 / 2010).
**In these graphs LULUCF CO_2 sinks are singled out and not included in the LULUCF and CO_2 categories.*
Source: JRC POLES model

The Baseline emissions are on the path of significant temperature change by the end of the century, around +4˚C relative to 1850-1900 (depending on the post-2050 evolution).

Figure 9. Baseline related temperature changes and CO_2 emissions



Source: Fuss et al. (2014) , JRC POLES model

The decomposition[18] of the World GHG emissions (Table 4 and Figure 10) shows that, although the energy intensity of the GDP keeps decreasing (-53% in 2010-2050) and the GHG content of the energy mix declines slightly over time (-14% in 2010-2050), the policies envisaged in the Baseline are far from allowing a decoupling of emissions and economic growth sufficient to stay below 2°C. The average GDP per capita triples in 2010-2050 while the GHG emissions per capita remain fairly stable throughout the period, around 6.5 tCO_2e per capita.

[18] Decomposition of the emissions into the following four explanatory variables: the GHG content of energy use, the energy intensity of GDP, the GDP per capita, and the population

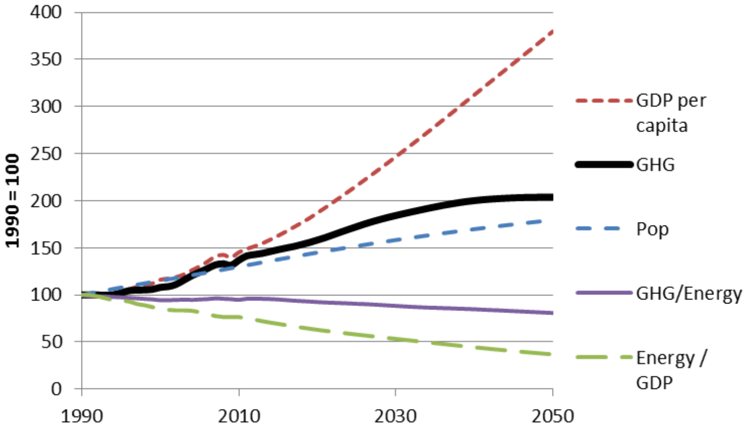
GHG = [GHG / Energy] * [Energy / GDP] * [GDP / Pop] * [Pop]

Table 4. Baseline decomposition of World GHG emissions

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
GHG ($GtCO_2e$)	43.4	50.2	54.9	58.7	64.1	65.6	138	160	187	204	209
Population (10^9)	6.9	7.7	8.1	8.4	9.0	9.6	130	145	158	170	180
GDP per capita (k$05)	10	13	15	17	21	26	145	187	247	312	380
GHG per capita (tCO_2e)	6.3	6.5	6.8	7.0	7.1	6.9	106	110	118	120	116
GHG / GDP (tCO_2e/M$)	634	511	461	415	333	266	73	59	48	38	31
Energy / GDP (toe/M$)	186	154	141	130	109	90	76	63	53	45	37
GHG / energy (tCO_2e/toe)	3.4	3.3	3.3	3.2	3.1	2.9	95	93	89	86	83

Note: includes GHG emissions from energy, industry and agriculture; does not include CO_2 emissions from LULUCF;
GDP in $05 PPP. Source: JRC POLES model

Figure 10. Baseline decomposition of World GHG emissions



Note: includes GHG emissions from energy, industry and agriculture; does not include CO_2 emissions from LULUCF. Source: JRC POLES model

4 Global Mitigation scenario

The Global Mitigation scenario is meant to represent the effects of possible new mitigation commitments beyond 2020. This scenario requires global participation by all countries and all sectors and greenhouse gases to be addressed; yet it is differentiated according to the countries' capabilities, especially giving time and flexibility to the lowest income countries to join the global mitigation efforts and sustain their growth potentials. This Global Mitigation scenario is illustrating how all countries can set milestones for action by 2025 or 2030 in relation to the common goal to stay below 2°C and integrating their national circumstances.

In this Global Mitigation scenario, global emissions (excluding land use sinks) would peak in 2020 at about 10% above 2010 levels, then decrease to 10% below 2010 levels by 2030 and by 60% below 2010 levels by 2050. This trajectory leaves space to countries to gradually embark on realising emission reductions. At the same time, it keeps global emissions on a path consistent with securing a 60-80% probability of staying below 2°C according to the latest IPCC report.

This scenario achieves a decoupling of emissions and economic growth by ensuring a very strong decarbonisation of the energy consumed and a more efficient use of energy across the world economy.

Key mitigation options by 2030 include: energy savings, decarbonising the power sector with renewables, nuclear and fuel switching, and actions to cut non-CO_2 emissions in agriculture and waste. Carbon Capture and Storage (CCS) becomes an important mitigation option after 2030.

Keeping a high probability of staying below 2°C requires immediate policy response and a comprehensive policy framework put in place already in 2015-2020, immediately after the COP 21 in Paris in 2015. Global emissions peak in 2020 and decline afterwards to already 10% below 2010 levels by 2030 and 50% below 1990 levels in 2050.

Fossil fuel energy producers have to adapt to improved energy use at global level. Nonetheless, Sub-Saharan Africa and Latin America remain net fossil fuel exporters, Gulf countries and Russian Federation remain the world's dominant suppliers, and energy trade remains an important source of their income.

The global investment patterns in power production are substantially modified by the introduction of ambitious GHG mitigation policies and by the related major changes in the energy mix towards renewable sources representing 40% of primary energy in 2050. Investments shift away from fossil fuels towards the power sector to tap capital-intensive mitigation opportunities. These investments enable to reduce other costs that would be required if abatement was not undertaken largely by the power sector but also by reducing expenditure on fossil fuel imports and subsidies.

4.1 GHG emissions and evolution of the energy system

4.1.1 Ambition and resulting GHG emissions

In view of the urgency to act to stay below 2°C, all countries are currently working to implement their current international mitigation commitments and are preparing contributions to the new climate agreement. More than 90 Parties representing around 80% of global emissions have put forward pre-2020 mitigation pledges and 120 Heads of States and Government joined the UN Secretary General climate summit in September 2014 demonstrating policies and efforts to prepare for a new climate agreement in Paris (see Annex 4).

We develop here a Global Mitigation scenario whose 2010-2050 GHG emission budget is consistent with a likely chance to meet the long-term goal of a maximum 2°C increase in temperature over pre-industrial levels in 2100, while reflecting the need for a global transition towards low-emission economic development.

The scenario respects short-term (2020) policy settings in countries that explicitly put forward domestic actions. In addition, a limited carbon value (5 $/tCO_2$ in 2020) has been introduced in all other countries to consider for minimum action, reflecting a minimum value actually taken into account in investment patterns.

To account for contrasting financial capacity across regions, the scenario differentiates the intensity of mitigation between regional groups. In particular "least developed countries[19]" (LDCs) are allowed a longer transition period (beyond 2030) while all other regions converge by 2030 to a common carbon price, although with different timing; OECD countries and high income non-OECD countries[20] converge in 2025, while middle-income non-OECD countries[21] converge only in 2030.

Short term policies to 2020

Table 5 describes the policies implemented by 2020 in the Global Mitigation scenario. The main difference with the policies implemented in the Baseline are the targets for renewable energy sources (RES), expressed mostly in the power generation sector (share or capacities) but also sometimes in terms of primary energy demand. The GHG objective is also more stringent in some countries, for instance in Canada and USA. However, we have not forced the models to deliver in full some pre-2020 pledges in line with currently available analysis: this is the case for Canada, Switzerland, Korea, Rep. and Norway, as in UNEP (2014) and Climate action tracker (2015) indicate these countries are not expected to deliver their pre-2020 pledges in full with the domestic policies currently in implementation.

[19] Countries with a GDP per capita under 5 k$ ($05) PPP in 2010: Indonesia, India, South Asia, Sub-Saharan Africa, Central America.
[20] Countries with a GDP per capita above 10 k$ ($05) PPP in 2010: Turkey, Russia, Ukraine, Gulf, Brazil, Rest South America.
[21] Countries with a GDP per capita between 5 and 10 k$ ($05) PPP in 2010: China, Rest South-East Asia, North Africa, South Africa, CIS (excl. Russia and Ukraine), Mediterranean Middle-East.

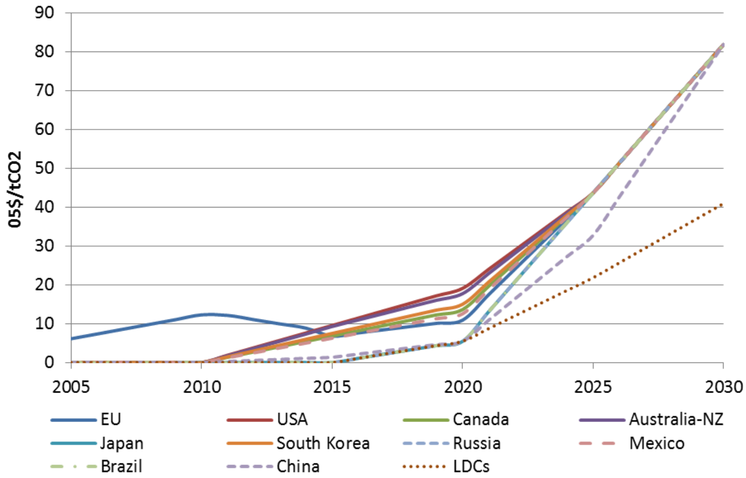
Table 5. 2020 pledges and policies implemented in the Global Mitigation scenario

	2020 pledge	Policies implemented	Binding emission constraint?	Other policy instruments
AUS	GHG 5%-25% below 2000	GHG 5% below 2000	Yes	RES target (20% share electricity)
NZL	10% to 20% below 2000 incl. land management	aggregated with AUS	Yes	aggregated with AUS
BRA	GHG 36% - 39% below national BAU by 2020	GHG do not exceed 2000 $MtCO_2e$ including LULUCF	No	
CAN	GHG 17% below 2005, incl. 12% from domestic action; standards in transport	GHG 12% below 2005	Yes	Fuel standard for new vehicles (44 mpg)
CHE	GHG 20%-30% below 1990	Joins the EU ETS	Yes	
CHN	CO_2 emission/GDP -40–45% vs. 2005; 15% share of non-fossil fuel in primary energy consumption by 2020; increased forest coverage/stock volume	CO_2 emission/GDP -40 by 2020 vs. 2005	Yes	15% share of non-fossil fuel in primary energy consumption
EU28	GHG 20% below 1990, 30% conditional; standards in transport	GHG 20% below 1990	Yes	Fuel standard for new vehicles (95 g CO_2/km)
IDN	GHG 26% below national BAU by 2020	GHG 78% above 2010 (68% excl. LULUCF)	No	RES target (15% share electricity)
IND	GHG/GDP (except agriculture) -20–25% vs. 2005; Share or RES in electricity 15%, wind and solar capacity target	Reduce GHG/GDP (except agriculture) by 25% vs. 2005	No	RES target (15% share electricity)
JPN	GHG 3.8% below 2005; RES targets 2022: Wind (38 GW), Solar (20 GW) Solar thermal capacity (14 GW)	GHG 3.8% below 2005	No	RES target (capacities)
KOR	GHG 30% below national BAU by 2020; 6% share RES in primary energy	GHG 3% above 2010	Yes	RES target (6% primary energy)
MEX	GHG 30% below national BAU; non- CO_2 electricity share 35% in 2024	GHG 2.5% above 2010	Yes	35% clean electricity in 2024 (non- CO_2 emitting)
NOR	GHG 30%-40% below 1990 (2/3 domestic)	Joins the EU ETS	Yes	
RUS	GHG 15-25% below 1990; RES target (5% share of electricity)	GHG 25% below 1990	No	RES target (5% share electricity)
USA	GHG 17% below 2005; standards in transport, share of RES electricity 14%	GHG 17% below 2005	Yes	Fuel standard for new vehicles (44 mpg), RES target (14% share electricity)
ZAF	GHG 34% to 42% below national BAU by 2020; RES capacity target (25 GW 2030)	GHG 19% above 2010	No	RES capacity target (25 GW 2030)

Note: When the emission constraint is not binding, a minimal carbon price (5 $/tCO_2$) has still been introduced in 2020 to simulate low intensity measures, that could actually be financed by credit purchase from other countries.
Source: (Den Elzen et al., 2015)

The resulting carbon values lie within a 10-20 $/tCO_2$ range as presented in Figure 11 (to which we can add the 5 $/tCO_2$ carbon value applied to countries have no or non-binding objectives). In 2020 the resulting deviation of World emissions with the Baseline is small.

Figure 11. Global Mitigation scenario: carbon value to 2020 and to 2030



Source: JRC POLES model

Transition phase to 2030

Assuming as a starting point the climate policy implemented by 2020, it is considered that all countries will continue implementing mitigation policies, which translates in modelling terms into applying a growing carbon value (CV) on their GHG emissions. Most countries converge towards a common CV by 2030. To consider for the lower income of LDCs and thus for their lower capacity to engage in ambitious mitigation policies, their participation to the Global Mitigation scenario is differentiated: in 2030 their CV is only 50% of the other regions'. At about 43 $GtCO_2e$ in 2030 in the Global Mitigation scenario, World GHG emissions are still higher than in 1990 (+20%) but lower than in 2010 (-10%) and the total cumulative carbon budget is in line with the target of below 2°C by 2100.

The 2030 carbon value[22] (80 $05/$tCO_2$) allows the EU to comply with its internal objectives set for 2030: to reduce its domestic GHG emissions by at least -40% compared to 1990, to reach the objective of renewable energy sources representing 27% of final demand (see EC 2014).

In the Table 6 the resulting emission reductions for different regions in 2020, 2030, 2040 and 2050 are expressed in "2020 pledge" terms[23] to illustrate how they all represent a progression beyond the 'numbers' in the current pre-2020 pledge.

It is important to note that these numbers should not be taken at their face value to discuss about the level of ambition of the future targets that the countries may propose as contributions to the new climate agreement. Choices have been made about the inclusion in the Baseline of specific policies that countries are currently putting in place. If more or less policies had been considered in the Baseline, the imposition of a carbon value may have led to a different picture of country-

[22] The carbon value (80 $05/tCO2, or 72 €10/$tCO_2$) is higher than the one displayed in the 2014 EC Impact Assessment (IA) "A policy framework on climate and energy in the period from 2020 up to 2030", which gives 40-53 €10/tCO_2 (see Table 15 of EC (2014)). Conditions are slightly different: first, the CV here is determined to reach a World emission objective, that leads total EU GHG to be slightly more reduced (-43% excluding sinks, vs. -40% in the IA). Second, this CV is combined in the EU with a lower renewable value (9 €10/MWh vs. 34 €10/MWh in the IA - see Table 15 of EC, 2014) while reaching the same share of renewables.

[23] The individual country objectives for 2020 do not share a common reference year nor are expressed in the same metric.

specific numbers. The POLES results of the Global Mitigation scenario are only based on domestic emission reductions.

Table 6. Extension of 2020 GHG emissions and RES objectives to 2030, 2040, 2050

Region	Objective type	Reference year	2020	2030	2040	2050
EU28	GHG	1990	-26%	-43%	-60%	-80%
RUS	GHG	1990	-50%	-66%	-75%	-85%
AUS-NZL	GHG	2000	-4%	-21%	-65%	-90%
CAN	GHG	2005	-11%	-34%	-50%	-95%
JPN	GHG	2005	-8%	-29%	-55%	-70%
USA	GHG	2005	-16%	-43%	-60%	-85%
KOR	GHG	2010	0%	-15%	-40%	-65%
MEX	GHG	2010	4%	-9%	-40%	-70%
ZAF	GHG	2010	-6%	-22%	-50%	-65%
CHN	CO_2/GDP, excl. LULUCF	2005	-41%	-72%	-90%	-95%
CHN	Share non-fossil fuels in primary energy	-	15%	36%	60%	75%
IND	GHG/GDP, excl. AFOLU	2005	-36%	-63%	-80%	-95%
IND	Share of RES in power, excl. large Hydro	-	15%	29%	45%	55%

Note: the "non-fossil fuels" target of CHN includes CCS
Source: JRC POLES model

The pace of global emission reductions is actually already significant by 2030, the yearly reduction being -1.5% in 2020-2025 (-2% including sinks), and then -2.2% in 2025-2030 (-3% including sinks).

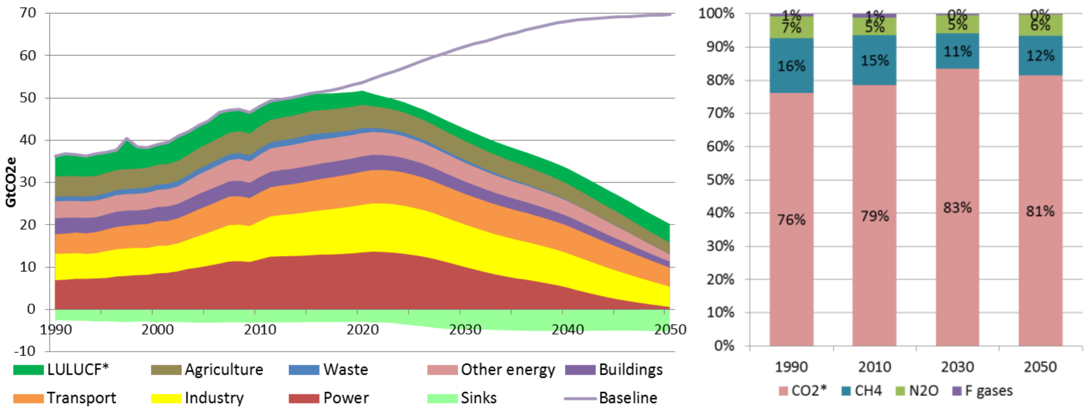
Post-2030 decarbonisation

Post-2030, emissions in the modelling scenario are characterised by three main restrictions. Firstly, global emissions must respect the IPCC recommended carbon budget. This is maximum level of cumulative GHG emissions considered compatible with a reasonable probability of maintaining global temperature rise below 2°C compared to the pre-industrial levels (see Figure 14 and IPCC 2014[24]). In order to respect this target, the scenario requires steady restrictions of GHG emissions from 2020 in various sectors of the economy. Respecting the prescribed carbon budget and considering the system inertia this leads to a very high carbon value in the modelling exercise. Secondly, the scenario respects the EU's internal objective of reaching by 2050 a domestic 80% reduction in GHG emissions compared to 1990 (EC 2011). Finally, differentiation in the carbon value between countries with capacity constraints (defined as countries and regions with a low level of Human Development Index) and other countries is maintained in the post-2030 period, with capacity-constrained countries reaching a carbon value set at 30% of the rest-of-world level up to 2050. The resulting GHG emissions are reduced to about 30 $GtCO_2e$ in 2040 and 20 $GtCO_2e$ in 2050 (vs. 70 $GtCO_2e$ in the Baseline). The global power production sector undertakes the strongest mitigation effort, being almost fully decarbonised by 2050. As mentioned earlier the

[24] See Table 6.3 of the IPCC AR5, WG III, Chapter 6, p431

emission reduction from 2030 onwards is important, falling by 5.5%/year, which leads to a 60% reduction in 2050 compared to 2010 (all GHG, all sources).

Figure 12. World GHG emissions in the Global Mitigation scenario, by sector (left) and by gas (right)



In these graphs LULUCF CO_2 sinks are singled out and not included in the LULUCF and CO_2 categories.
Source: JRC POLES model

The distribution by greenhouse gas shows that at first non-CO_2 are more reduced that CO_2, but by 2050 the shares are close to the Baseline situation (see Figure 17 for a more detailed analysis). At sectoral level, emissions from the power system and from waste tend to reduce close to 0 in 2050.

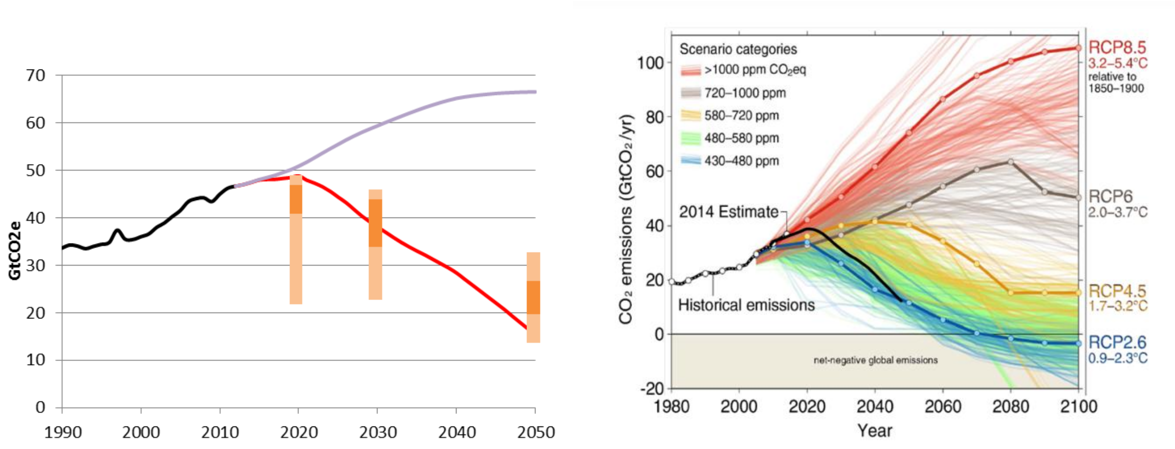
4.1.2 Global Mitigation

Considering recent evolution and the system inertiae, the deviation of Global Mitigation scenario from the Baseline appears modest by 2020. However, the mitigation effort accelerates significantly in the 2020-2030 decade, with 2030 emissions already at -10% of 2010 levels.
The peaking of emissions in 2020 and their regular decrease onwards maintains a reasonable probability to stay below the target over the long run.

4.1.3 Probability to stay below 2°C

Figure 13 shows that the constrained scenario enable to stay on pathways securing a likely chance to stay below 2°C by the end of the century: the low level in 2050 compensates for the high emissions in 2030, leading to limited cumulated emissions by 2050 compatible with the range indicated by the latest UNEP Gap Report as in line with staying below 2°C (UNEP 2014).

Figure 13. World GHG emissions & probability to stay below 2°C



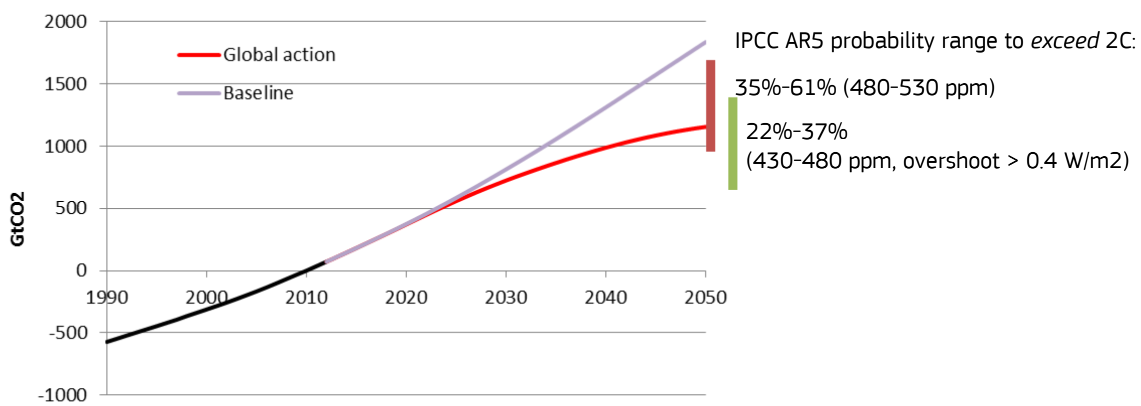
Source: JRC POLES model, UNEP Gap Report 2014 *Source: Fuss et al. (2014)*

Note 1: Left graph: POLES emissions include LULUCF CO_2 *sinks*

Note 2: Left graph: Bars give the range and spread of trajectories with a likely chance (> 66%) of limiting the temperature increase below 2°C during the 21st century derived from "optimal mitigation from 2010 onwards"; "range" and "spread" are defined as the [minimum – (15th percentile – 85th percentile) – maximum value]; source: UNEP (2014), Table 2.2.

CO_2 emissions in the Baseline scenario by 2050 would accumulate far beyond the ranges compatible with staying below 2°C, as shown in Figure 14. By contrast, in the Global Mitigation scenarios, global CO_2 emissions are curbed and the joint efforts of all countries put the world on pathways consistent with a 60-80% probability of staying below 2°C according to the range provided by IPCC[25] (2014) for the correspondence between cumulative emissions and chances to stay below 2°C.

Figure 14. Cumulative CO_2 emissions from 2010



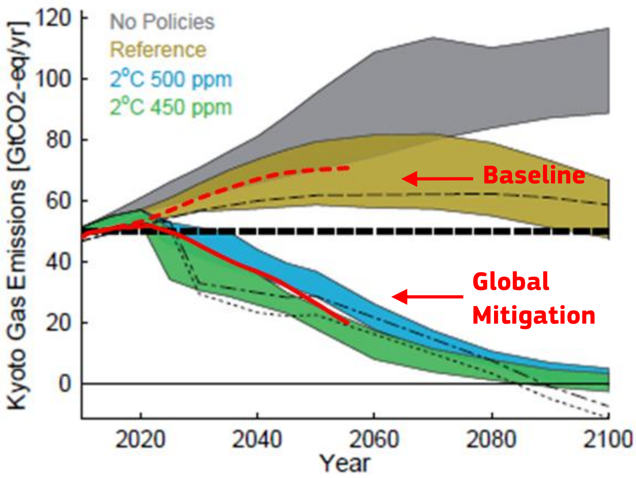
Note: includes all CO_2 *emissions, including sinks; the negative values before 2010 give the historical evolution. Source: JRC POLES model, IPCC (2014[25])*

Moreover, in Figure 15 we compare the Baseline and Global Mitigation scenarios with long term projections compatible with GHG concentration of 500 ppm and 450 ppm from the European FP7 LIMITS project[26]. The graph shows that the Global Mitigation scenarios we represented falls in the range of the long-term 450 ppm scenarios compatible with securing our chances to staying below 2°C. The modelling framework considered here does not extend in the period beyond 2050, but it is

[25] The Global Mitigation scenario leads to CO_2 emissions up to 2050 below the 90th percentile of the following IPCC long-term scenarios: Scenario 430-480 with overshoot > 0.4 W/m2, scenario 480-530 with overshoot < 0.4 W/m2, scenario 480-530 without any exceedance of 580 ppm CO_2e (IPCC AR5 WGIII,, Chapter 6, page 431, Table 6.3)

clear from the graph that these long-term scenario lead to near zero global emissions before the end of the century.

Figure 15. World GHG : comparison with LIMITS project

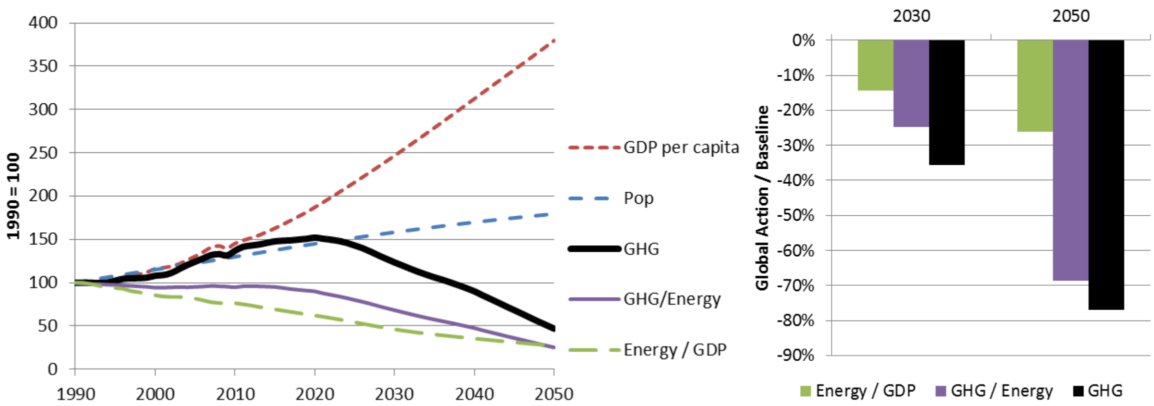


Source: LIMITS project (Tavoni et al., 2014), JRC POLES model

4.1.4 Decomposition of World emissions

The scenario leads to a further improvement of the energy intensity of GDP compared to the Baseline case, decreases by a factor of four from 1990 to 2050 at World level; and to a very strong decarbonisation of the energy consumed, with the ratio GHG/energy being divided by 4 from 2010 to 2050, meaning the emission intensity of energy use is reduced by 75% over the period. This can only take place with an accelerated fuel and technology shift towards GHG neutral options. It must be noted that the results on Table 7 do not consider the impact of policies on population and GDP per capita – a detailed assessment of the macro-economic impacts is carried out in Section 4.2.

Figure 16. Global Mitigation scenario decomposition of World GHG emissions & deviation from Baseline



Source: JRC POLES model

[26] http://www.feem-project.net/limits/index.html

Table 7. Global Mitigation scenario decomposition of World GHG emissions

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
GHG ($GtCO_2e$)	43.4	48.4	45.7	39.8	29.7	15.8	138	154	127	95	50
Population (10^9)	6.9	7.7	8.1	8.4	9.0	9.6	130	145	158	170	180
GDP per capita (k$05)	10	13	15	17	21	26	145	187	247	312	380
GHG per capita (tCO_2e)	6.3	6.3	5.7	4.7	3.3	1.7	106	106	80	56	28
GHG / GDP (tCO_2e/M$)	634	492	385	281	155	64	73	57	32	18	7
Energy / GDP (toe/M$)	186	152	133	113	87	66	76	62	46	36	27
GHG / energy (tCO_2e/toe)	3.4	3.2	2.9	2.5	1.8	1.0	95	91	70	50	27

Note: includes GHG emissions from energy, industry and agriculture; does not include CO_2 *emissions from LULUCF;*
GDP in $05 PPP. Source: JRC POLES model

4.1.5 Emission reductions by gas

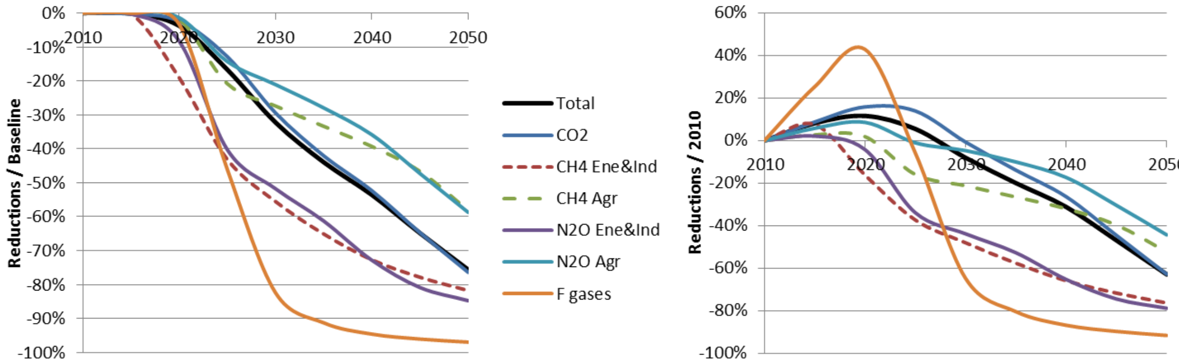
The relative shares of emission reductions delivered by addressing specific gases are influenced by the choice of the model. A robust finding remains: Global Mitigation scenarios require emissions reductions in all sectors, including agriculture, forestry and other land uses, international aviation and shipping and fluorinated gases, and very significant reductions in the levels of CO_2 emissions, compared to Baseline and compared to absolute 2010 emissions levels. By the 2nd half of the century, emissions from all sectors and sources have to come down sharply.

In POLES, the contributions to total reductions from the various gases present different time profiles as shown in Figure 17. The reductions of CO_2 emissions take place progressively over time (compared to Baseline: -30% in 2030, -50% in 2040, -75% in 2050), while emission reductions from agriculture[27] (both CH_4 and N_2O) are slower to implement (-60% in 2050 compared to Baseline).

The profile of F gases emissions is remarkable: it starts with a massive growth in use in industrial sectors to an almost phasing-out as soon as mitigation policies (and most notable the carbon value) are being implemented.

[27] Agricultural emissions come from the GLOBIOM model - see IIASA (2015). No shift in socio-economic storyline has been considered from the Baseline to the Global Mitigation scenario, meaning that agricultural commodities consumption (food diet) only evolves as a response to price changes induced by the carbon constraint in the sector - see Havlík P. et al. (2014).

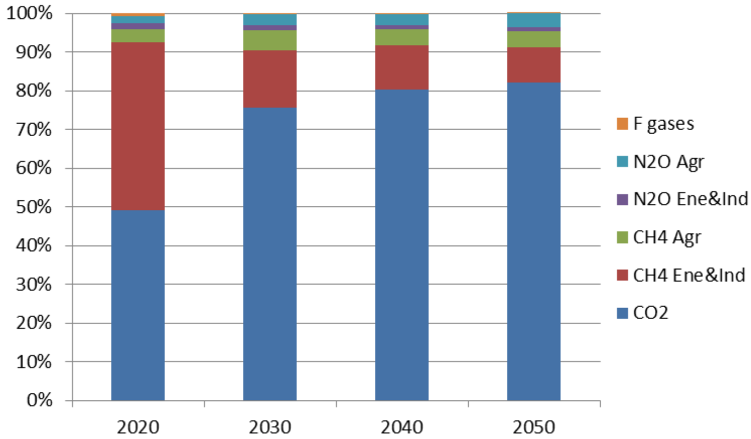
Figure 17. Emission reductions by GHG (left: compared to Baseline, right: to 2010)



Note: CO_2 does not include LULUCF emissions. Source: JRC POLES model

In terms of volume and contribution to total abatement, CO_2 bears most of the reductions throughout the whole period.

Figure 18. Contribution of individual gas to reductions



Note: CO_2 does not include LULUCF emissions. Source: JRC POLES model

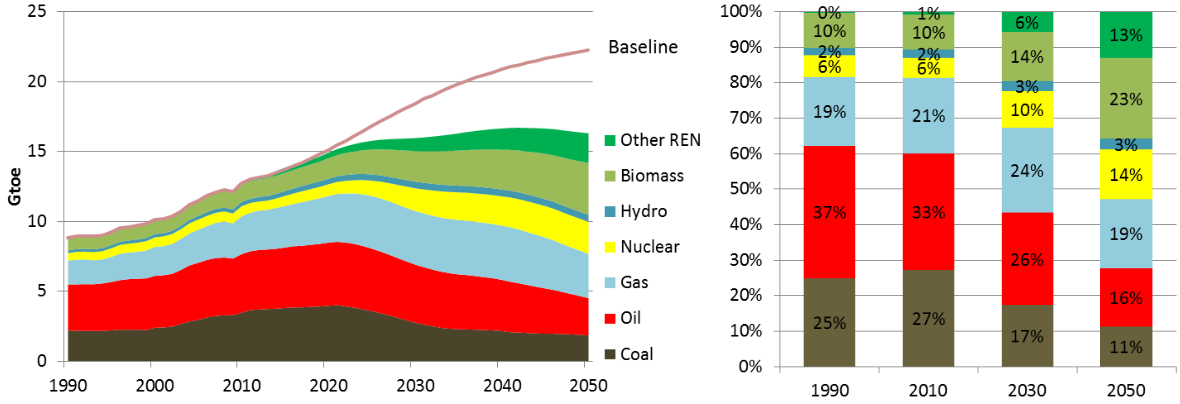
4.1.6 New energy balance

<u>World primary energy demand</u>

Total energy consumption[28] stabilises around 16-16.5 Gtoe from 2030 onwards (vs. 9 in Gtoe en 1990 and 13 Gtoe in 2010), while the share of carbon-free fuels shows a steep increase. In 2050 renewables reach 38% of primary energy and nuclear 14%. The share of gas increases by 2030 before decreasing afterwards (although in volume the consumption is higher than in 2000). The continuous decrease of oil consumption is demand-driven (this contrasts with the Baseline where decreased oil use is driven by supply scarcity). Finally, as expected since it is the most carbon-intensive fuel, the contribution of coal keeps decreasing, down to 10% of the energy mix in 2050, most of which being associated with CCS.

[28] Primary energy demand is calculated using the IEA conversion factors – see Annex 2

Figure 19. World primary energy demand, Global Mitigation scenario

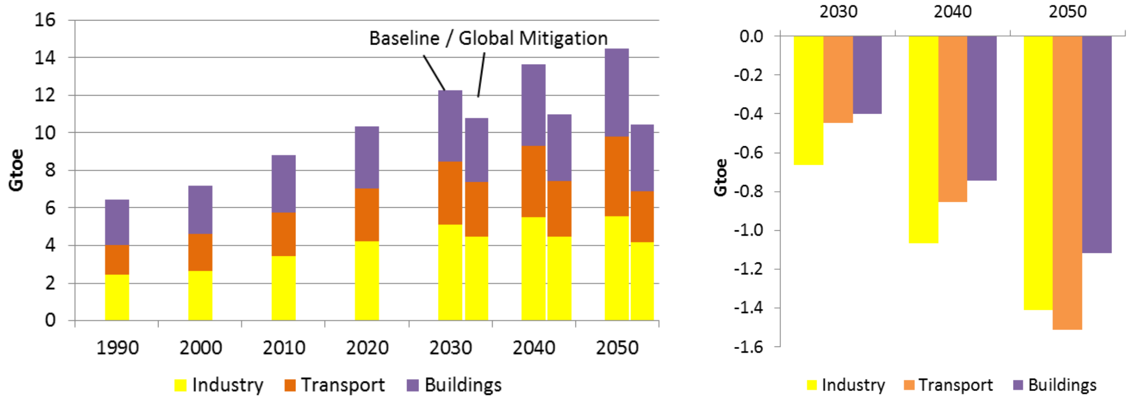


Source: JRC POLES model

<u>World final energy consumption</u>

While it keeps increasing in the Baseline, final energy demand slows down significantly from 2020 onwards in the Global Mitigation scenario, stabilising slightly above 10 Gtoe.

Figure 20. Final energy by sector (left), comparison between Baseline and Global Mitigation scenario (right)



Source: JRC POLES model

<u>Regional energy demand</u>

In OECD countries energy demand per capita keeps decreasing over time throughout the Global Mitigation scenario. In non-OECD countries, by contrast, it increases up to 2030 on average, before stabilising afterwards. In particular, India, rest of Asia and Latin America show an increase in energy demand per capita up to 2050. However, non-OECD regions with very low energy prices before the carbon value (mostly oil and gas exporters: CIS, Gulf) as well as low GDP per capita growth (Africa) see their energy per capita decrease compared to 2010.

Table 8. Energy demand per capita in the Global Mitigation scenario

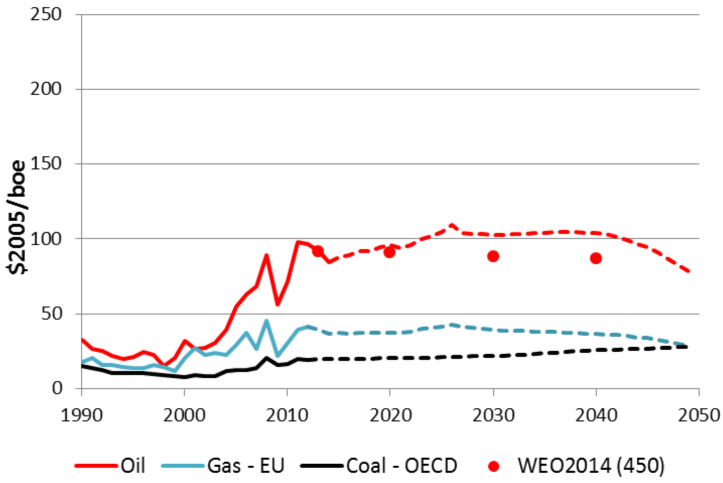
ktoe per capita	1990	2010	2030	2050	1990-2010	2010-30	2030-50
EU28	3.4	3.4	3.1	2.7	0.0%	-0.6%	-0.6%
USA	7.8	7.2	5.5	5.0	-0.4%	-1.3%	-0.5%
Canada	7.6	7.4	6.8	6.7	-0.2%	-0.4%	-0.1%
Japan	3.6	3.9	3.8	3.8	0.4%	-0.1%	0.0%
Other OECD	3.9	4.1	4.0	3.7	0.2%	-0.1%	-0.4%
Russia	5.9	4.9	4.8	4.1	-1.0%	-0.1%	-0.7%
Other CIS	5.0	3.7	3.6	3.3	-1.5%	-0.1%	-0.5%
China	0.7	1.8	2.7	2.8	4.4%	2.1%	0.3%
India	0.4	0.6	0.8	0.8	2.5%	1.6%	0.1%
Rest Asia	0.6	1.1	1.5	1.5	3.4%	1.6%	-0.1%
Mexico	1.4	1.5	1.9	2.1	0.5%	1.1%	0.6%
Brazil	0.9	1.4	1.8	2.2	2.2%	1.5%	1.0%
Rest Latin America	1.0	1.3	1.7	1.9	1.3%	1.3%	0.6%
Africa	0.6	0.6	0.6	0.5	0.5%	-0.2%	-0.5%
Middle-East	1.7	2.9	2.6	2.2	2.7%	-0.7%	-0.7%
OECD	**4.3**	**4.4**	**3.9**	**3.7**	**0.1%**	**-0.6%**	**-0.3%**
Non-OECD	**0.9**	**1.2**	**1.4**	**1.3**	**1.3%**	**0.8%**	**-0.4%**
World	**1.6**	**1.8**	**1.8**	**1.7**	**0.5%**	**0.1%**	**-0.5%**

Source: JRC POLES model

Impact on international energy prices

As shown above, the Global Mitigation scenario leads to lower consumption of fossil fuels. This reduced demand entails a decrease of international fuel prices (Figure 21). Both oil and gas prices are significantly reduced. In contrast, coal delivery prices are less affected because the carbon value introduced by the policy increases strongly its production and transport costs, compensating the reduction in mining costs due to lower demand.

Figure 21. Impact of the Global Mitigation scenario on international energy prices



Source: JRC POLES model

<u>Energy trade</u>

The GHG policy has first an impact on expensive production in importing countries, which thus reduce their output by 2030 in favour of maintaining some imports from large exporting regions. As a result, traded *volumes* remain fairly similar by 2030 across both scenarios, while the traded *value* is lower in the Global Mitigation scenario than in the Baseline because of lower prices.

In the Baseline, the future of energy markets will depend to a large extent on the relations between on the one hand Gulf and CIS countries (the major net exporters) and on the other hand Asia (where many countries, notably China, are large net importers). It thus assumes a long-term geopolitical stability, which is obviously not guaranteed. The regional trading situation evolves as follows:

- Europe remains a large importer of energy throughout the whole period, with a fairly consistent cost for European economies (2.5% of GDP);
- Asian countries, and most notably China, become very large importers, the cost increases compared to GDP (to a substantial 5-6% of GDP);
- North America presents first a positive balance in 2030 (in value), and then becomes a large exporter beyond 2030[29];
- Gulf and CIS remain the dominant suppliers, energy trade is a major source of income for these regions;
- Sub-Saharan Africa presents a positive balance throughout the period;
- Latin America becomes progressively a net importer of energy in volume, even though revenues from (oil) exports more than cover the (gas and coal) import costs.

In the Global Mitigation scenario this picture changes, especially after 2030. Volumes traded, especially between Asia and Gulf / CIS, remain important. However the associated financial flows represent a smaller share of the GDP than in the Baseline case. The regional evolution in this scenario is as follows:

- Europe and Asian countries see their imports in volume and monetary value decreasing substantially (divided by a factor of 2-4);
- North America presents a balanced energy trade;

[29] It must be mentioned that the new role of North America as a net exporter depends a lot on the development of non-conventional resources, for which environmental externalities are overlooked in this report beyond the required energy input and related GHG emissions.

– Sub-Saharan Africa and Latin America remain net exporters;
– Gulf and CIS are still the dominant suppliers, energy trade remains an important source of income for these regions.

Table 9. Regional energy trade (Mtoe), Baseline vs Global Mitigation scenario

***Mtoe* (>0: net imports)**		**Baseline**		**Global Mitigation**	
	2010	*2030*	*2050*	*2030*	*2050*
Europe	880	1020	1010	840	580
North America	390	-260	-1080	-210	-290
OECD-Pacific	450	300	150	300	240
China	340	1250	1530	990	570
India	180	540	750	470	410
Other Asia	90	110	830	-40	270
Latin America	-200	-80	220	-100	-80
Sub-Saharan Africa	-290	-320	-350	-230	-130
CIS	-670	-990	-1820	-870	-800
Middle East & North Africa	-1180	-2280	-2320	-1770	-1300

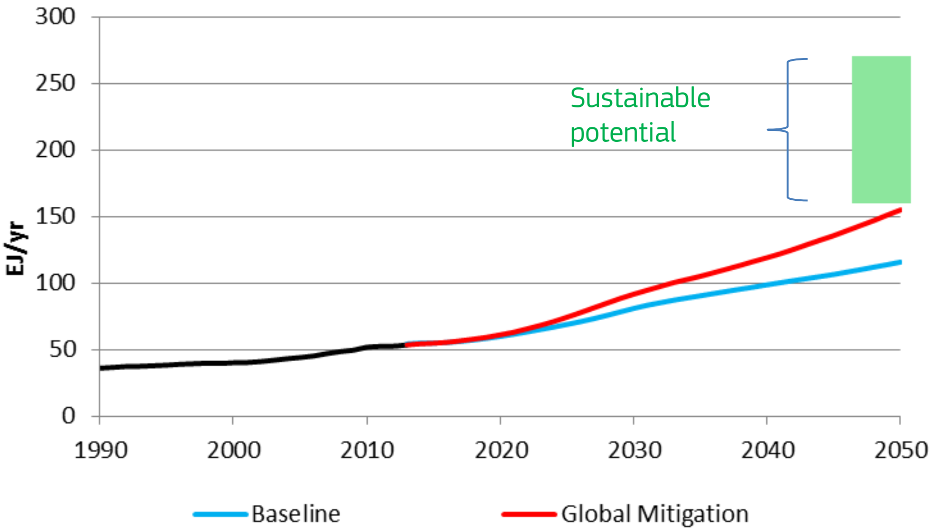
Note 1: includes oil, gas, coal, biomass trade – in 2010 oil represented most of the trade (75% in volume), ahead of gas (15%) and coal.
Note 2: Demand for international air and maritime bunkers are not reported in this table – they make the difference with total exports.

4.1.7 Future bioenergy demand

Current use of biomass in the energy sector represents about 50 EJ/yr, which develops by 2050 to more than double in the Baseline and triples to 150 EJ/yr in the Global Mitigation scenario, bioenergy being characterised as a way to reduce CO_2 emissions from the energy sector. This raises a number of questions on the impact the increasing use will have on land-related issues, most notably food production and environmental targets like biodiversity conservation or water cycles.

We compare in Figure 22 the evolution of the demand in the scenarios with results of Helmut et al. (2010) that reviewed various estimates of biomass and bio-energy potentials. Although studies provide a range of bio-energy potentials from 30 EJ/yr (below current levels) to 1000 EJ/yr, they consider that a range of 160-270 EJ/yr is compatible with sustainability criteria. This is consistent with the POLES potential for bioenergy of 240 EJ in 2050 and the use of bio-energy produced by the model by this time.

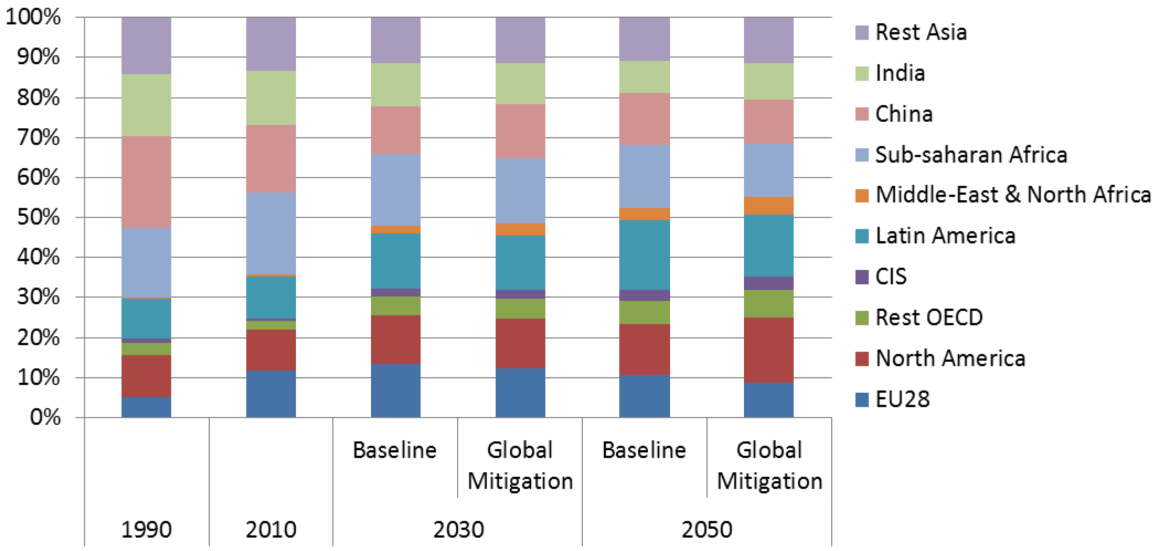
Figure 22. Biomass use in the energy sector, comparison with sustainable potential



Source: JRC POLES model, potential range is given by Helmut H. et al. (2010)

The following graph gives the regional distribution of biomass energy consumption. The shares of OECD regions and Latin America tend to increase over time, while Africa and India sees the role of traditional biomass much reduced and replaced by more efficient biomass use in the economy.

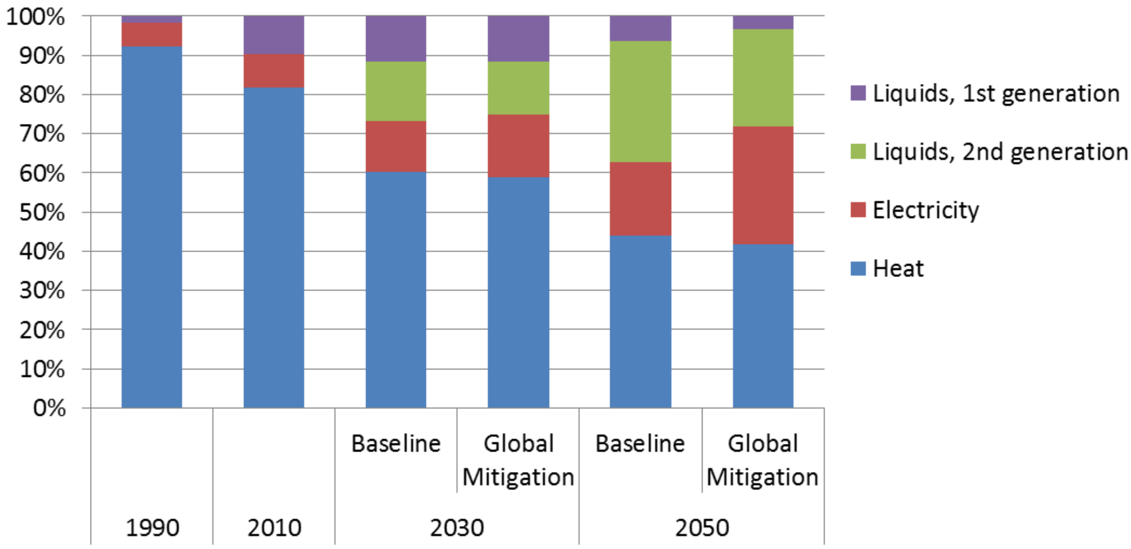
Figure 23. Primary biomass demand by region, share



Source: JRC POLES model

In terms of use, while most of the past consumption was going to heat needs, with some development of biofuels in the last 10 years, demand for power production and 2nd generation biofuels will be the key drivers of the future growth in both scenarios. One can notice that the share of 1st generation biofuel reduces significantly after 2030, most of the BTL being then produced in the form of 2nd generation, meaning that direct pressure from the energy sector on food commodities should reduce. While we acknowledge that the land allocation to food or energy biomass remains an open issue, Figure 22 showed that, by 2050, the level of bioenergy (mostly cellulosic resource) used remains within "sustainable" quantities, which should give room for both uses.

Figure 24. Primary biomass demand by use, share



Note: heat, electricity and 2nd generation biofuels all use cellulosic resource. 1St generation uses crops that can also be used for food purposes. Source: JRC POLES model

4.1.8 Key indicators

<u>Emission reduction rates</u>

Table 10 shows the projection of emission growth in the Global Mitigation scenario compared to the historical evolution since 1990. While OECD countries have been undergoing a stabilisation, most non-OECD countries have seen a fast increase of their emissions (the small 1990-2000 increase on average is heavily influenced by the sharp reduction in CIS). The average World 2010-2020 growth is half the 2000-2010 level: OECD decreases its emissions, while non-OECD reduces substantially the growth (it is more than halved for China and India). In the decade 2020-2030 most countries, except countries with capacity constraints (low HDI), have their emissions already declining. From 2030 onwards the yearly decline is steep, with both OECD ad non-OECD reaching respectively -6% and -7% in 2040-2050. These emission reduction rates are consistent with IPCC (2014)[30].

[30] See Figure TS.9 of the IPCC AR5, Working Group III, Technical Summary,(p55)

Table 10. Yearly GHG emission growth (%), Global Mitigation scenario

Region	1990-2000	2000-'10	2010-'20	2020-'30	2030-'40	2040-'50
EU28	-1	-1	-1	-3	-4	-7
USA	1	0	-1	-4	-3	-8
Canada	2	0	0	-3	-3	-9
Japan	1	-1	-1	-3	-4	-6
Other OECD	0	-1	-1	-2	-4	-7
Russia	-4	0	0	-4	-4	-7
Other CIS	-6	1	0	-2	-3	-5
China	3	7	3	-3	-4	-6
India	3	4	2	1	-1	-7
Indonesia	4	3	2	-1	-2	-9
Rest Asia	3	3	2	-1	-2	-7
Mexico	2	2	1	-1	-3	-6
Brazil	3	3	1	-2	-2	-7
Rest Latin America	2	2	1	-1	-2	-6
North Africa	2	4	2	0	-2	-4
Sub-Saharan Africa	2	2	3	0	-1	-8
South-Africa	1	2	-1	-2	-5	-6
Middle-East	5	5	1	-1	-2	-5
OECD	**1**	**0**	**-1**	**-3**	**-3**	**-7**
Non-OECD	**1**	**4**	**2**	**-2**	**-3**	**-6**
World	**1**	**2**	**1**	**-2**	**-3**	**-6**

Note 1: Excludes LULUCF emissions
Note 2: A higher decarbonisation rate does not necessarily imply a much higher reduction in volume: for instance while the average decarbonisation rate doubles from 2030-40 to 2040-50, yearly emission reductions (World level) increase only by 30 (from 850 MtCO2/year to 1150 MtCO2e/year).
Source: JRC POLES model

The deployment of low-carbon energies increases slowly by 2020 (World average stays flat because of the reducing share of (traditional) biomass in some capacity-constrained countries) before accelerating in the 2020-2030 transition from 24% to 38% at World level. By 2040 the share exceeds 50% in most regions, and reaches 70% on average by 2050, underlying a massive shift away from the fossil-based economic development of the 20th century. These findings are also consistent with IPCC[31].

[31] See Figure TS.10 of the IPCC AR5, Working Group III, Technical Summary (p56)

Table 11. Share of low-carbon energy in primary energy (%)

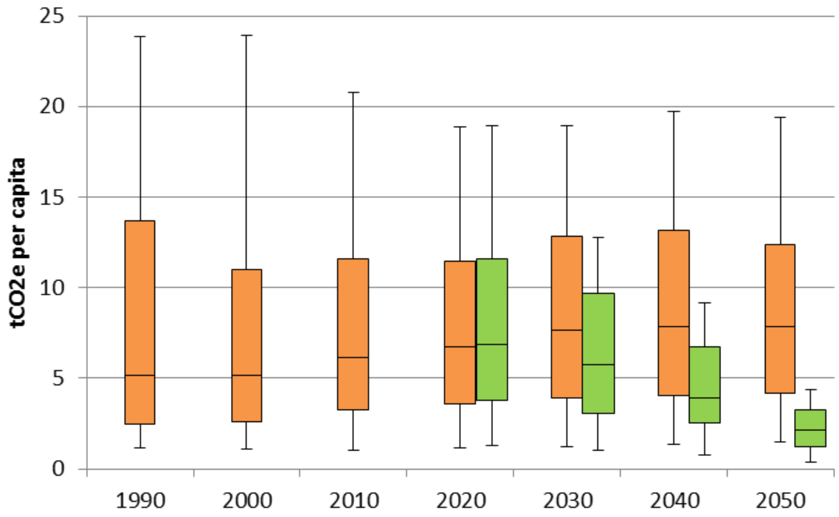
Region	1990	2000	2010	2020	2030	2040	2050
EU28	17	21	26	31	41	55	73
USA	14	14	17	21	38	55	73
Canada	25	23	26	31	48	63	81
Japan	16	20	19	21	34	52	65
Other OECD	21	23	27	32	42	55	72
Russia	6	8	9	10	26	44	60
Other CIS	5	10	10	14	27	44	64
China	24	19	12	15	36	59	74
India	46	35	27	28	32	46	69
Indonesia	45	36	32	31	41	54	71
Rest Asia	35	27	23	22	33	47	66
Mexico	13	13	11	15	27	48	64
Brazil	46	41	47	44	57	66	79
Rest Latin America	24	21	20	22	36	54	72
North Africa	4	4	4	5	16	39	58
Sub-Saharan Africa	81	81	79	71	67	67	77
South-Africa	12	12	10	14	31	54	65
Middle-East	1	0	1	2	13	32	51
OECD	**17**	**18**	**20**	**24**	**38**	**55**	**71**
Non-OECD	**21**	**22**	**19**	**20**	**35**	**53**	**70**
World	**19**	**20**	**19**	**21**	**36**	**53**	**70**

Note: low carbon energy includes renewables (hydro, biomass, wind, solar, geothermal, ocean), nuclear, fossil fuel with carbon capture and sequestration.*
**Biomass includes traditional biomass, which can be high in some regions like Asia or Sub-Saharan Africa.*
Source: JRC POLES model

<u>Per capita emissions</u>

While the Baseline case maintains large regional differences in emissions per capita throughout the entire period, the Global Mitigation scenario leads to greater convergence among countries. World average emissions reach 1.5 tCO_2e per capita (50th percentile is 2 tCO_2e per capita), slightly above the level of the least emitting regions in 2010.

Figure 25. Distribution of per capita GHG, Baseline (orange boxes) vs Global Mitigation (green boxes)



Note: The boxes indicate 20th, 50th and 80th percentiles. GHG emissions from energy, industry and agriculture considered (thus excluding LULUCF emissions and sinks). The dispersion is done on the basis of POLES countries and regions disaggregation, considering EU28 as a single entity and EFTA as a single entity (Table 43). Source: JRC POLES model

The very low levels of emissions per capita in 2050 are reached through an increased use of CO_2-free technologies, most notably renewables, and the radical drop of non-CO_2 GHG emissions in most sectors.

Table 12. Per capita GHG emissions in the Global Mitigation scenario (tCO_2e)

Region	1990	2000	2010	2020	2030	2040	2050
EU28	11.5	10.3	9.3	7.9	6.0	4.2	2.1
USA	23.9	23.8	20.7	17.0	11.0	7.4	3.1
Canada	20.8	22.7	20.2	17.6	12.6	9.0	3.5
Japan	9.8	10.4	9.7	9.3	7.3	5.0	2.9
Other OECD	7.9	9.9	10.5	9.9	7.9	5.4	2.8
Russia	22.5	14.8	15.8	15.9	11.4	7.7	3.9
Other CIS	15.3	7.8	8.8	8.2	6.9	5.2	3.0
China	3.4	4.1	7.8	10.0	7.5	4.9	2.9
India	1.5	1.7	2.2	2.4	2.3	1.9	0.9
Indonesia	2.0	2.5	3.0	3.4	2.8	2.2	0.8
Rest Asia	2.2	2.4	2.9	3.1	2.5	1.9	0.9
Mexico	5.4	5.5	6.2	6.0	5.2	3.7	2.0
Brazil	3.9	4.6	5.4	5.7	4.4	3.6	1.8
Rest Latin America	4.3	4.4	4.8	4.9	4.2	3.1	1.5
North Africa	2.9	3.0	3.8	4.0	3.6	2.7	1.6
Sub-Saharan Africa	1.1	1.1	1.1	1.1	0.8	0.6	0.2
South-Africa	9.8	9.1	9.6	8.4	6.6	4.0	2.0
Middle-East	6.4	7.9	10.0	9.4	7.3	5.2	2.9
OECD	**13.6**	**13.7**	**12.5**	**10.8**	**7.8**	**5.4**	**2.6**
Non-OECD	**3.8**	**3.5**	**4.7**	**5.1**	**3.9**	**2.6**	**1.3**
World	**5.8**	**5.4**	**6.1**	**6.1**	**4.5**	**3.1**	**1.5**

Note: GHGs from energy, industry and agriculture (excludes LULUCF emissions and sinks)
Source: JRC POLES model

Emission intensity of GDP

In 2010 the emission intensity of GDP appears much contrasted across countries, with coal-intensive countries and oil & gas exporters displaying the highest ratio.
The Global Mitigation scenario reduces the emission intensity in all countries, again leading to a much more balanced situation across regions by 2050.

Figure 26. Emission intensity of GDP, Global Mitigation scenario

Note: GHG from energy, industry and agriculture; GDP in $05 PPP
Source: JRC POLES model

Table 13. Emission intensity of GDP, Global Mitigation scenario (tCO_2e/M$05)

Region	1990	2000	2010	2020	2025	2030	2040	2050
EU28	567	420	336	250	208	165	98	43
USA	739	598	485	338	257	193	115	42
Canada	767	697	572	447	351	280	174	57
Japan	364	358	312	268	230	183	108	55
Other OECD	692	637	524	386	303	233	134	60
Russia	1779	1726	1126	836	619	431	236	112
Other CIS	2518	2338	1402	877	669	466	241	101
China	2839	1464	1129	751	536	336	153	69
India	1207	974	705	467	352	261	133	42
Indonesia	984	928	776	542	392	294	161	44
Rest Asia	951	787	662	526	408	299	161	55
Mexico	541	469	497	378	309	250	139	57
Brazil	543	576	537	466	349	275	173	68
Rest Latin America	785	658	543	426	347	273	157	60
North Africa	671	638	598	503	406	299	152	68
Sub-Saharan Africa	1020	973	703	518	368	281	139	34
South-Africa	1288	1215	1037	711	536	360	158	67
Middle-East	717	790	801	656	530	397	231	112
OECD	**605**	**496**	**411**	**305**	**243**	**189**	**112**	**46**
Non-OECD	**1361**	**1054**	**867**	**629**	**467**	**321**	**161**	**62**
World	**848**	**685**	**615**	**475**	**370**	**268**	**143**	**57**

Note: GHG from energy, industry and agriculture; GDP in $05 PPP
Source: JRC POLES model

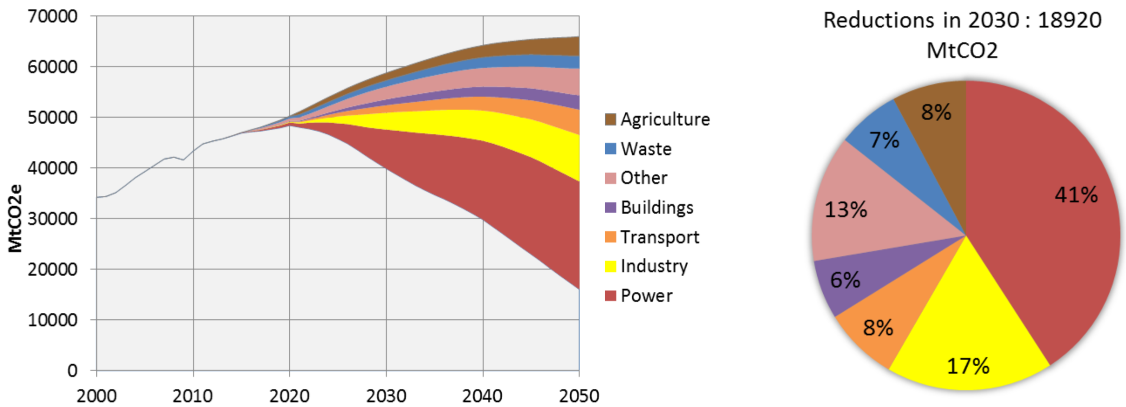
4.1.9 Sectoral policies to deliver changes for the Global Mitigation scenario

<u>Mitigation options delivering the emission reductions</u>

Figure 27 and Figure 28 give the contribution to emission reductions at World level by economic sector and technological option respectively.

The power sector is the largest contributor in the whole period, representing 43% of the effort in 2030, ahead of industry with 17% and energy production and transformation ("Other") with 13%. Transport and buildings have a "direct" smaller contribution (both 6% in 2030), smaller than waste management and agriculture both at 7-8%; however transformation of the transport and buildings sector to a low-emission economy is a major driver of the transformation of the power sector.

Figure 27. Sectoral emission mitigation: World (excl. LULUCF)



Source: JRC POLES model

In terms of technological options, energy demand reduction plays a key role in GHG reductions by 2030 (23%, playing a role in all economic sectors), ahead of renewables (biomass 7% and other renewables 12%) and nuclear & fossil fuel switching (mostly in power production). Non-CO_2 reductions represent 31% of total reductions in 2030, including CH_4 and N_2O emissions from agriculture (8%) and from waste (7%). CCS[32] is still a modest contributor in 2030 (7%), but becomes very important afterwards (in 2050 it represents 23% of total reductions).

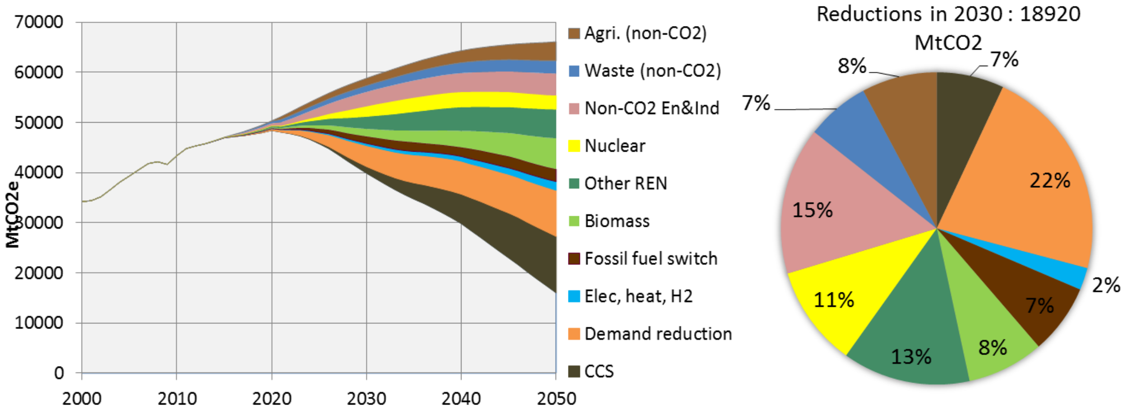
The results are modelling outputs, which depend on the estimates of current and future technology costs[33] and on whether the development of technologies are politically acceptable in the different countries. As a consequence they give an indication on the possible developments of the future energy mix under specific constraints, and should not be taken as policy prescribing. This point is particularly true for nuclear, for which safety concerns and delays in construction time of some current projects make the cost ranging fairly widely[34] and the future contribution of this technology remaining uncertain – this report actually includes a sensitivity scenario on nuclear availability in the case of Japan (see 5.8).

[32] CCS develops in the power sector, industry, and energy transformation sectors (BTL, CTL, GTL, H2 production)

[33] For instance the REmap2030 (IRENA, 2014) gives some uncertainty range of future costs of a number of technologies depending on the country and the investor perspective: see Figure 3.8 p29, and Table 3.3 p28.

[34] For instance the World Nuclear Association (2015) has done a data collection of overnight investment costs ranging from less than 2000 $2013/kW to more than 7000 $2013/kW. The cost used in POLES appears slightly in the upper part of this range: it evolves from 5500 $2013/kW in 2010 to 4500 $2013/kW in 2050.

Figure 28. Emission mitigation options: World (excl. LULUCF)



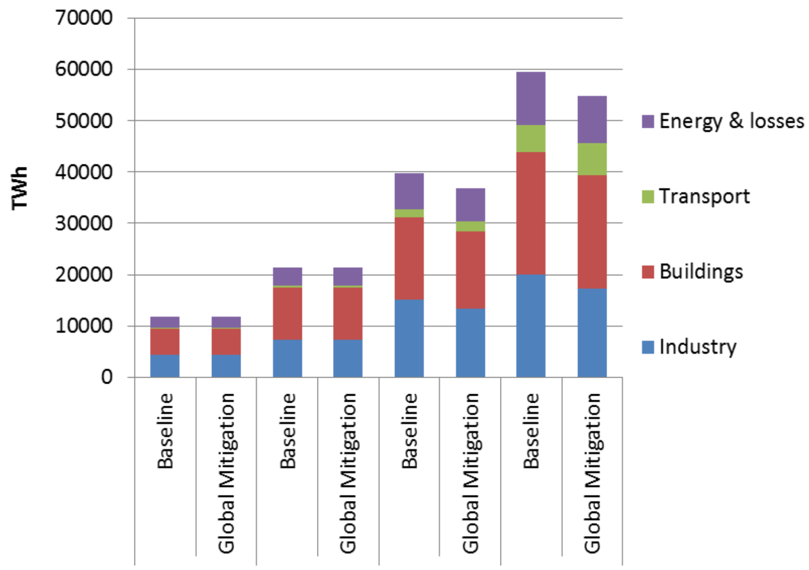
Source: JRC POLES model

4.1.10 Mitigation in the power sector

Figure 29 gives the evolution of World electricity demand, which increases by 10 000 TWh every ten years, from 20 000 TWh in 2010 to 60 000 TWh in 2050: this represents 33% of the final energy demand in the Baseline, vs. 13% in 1990 and 18% in 2010. All final demand sectors see an increase in electricity demand, which is multiplied by about 2.5 in both industry and buildings and by 20 in transport with the development of electrical vehicles.

Electricity demand is slightly lower in the Global Mitigation scenario, but represents a greater share of total final energy demand (40%). The carbon policy implies a lower use of electricity in the industry due to higher electricity prices, which is partially compensated by an increase in the (road) transport sector where electrical vehicles develop faster than in the Baseline case.

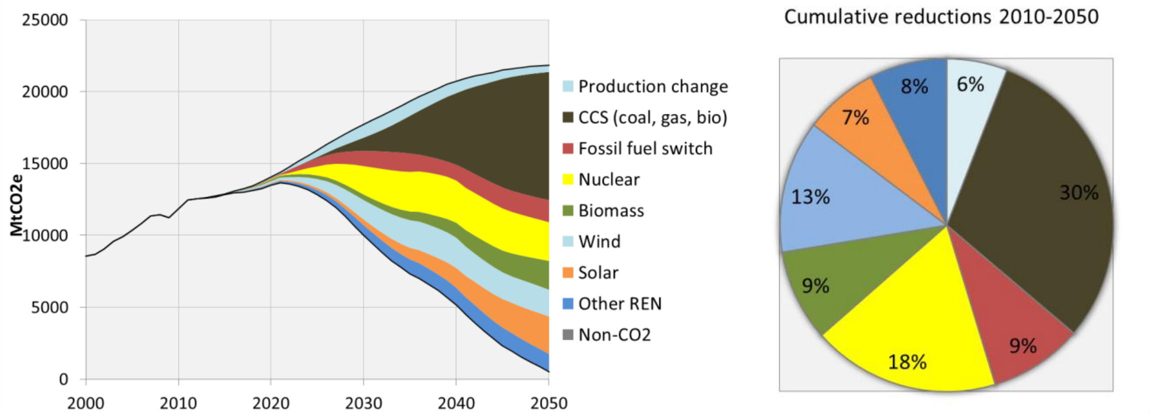
Figure 29. Electricity demand, 1990-2050



Source: JRC POLES model

By 2050 the various mitigation options play a balanced role: reduction of demand represents 6% of the cumulated reductions, fossil fuel switch 9% (usually from coal to gas), nuclear 18%, renewables 36% (biomass 9%, wind 13%, solar 7% and others 8%). CCS is the largest contributor with 30% of total cumulated CO_2 reductions: it includes CCS used with coal, gas and biomass power plants.

Figure 30. Emissions mitigation options in power: World



Source: JRC POLES model

Table 14. Share of renewables in gross final demand (%), 2030

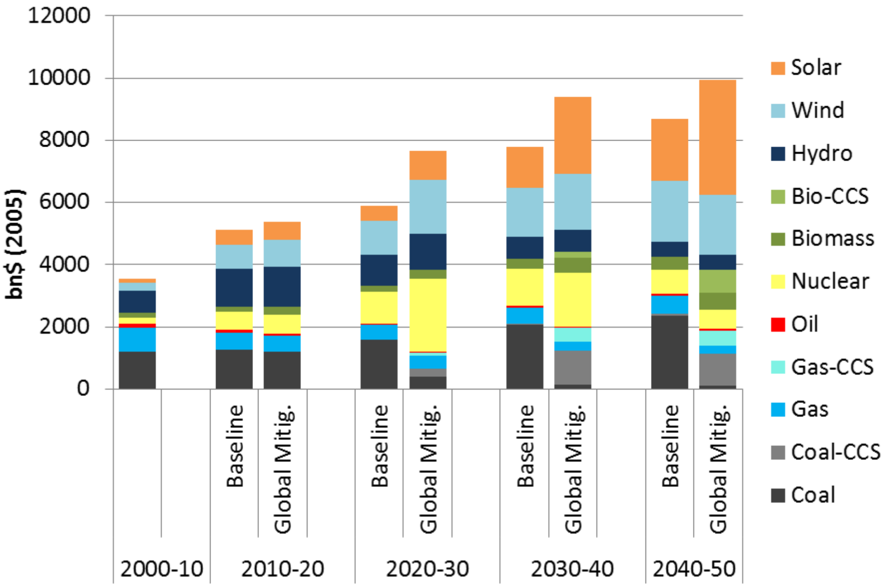
Region	Total	Biomass	Hydro	Wind	Solar	Others
EU28	26	15	3	5	3	1
USA	25	13	2	6	3	0
Canada	43	16	20	6	1	0
Japan	19	9	3	4	3	0
Other OECD	28	11	9	5	2	0
Russia	11	5	5	1	0	0
Other CIS	11	6	3	1	0	0
China	25	9	6	7	3	0
India	36	25	3	5	3	0
Indonesia	37	31	1	1	2	3
Rest Asia	28	22	2	2	1	1
Mexico	24	12	2	5	4	1
Brazil	53	29	18	4	2	0
Rest Latin America	37	21	12	3	1	0
North Africa	16	7	1	4	3	0
Sub-Saharan Africa	69	64	2	1	1	0
South-Africa	28	19	1	4	4	0
Middle-East	12	8	1	1	2	0
OECD	**26**	**13**	**4**	**5**	**3**	**1**
Non-OECD	**30**	**18**	**5**	**4**	**2**	**0**
World	**28**	**16**	**5**	**5**	**2**	**0**

Source: JRC POLES model

Moreover the regions diversify their energy mix to low-emission sources as a growing diversity of renewable energy sources for power production gets exploited in the different regions according to the domestic potential and the market conditions[35] (see Table 14).

The investment pattern in power production is substantially modified by the introduction of ambitious GHG mitigation policies. First of all, it is interesting to notice that investment increases even though demand is lower: the new power mix is more capital-intensive and consumes less (usually fossil-based) fuels. Second, we can observe a clear shift towards nuclear, biomass, wind and especially solar capacities to the detriment of carbon-intensive coal (despite the higher investment cost of coal-CCS compared to coal without CCS). Investments in gas and large hydro also benefit although to a lower extent. The time profile of the additional investments is different across technologies: most investment for nuclear and wind takes place in 2020-2040, while for solar and biomass most occurs in 2030-2050. Most new investments in gas and coal from 2030 onwards have CCS (Figure 31 and Figure 32).

Figure 31. World investment in power (cumulative per decade)



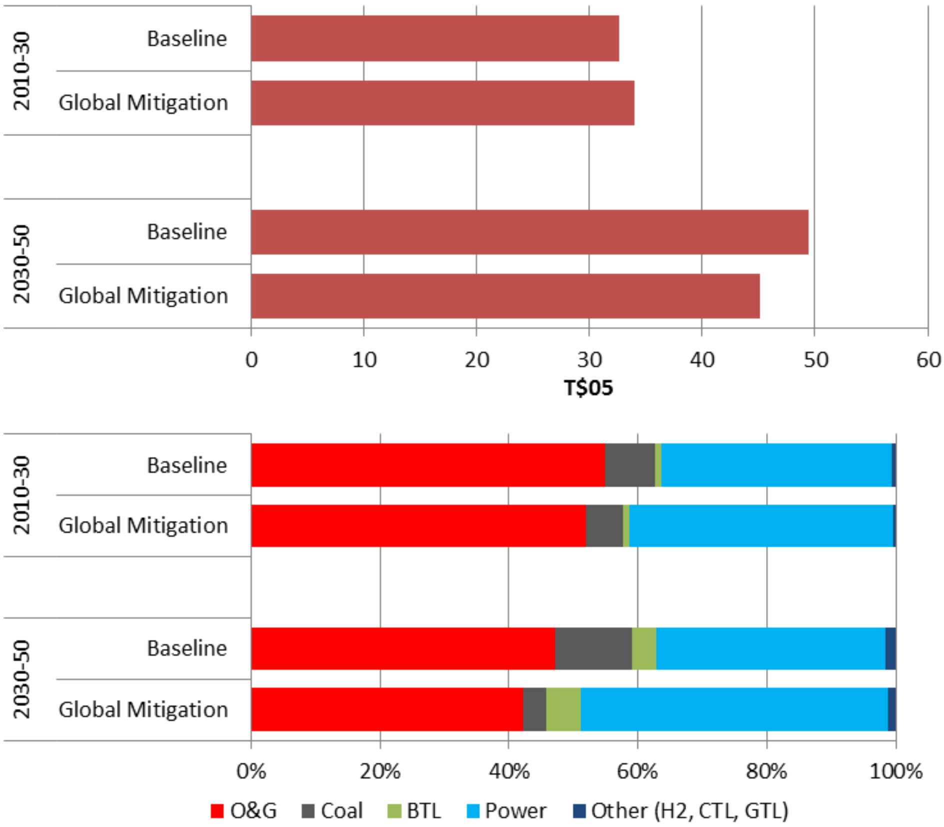
Source: JRC POLES model

4.1.11 Investment needs in energy supply and transformation

The investment required in the energy suply and transformation (power, hydrogen, biofuels) exceed 30 T$ by 2030 and 45 T$ in 2030-2050. Total investment costs are 5% higher over 2010-2030 in the Global Mitigation scenario compared to the Baseline case, but 8% lower over 2030-2050: this reflects first the transition towards a carbon–free power system, which is more capital-intensive, which is later compensated by a reduced energy demand that lowers the total investment needs in supply and transformation.

[35] The evolution of the role of renewable energy sources in the Global Mitigation scenario across major economies is of the same nature as in IRENA,2014a where energy access is secured for all.

Figure 32. World investment in energy supply and transformation



Source: JRC POLES model

In addition, the Figure 32 shows clearly the shift in investment from fossil fuels, that represent more than 60% of the total in the Baseline case, towards power production and biofuels in the Global Mitigation scenario.

4.2 Macro-economic impacts

This section quantifies the economy-wide impacts of the Global Mitigation scenario. The economy-wide impacts are twofold. Firstly, there are direct costs of mitigation due to regional emission constraints and the reallocation of resources for the mitigation effort. Secondly, there are indirect costs or benefits from changes in competitiveness, production patterns, investment and relative prices of energy, labour and capital. It is seen that carbon-intensive sectors need to adjust their investments in order to reduce their emissions, and sectors with a lower emission-intensity are affected according to their integration with these emitting sectors.

The co-benefits of mitigation policies in terms of reduced air pollution, improved health, development, innovation, energy security and productivity are not described here, although other studies have indicated that these benefits can be expected. Moreover, the costs of mitigation have not, in this analysis, been balanced by the benefits of avoided climate change. Recent reports for the cost of climate change in Europe (e.g. PESETA II project, see Ciscar et al., 2014) indicate that incurring the costs of mitigation in the first decades of the 21st century may lead to the avoidance of more significant costs by the end of the century.

In this section, the macro-economic effect of a Global Mitigation scenario is analysed using GEM-E3[36], a general equilibrium modelling framework. Using GEM-E3 allows us to capture the following essential features of a global mitigation effort in a macro-economic context.

Firstly, mitigation efforts entail a reallocation of employment and investment across sectors and the requirement to introduce more environmental friendly production technologies. In order to understand the economic-wide effects it is necessary to combine the consumption choices of households, the input decisions of firms, the inter-industry feedbacks and the effects of government policy instruments in a consistent manner. In particular, the feedback of the energy system on the rest of the economy will be essential in the climate change policy arena. Secondly, emission reduction policies may affect the relative competitiveness of different regions and industries. For that reason it is fundamental to consider the impact on global trade flows as well.

However, it should be noted that the macro-economic analysis in this section does not cover the co-benefits of climate mitigation policies. Such benefits could include improvements in human health via air quality improvement, as well as the potential benefits from reductions in the impact of climate change itself (e.g. JRC PESETA II project, see Ciscar et al., 2014). Moreover, the analysis does not include any endogenous technical progress that is induced by the mitigation policies beyond the technical progress that is assumed in the Baseline. Hence, the costs of the policy may be overestimated.

The remainder of this chapter is organised as follows. Section 4.2.1 studies the economic implications of the Global Mitigation scenario introduced in section 4.1. Here, countries implement national policies from the year 2020 onwards according to their nationally determined contributions to the new agreement aiming to stay below 2°C. To ensure consistency in our analysis, a link has been established between the POLES model and the GEM-E3 model. E.g. for the non-EU regions and countries, the GEM-E3 model uses the power technologies mix of the POLES model for the baseline and the 2°C-consistent scenario. For the EU, the power mix and the overall emission reductions are consistent with the PRIMES model as described in the "2030 Framework for Climate and Energy Policies[37]". Section 4.2.2 highlights the different economic and societal impacts of using alternative mechanisms to recycle the revenue of auctioning emission permits.

[36] www.gem-e3.net
[37] http://ec.europa.eu/clima/policies/2030/index_en.htm

4.2.1 Macro-economic impacts of the Global Mitigation scenario

The Global Mitigation scenario secures a likely chance of staying below 2°C, while maintaining economic growth at rates comparable to the Baseline, including higher rates of growth in low income regions and fast-growing emerging economies.

The impact of mitigation action translates mainly into a modest fall in consumption, with a smaller reduction in investment. However, some countries and sectors are able to improve their net trade position as the shift to a low emission economy improves their competitiveness or results in a higher decrease of imports than that of exports.

The Global Mitigation scenario analysed in this section involves a global reduction of greenhouse gas emissions according to the path described in section 4.1 (emissions from LULUCF are not considered). This path specifies lower emissions for all regions compared to the Baseline scenario. Global GHG emissions are 32% lower than the Baseline in the year 2030 (excluding LULUCF). The emission reduction targets and corresponding power mix from POLES are imposed for all GEM-E3 regions, so as to guarantee high consistency between the two models.

The Global Mitigation scenario is implemented via an allocation that matches the permit demand of all emitting sectors in all regions. Therefore, emissions reductions are allocated between sectors in the way that is most cost effective for the region as a whole. An alternative allocation scheme (auctioning) is presented in Section 4.2.2[38] together with different revenue recycling options. There are no permit markets linking different regions.

The Global Mitigation scenario requires significant emission reduction efforts from some high-income regions. By 2030, the European Union, the United States, Canada and Japan reduce their GHG emissions by 30% or more relative to 2005. On the other hand, the policies implemented leave room for a substantial increase of emissions compared to 2005 levels in many fast-growing regions, such as India, China and Sub-Saharan Africa. These countries are located to the right of the vertical axis in Figure 33. The respective differentiation in the emission reduction efforts highlights the different reduction capacities of the regions as well as the results from the optimization of the POLES model.

It should be noted that shifts in economic activity due to mitigation may result in different levels of tax revenue. In order to isolate the economic effects of the climate policy and avoid a worsening/improvement of public finances due to the climate policy, the public deficit/surplus as a share of GDP is fixed to the Baseline level, with the level of lump sum funds transferred between government and households adjusting to meet this condition. Moreover, in all scenarios the public consumption is fixed to Baseline levels. Other instruments for closing the public budget are considered in 4.2.2.

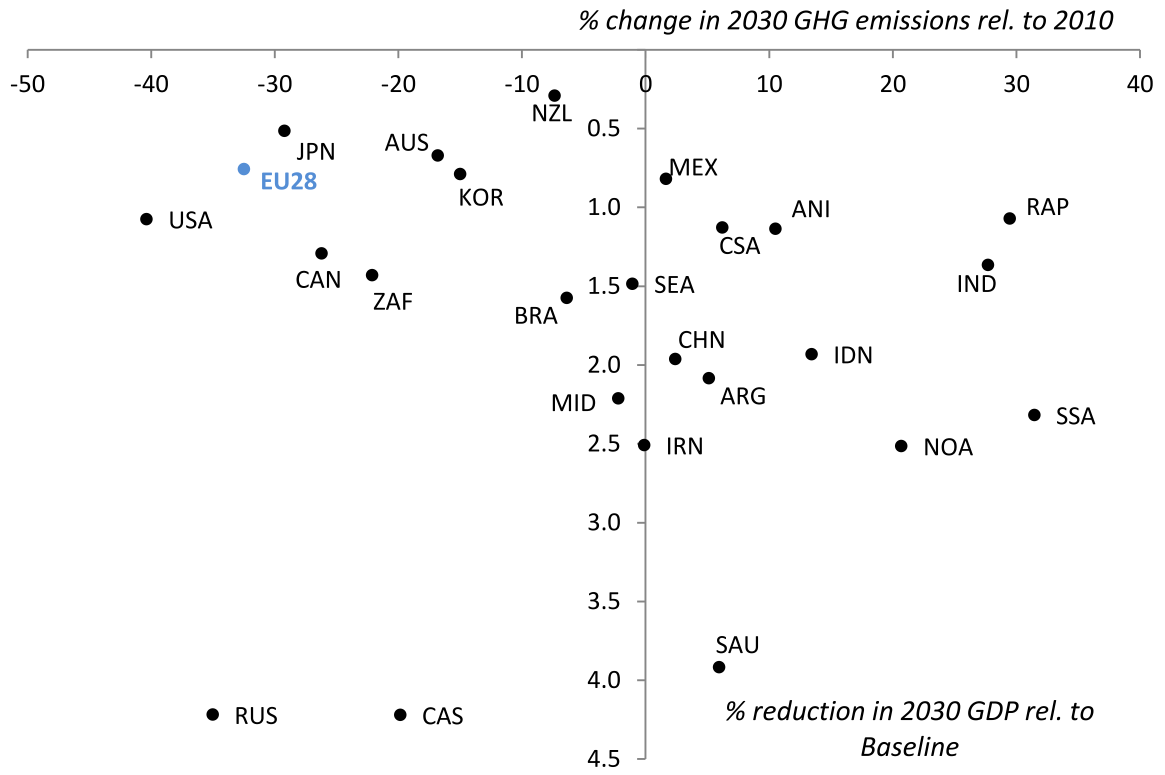
The **GDP impact** of the Global Mitigation scenario in the year 2030 is illustrated in Figure 33. On the horizontal axis, the percentage change in greenhouse gas emissions relative to 2010 is displayed, while the vertical axis represents the reduction in GDP compared to the GEM-E3 Baseline for 2030.

Due to reallocation of resources created by a global mitigation effort, negative impacts on GDP are seen for all regions (all countries lie below the horizontal axis in Figure 33). This is due to the fact that in a CGE framework the Baseline allocation of resources is seen as optimal, and any additional constraint will be suboptimal (as the analysis does not take account of the eventual avoided damage costs from pollution and climate change, or other positive feedback effects). The decarbonisation of the economy requires a shift of industries to alternative, cleaner inputs and a switch of households to different consumption patterns that would not occur without policy. In the

[38] Other allocation schemes have also been examined with the GEM-E3 model in EC (2013b). In particular, auctioning of permits for selected sectors (similar to the current EU-ETS operation).

GEM-E3 model this shift occurs endogenously in three ways, each of which imposes a cost on the economy. Firstly firms substitute away from carbon-intensive inputs in their production processes either by using cleaner energy sources or more capital, labour or intermediate goods. Secondly, specific abatement technologies are taken up as part of the production process, since embodied GHGs become more expensive. Thirdly, there can be a reduction in overall levels of production. Note that this analysis does not consider additional dynamic learning effects and positive technological changes that could result from more ambitious mitigation policy, and thus total mitigation costs may be overestimated.

Figure 33: GDP impact in 2030 of the Global Mitigation scenario



Note: This representation is sensitive to the assumptions about the inclusion of current or planned policies in the Baseline scenario. For instance, in the EU, a large number of policies are included in the Baseline thus leading already to emission reductions from 2010 levels and hence to lower efforts and costs for further reductions in the policy scenario. For other countries for which we had less precise information on the current policies or have not yet determined any particular future low-carbon policies, the Baseline does not assume any climate action and thus costs of a mitigation scenario seem higher.
The explanation of the abbreviations of the regions' names can be found in Table 44.
Source: JRC GEM-E3 model

Regions whose economy mainly relies on exports of fossil fuels may face a fall in GDP that is more than proportional to the level of their emission reduction targets. This is mainly due to that fact that the global mitigation effort leads to a reduction of fossil fuel consumption along with a decrease in fossil fuel prices due to lower demand, hence, reducing export revenues of fossil fuel producing countries. However, the negative GDP impact in these countries could be overstated since the scenario of Global Mitigation does not take into account the "economic diversification strategies" that are already pursued by some countries, or could be pursued in a world that agrees on adequate measures of climate change mitigation. Similarly, countries like Japan and EU that have already undertaken important efforts to decarbonise and make their economies more efficient see relatively limited impacts compared to their respective emission reduction efforts.

Table 15: Yearly growth rates of GDP in the Baseline and Global Mitigation scenarios

Region		Yearly growth rates of GDP (2020-2030)	
		Baseline	***Scenario***
World		**3.00**	**2.87**
European Union	EU28	2.01	1.93
USA	USA	2.01	1.90
Russia	RUS	2.79	2.34
Canada	CAN	2.12	1.98
Japan	JPN	1.01	0.96
Australia	AUS	2.96	2.90
China	CHN	5.02	4.81
India	IND	6.45	6.30
Indonesia	IDN	5.17	4.96
Brazil	BRA	3.34	3.17
Republic of Korea	KOR	3.16	3.07
Rest of Europe	ANI	3.00	2.88
Mexico	MEX	3.57	3.49
Argentina	ARG	2.96	2.75
North Africa	NOA	5.46	5.19
New Zealand	NZL	2.32	2.29
Saudi Arabia	SAU	3.53	3.12
Iran	IRN	5.22	4.95
South Africa	ZAF	4.96	4.81
Rest of Middle East	MID	3.18	2.95
Sub-Sahara Africa	SSA	6.31	6.07
Rest of Central and South America	CSA	3.75	3.63
Central Asia and Caucasus	CAS	4.51	4.06
South-East Asia	SEA	3.42	3.27
Rest of Asia and Pacific	RAP	6.62	6.51

Source: JRC GEM-E3 model

To put these results into perspective, it is useful to compare the **yearly growth rates of GDP** under the Global Mitigation scenario against those of Baseline (see Table 15). The first line of the table indicates that the global annual growth rate would fall slightly from 3% to 2.87%. As in Figure 33, the slight reduction in growth rates occurs in all regions. However, high rates of economic growth are maintained for emerging and lowest-income economies. For instance, the yearly growth rate in China only reduces slightly from 5.02% to 4.81% per year. Likewise, Indian growth of GDP remains high at 6.30% yearly, which is marginally lower than 6.45% per year according to the Baseline assumptions. Therefore, the GHG reduction policies would not prevent lower income countries from growing at a noticeably faster rate compared to the highest income economies. It is worth noting that the effect of the Global Mitigation scenario on global economic growth (in the order of 0.05%-0.3%) is much smaller in magnitude than the slowdown observed over the last seven years due to the global financial crisis.

Figure 34 provides further insight into the results of Table 15 by decomposing the impact on GDP into three components: changes in net exports (exports minus imports), private consumption of households and investment (public consumption is kept constant across the scenarios). This bar chart therefore draws a clear picture of what drives the changes in GDP between the scenario and the Baseline. For each region, the bars sum to 100%, such that the decomposition presents the shares of the total GDP change for each of the three categories.

Figure 34 shows that both consumption and investment fall in all regions[39]. The changes in the production processes that are required to decouple production from GHG emissions raise the cost of consumption goods. As a result, the level of **consumption** falls. In addition, lower levels of production require less capital input for the overall economy despite the increase in capital demand due to the transformation of the power sector. Consequently, **investment** demand is reduced in all regions.

The extent to which changes in consumption and investment demand contribute to the GDP reduction differs by region. In Canada for instance, a relatively large share of the GDP decrease originates from a drop in investment, while in Sub-Saharan Africa the decrease in GDP is almost entirely driven by lower private consumption. Factors explaining these differences include the initial share of each component in the GDP of each region, the capital intensity of the economy as a whole, the capital intensity of the industries that are most affected by climate policies, and the extent of substitution possibilities between capital, labour, energy and other material inputs. Countries with a greater share of capital-intensive industries and lower substitution possibilities see a greater share of investment in the overall GDP effect. On the other hand, output reductions in a labour intensive sector are more likely to affect consumption, as decreased employment levels and reduced wages lead to lower incomes. It is seen that there is an overall reduction in capital and labour demand due to reduced production levels, which leads to lower levels of factor prices (capital and labour), despite the substitution that takes place in order to reduce the role of emission-related inputs in the production process goods.

Figure 34 also shows that the effect of the Global Mitigation scenario on **net exports** (exports minus imports) varies across regions, indicating that the scenario causes changes in relative competitiveness. About half of the regions experience a decrease in net exports, while the others improve their net trade balance (indicated by negative values in Figure 34). Various mechanisms explain this variation.

Firstly, changes in regional competitiveness could be due to the different levels of national mitigation in the Global Mitigation scenario. For instance, the modest emissions restriction for the Rest of Asia and Pacific leads to relatively small increases in production costs compared to other regions. As a result, the Rest of Asia and Pacific improves its competitive position and exports larger volumes than in the Baseline. In particular, the increase in exports is strongest for agricultural and consumer goods, two important sectors for the region.

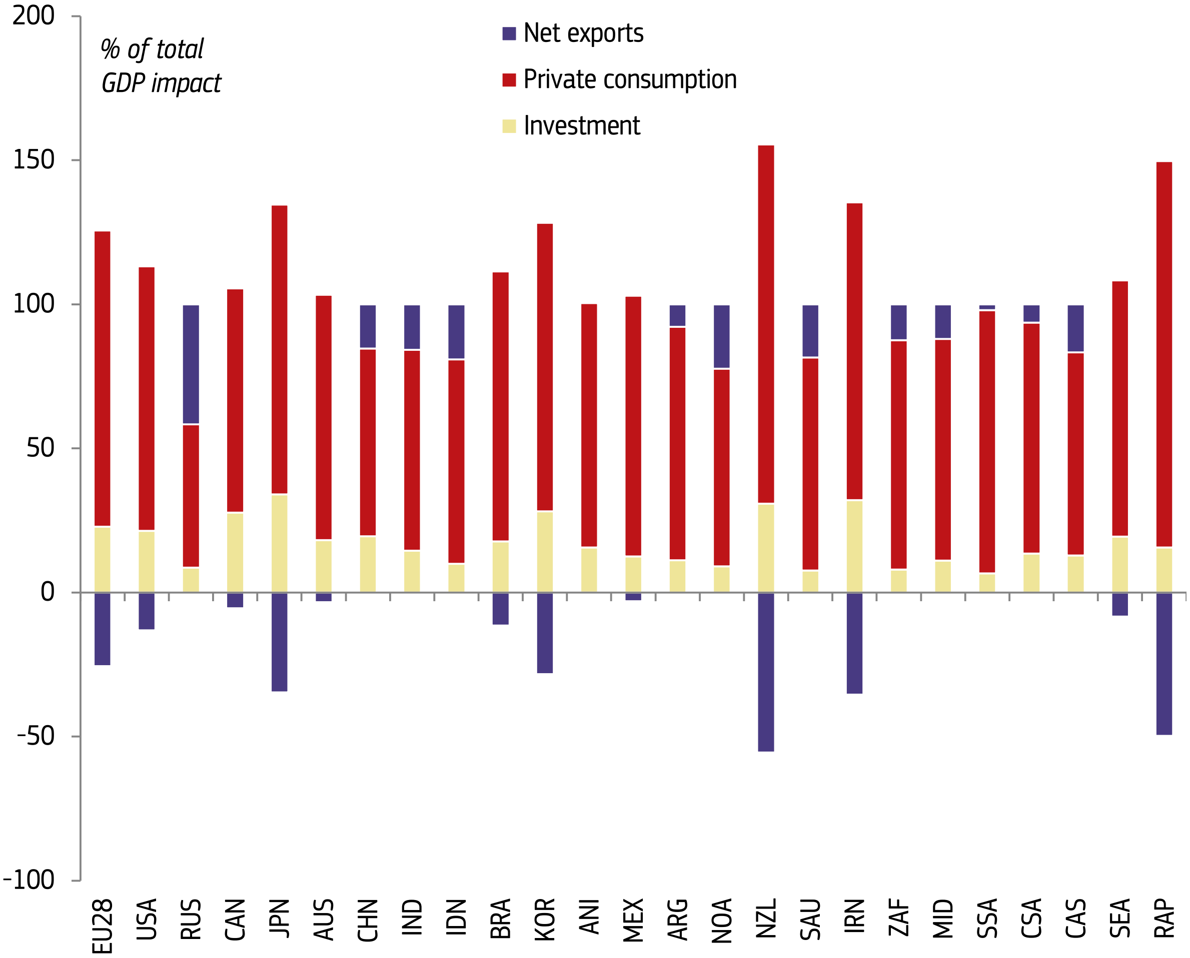
Secondly, sector specific abatement potentials can drive changes in competitiveness and **net trade** across the whole economy. Brazil is a good example of this. Although the GHG reduction efforts of Brazil are non-negligible, net export volumes increase by 9% compared to the Baseline. This is because a substantial share of emissions reduction is undertaken by the agricultural sector such that less effort is required from other industries (e.g. equipment goods industries) whose competitiveness therefore improves.

[39] In Figure 34, % changes above zero add to the overall negative GDP effect, whereas % changes below zero have a positive impact on the GDP.

A third factor that contributes to Figure 34 is the relationship between the industry structure of a given region and the changing structure of global demand. For example, fossil fuel exporting regions such as Russia, North of Africa, Saudi Arabia and Central Asia & Caucasus, face a decreased demand for their main export goods. Therefore, the net export volumes for these regions show a clear fall.

Lastly, an improvement in the **net trade balance** can be driven by a fall in imports. Therefore, countries whose GDP is mainly driven by private consumption may see a reduction in imports resulting from a combination of lower private consumption and less competitive import prices. Similarly, countries that switch to a less import-dependent energy system can also see beneficial effects in their trade balance. The EU, along with other OECD members, is such an example. Despite an overall drop in exports, the trade balance is improved by 50% compared to the Baseline due to a higher drop in imports. This drop is due to: i) decreased household income, ii) a significant fall in energy imports as mitigation policy lowers demand, iii) a drop in imports of certain energy-intensive products where the domestic production becomes more competitive under global mitigation. In particular, EU becomes more competitive in most energy-intensive sectors (e.g. chemical, paper and pulp and non-ferrous metal industries) for which it actually increases export volumes and decreases imports. This effect is noted also in certain energy-intensive sectors of the USA, Japan, Australia, New Zealand and Rest of Annex I countries. Therefore while energy-intensive and energy-supplying sectors are the most greatly affected in overall terms, the effect differs between regions. Global mitigation action can be beneficial in regions that undertake substantial industrial mitigation even in the Baseline and in regions that are best placed to meet their Global Mitigation scenario commitments in other ways.

Figure 34: Decomposition of GDP impact in the Global Mitigation scenario



Source: JRC GEM-E3 model

4.2.2 The impact of different auction revenue recycling options

In 2015 countries are preparing nationally determined contributions to the global mitigation effort under the framework of the preparation for COP21 of UNFCCC. This process enables countries to consider the mitigation policies that are most appropriate both for their national economies and the overarching global agreement and development strategies.

In the context of the Global Mitigation scenario represented here, economic growth is improved in every region when emissions permits are auctioned (or similarly a tax on emissions) with the proceeds used optimally for each region. It is found that for the majority of the regions the optimal recycling of permit auction revenues is to lower indirect taxes while for some countries it is best to use emissions revenues to reduce taxes on labour.

The Global Mitigation scenario with greatest global GDP is achieved when auction or tax proceeds are used to reduce the indirect taxes that have the greatest distorting effects in the individual regions concerned. This demonstrates the important role that smart fiscal policies can play in reducing the costs of meeting climate change mitigation targets.

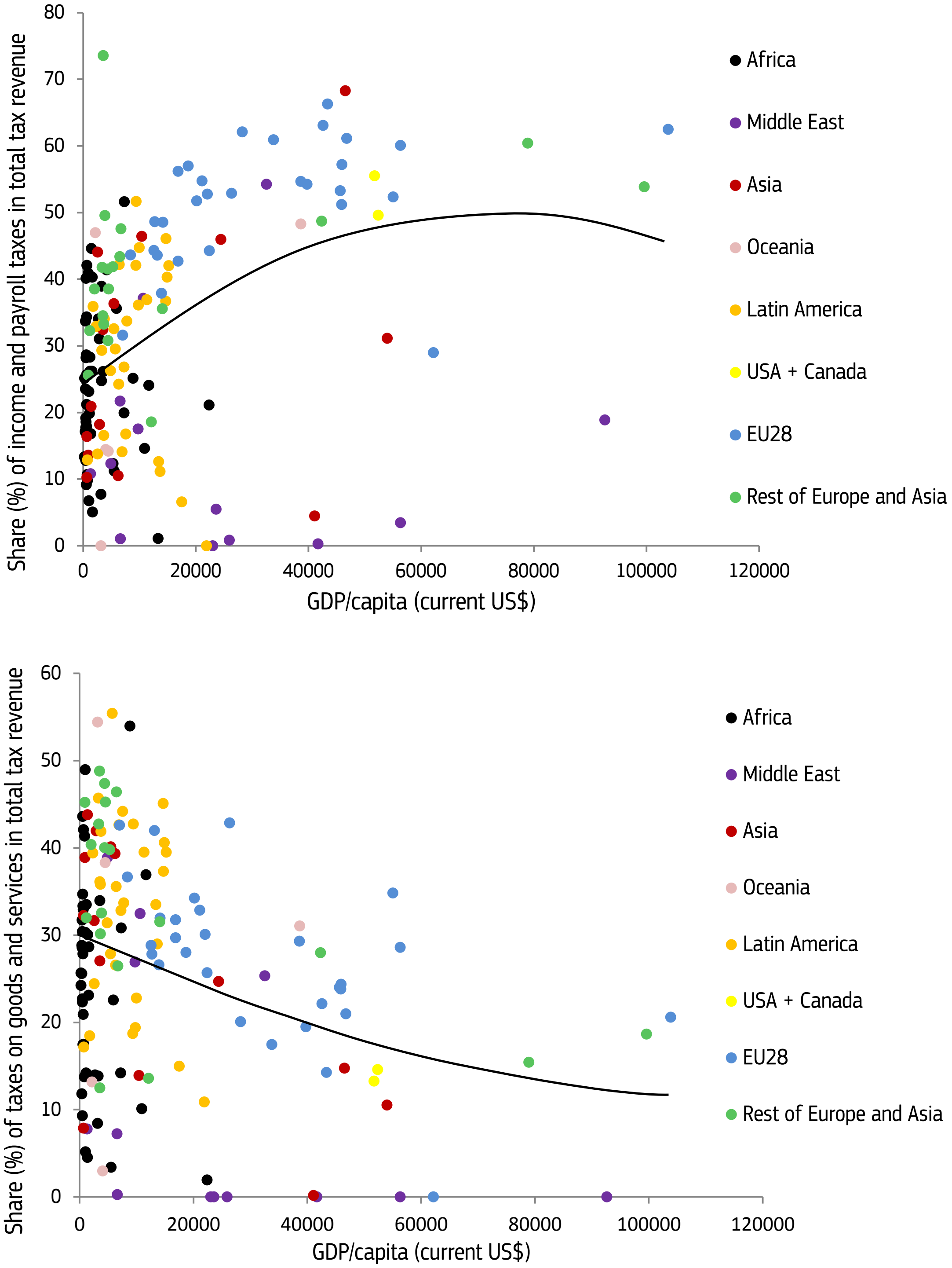
In the previous section, carbon taxation or auctioning of emission permits was not considered, but instead emission permits were allocated according to the permit demand. As such, no additional revenue was raised for the government. However, if emission permits are auctioned[40], the additional government revenue can be used in a growth-enhancing manner, by eliminating other distortionary policies. This section studies how the revenue recycling can alter the economic impact of the global mitigation action. In this exercise, several recycling options have been considered in order to maintain the government budget as a percentage of GDP equal to the Baseline levels. These options include the reduction of taxes (labour, indirect, production taxes) or the support of investment and other policies. It is seen that different regions show different optimal policies depending on the structure of the economy.

The first component of the analysis studies the economic impact when the additional revenue is used to lower **labour taxes** (e.g. social security contributions). Labour taxes are generally considered as rather distortive because they discourage labour supply and labour demand (employment). Therefore, this option considers the reduction of taxes on labour by a revenue raising instrument with an additional environmental goal: the auctioning of GHG emission permits. Moreover, reductions in **indirect taxes** on consumption and investment purchases have been implemented as a revenue recycling mechanism in a subset of regions. This is because taxes related to consumption are typically a greater share of revenue in regions with low GDP per capita. On the other hand, labour taxes are higher in regions with higher GDP per capita, such as the EU. This could be because high-income regions have elaborated social benefit schemes that require a substantial amount of financing, often by taxing labour, or because other regions have a large shadow economy which may narrow the labour tax base. Figure 35 illustrates how tax structures differ across countries around the world (based on the numbers used in IMF (2013) for the year 2012). The upper panel shows that particularly in high-income countries labour taxation is an important source of revenue. In general, the share of labour taxes (income and payroll taxes) in the total tax revenue tends to increase with GDP per capita (the black line in Figure 35 shows an estimated polynomial function). The lower panel indicates that the share of consumption taxes (on goods and services) in total tax revenue appears to fall with GDP per capita, although substantial variation occurs between countries with a relatively low GDP per capita. Therefore, the effect of a reduction in labour taxes for low income regions may be limited.

[40] Although 4.2.2 discusses explicitly the auctioning of emission permits, this could be seen as equivalent to carbon taxation.

Ultimately, it is up to policymakers in each region to decide how to best use the additional public revenues. The analysis here merely illustrates how the economic impact may vary when carbon pricing is combined with alternative instruments to achieve budget neutrality. Note that indirect tax reductions on the outputs of the fossil fuel sectors (oil, coal and gas) are excluded here, as this would conflict with the spirit and general objective of the reform.

Figure 35: Difference in the structure and levels of taxation across world regions



Source: Own calculations based on IMF (2013) and World Bank statistics on GDP per capita

Table 16. Comparing GDP yearly growth rate changes under different revenue recycling options

Yearly growth rate (%) of GDP (2020-2030)					
		Baseline	***Global Mitigation scenario***		
Auctioning		***n/a***	***none***	***All***	***All***
Tax recycling		***n/a***	***n/a***	***LS***	***Lab. Tax / IT(*)***
	(1)	(2)	(3)	(4)	(5)
World		**3.00**	**2.87**	**2.87**	**2.91**
European Union	EU28	2.01	1.93	1.93	1.96
USA	USA	2.01	1.90	1.90	1.91
Russia	RUS	2.79	2.34	2.35	2.50*
Canada	CAN	2.12	1.98	1.98	1.99
Japan	JPN	1.01	0.96	0.96	0.97
Australia	AUS	2.96	2.90	2.89	2.89
China	CHN	5.02	4.81	4.82	4.91*
India	IND	6.45	6.30	6.31	6.37*
Indonesia	IDN	5.17	4.96	4.96	5.07*
Brazil	BRA	3.34	3.17	3.17	3.34*
Republic of Korea	KOR	3.16	3.07	3.07	3.09
Rest of Europe	ANI	3.00	2.88	2.88	2.89
Mexico	MEX	3.57	3.49	3.49	3.50*
Argentina	ARG	2.96	2.75	2.75	2.91*
North Africa	NOA	5.46	5.19	5.19	5.35*
New Zealand	NZL	2.32	2.29	2.29	2.29
Saudi Arabia	SAU	3.53	3.12	3.12	3.29*
Iran	IRN	5.22	4.95	4.95	5.10*
South Africa	ZAF	4.96	4.81	4.81	4.87*
Rest of Middle East	MID	3.18	2.95	2.95	3.03*
Sub-Sahara Africa	SSA	6.31	6.07	6.06	6.20*
Rest of Central and South America	CSA	3.75	3.63	3.63	3.72*
Central Asia and Caucasus	CAS	4.51	4.06	4.06	4.09
South-East Asia	SEA	3.42	3.27	3.26	3.37*
Rest of Asia and Pacific	RAP	6.62	6.51	6.51	6.57*

* indicates that the revenue is recycled via a reduction in indirect taxes on consumption and investment in this region.
LS = Lump sum, *Lab. Tax* = Labour tax, *IT* = Indirect tax
Source: JRC GEM-E3 model

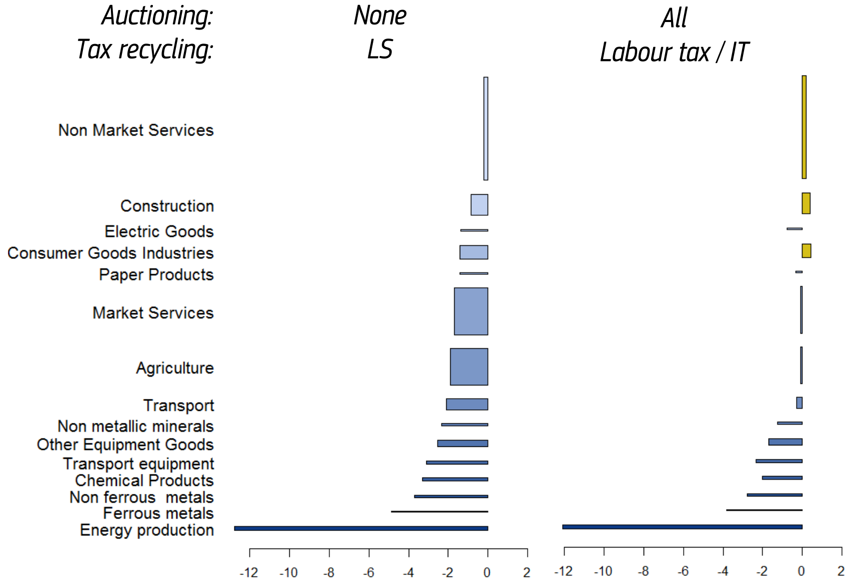
Table 16 shows the results of the different revenue recycling schemes on annual GDP growth. The difference in scenarios is that the permits are auctioned with the resulting additional revenue used for lump sum transfers or reductions in taxes. Column 2 shows GDP growth rates in the Baseline, while Column 3 shows growth rates in the Global Mitigation scenario presented in Section 4.2.1 (with no auctioning of emissions credits). The four additional scenarios involve auctioning of GHG emission permits in all sectors. In column 4, the auctioning revenue is recycled via lump sum transfers to the households. Column 5 features labour tax reductions in high-income regions and lower indirect taxes in a subset of regions (indicated with a star in Table 16, *Lab. Tax / IT(*)*). Note that the emission reduction profiles and the shares of technologies in power generation are identical to the information used in the scenario in the previous section.

A number of interesting conclusions can be drawn from these results. On a global level, the recycling of tax revenue via lower labour or indirect taxes leads to higher GDP growth rates than lump sum transfers or free allocation of permits, bringing yearly growth rates closer to Baseline levels. The results illustrate that lowering pre-existing distortions can have economic benefits compared to a simple lump sum redistribution of tax revenue. This *weak double dividend* generally finds support in both theoretical and empirical economic literature and is a solid, generally accepted concept.

A lower **labour tax** favours the use of labour in the production process, which leads to higher employment levels, wages and household incomes. This is of particular importance for the high-income countries that face increasing levels of unemployment, higher than those of some big emerging economies.

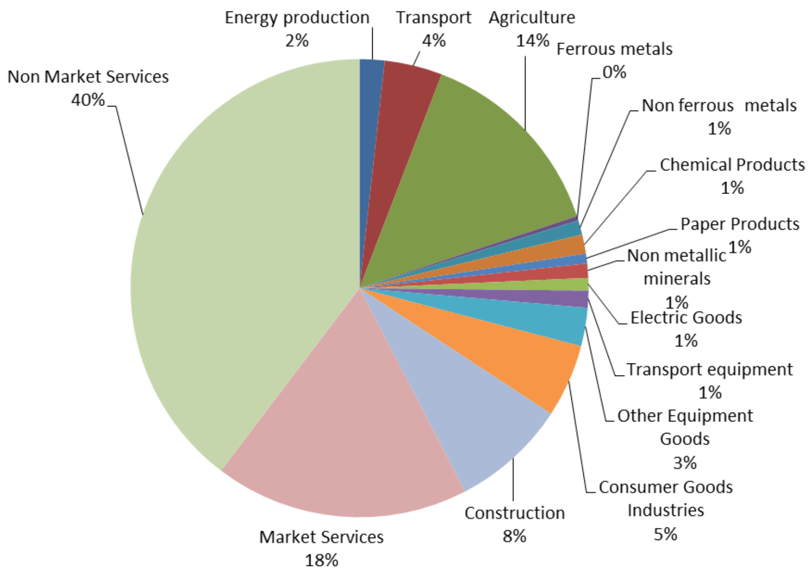
Reducing labour or indirect taxes is also beneficial for **employment**. Figure 36 presents the impact on **employment by sector** for the three scenarios shown in columns 3, 5 and 7 in Table 16 respectively. The length of the bars indicates the percentage change in employment per sector relative to the Baseline. The height of the bars is scaled to reflect the employment levels by sector in the Baseline for 2030. As a result, the surface of the bars indicates the change in the number of jobs. The figure illustrates that tax recycling is beneficial for global employment in all sectors. Some sectors, like consumer goods industries and construction, see higher employment levels than those of the Baseline.

Figure 36. Global employment impact by sector (% change relative to baseline, 2030) in Global Mitigation Scenarios



Note: The height of the bars indicate employment levels in the baseline (2030) thus the surface of the bars reflects the change in absolute number of jobs for different scenarios. Blue indicates negative values and yellow are employment gains. Source: JRC GEM-E3 model

Figure 37: Distribution of global employment across sectors in the Baseline



Source: JRC GEM-E3 model

On a sectoral level, benefits from the enhanced-policies scenarios (with smart revenue recycling) differ significantly among regions according to their comparative advantage or the revenue recycling tool utilized.

The change in overall employment is -1.36% compared to the baseline for the scenario without permit auctioning (Column 3 in Table 16). However, when the permit auctioning revenues are used to lower pre-existing taxes (Column 5 in Table 16), the impact on employment is reduced to -0.29% as a significant number of sectors with a large share of total employment in the economy benefit from the improved policy. The Services sectors, Construction, Consumer goods industries and Agriculture indeed represent the sectors with the highest number of jobs by 2030 (Figure 37).

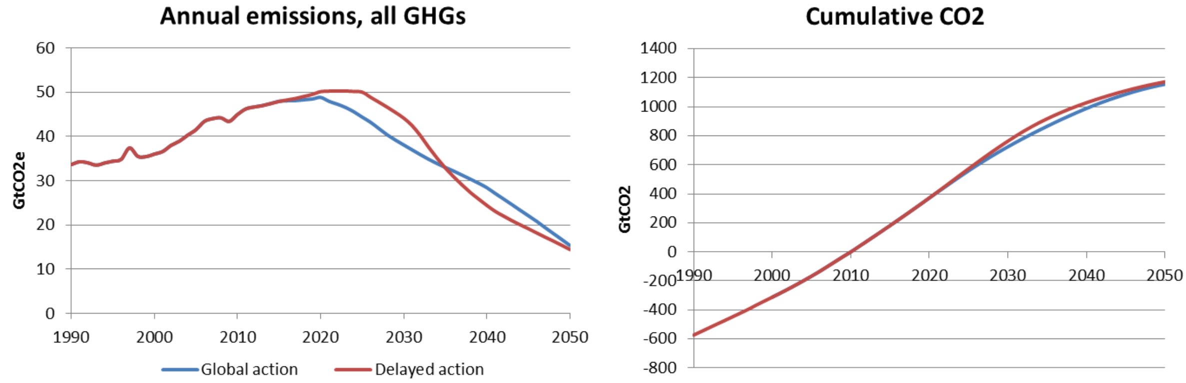
With respect to the positive effects of indirect tax reductions, there are several mechanisms at work. On the one hand, decreasing indirect taxes removes a pre-existing distortion and stimulates consumption and investment by lowering final prices. On the other hand, some industries shift their sales from the foreign to the domestic market, lowering export volumes. At the same time, total imports are higher than in previous scenarios because the indirect tax reduction applies for all goods, both domestically produced and imported and therefore households see lower prices and can consume more goods for a given income. Due to the beneficial effects of auction revenue recycling, the disposable income of lower-income regions increases (lower indirect taxes results in lower prices) at the same time that the competiveness of high-income regions is improved (by lowering labour taxes) and thus an increase in total exports of regions like EU, US, Australia, Korea, Rep. and New Zealand is seen compared to Baseline levels. Moreover, the increased consumption demand creates a secondary positive impact on production and employment. The net effect on GDP shows higher yearly growth rates compared to the scenario without auctioning in all regions where the indirect tax reduction is applied. This indicates that a policy design tailored to the specifics of each region may be most beneficial, and proves to be the global least cost method of achieving climate change mitigation policies.

4.3 Delayed Mitigation variant: emissions, budget and system cost

An alternative Delayed Mitigation scenario has been evaluated in POLES: it considers more inertia in the pace of implementation of mitigation policies while still respecting the same 2010-2050 CO_2 budget as in the Global Mitigation scenario. The decade 2020-2030 becomes in this case a decade of soft transition before a very abrupt decline of emissions.

Figure 38 shows the evolution of emissions in both cases: yearly emissions start to decline only from 2030 in the Delayed action variant, vs. 2020 in the Global Mitigation scenario, but post-2030 effort is much stronger. By 2050 the cumulative CO_2 budgets in both scenarios reach 1150 $GtCO_2$.

Figure 38. GHG emissions in the Delayed Mitigation case vs. the Global Mitigation scenario

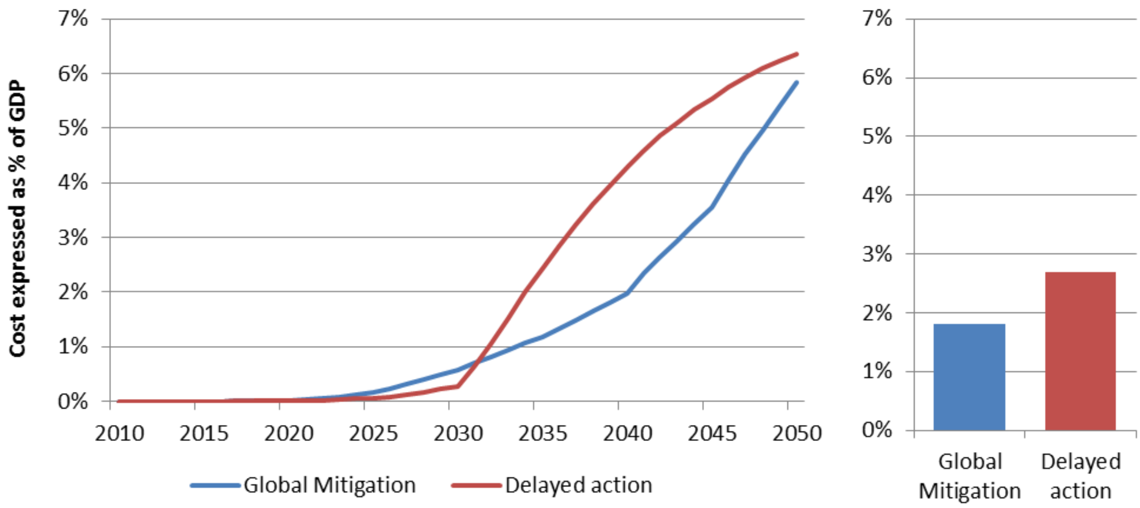


Source: JRC POLES model

The abatement cost[41] (Figure 39) shows that although the Delayed action is cheaper by 2030, it soon becomes more expensive afterwards. Indeed, while the Global Mitigation scenario undertakes more expensive action in the decade 2020-2030, the cumulated abatement cost over 2010-2050 remains below 2% of GDP (expressed in MER) vs. 2.7% of GDP in the Delayed action variant.

[41] The abatement cost is calculated as the area under the marginal abatement cost curve of the emitting sectors: energy, industry, agriculture. Although we express it here as % of GDP, it is not a macro-economic cost (GDP loss) as the one calculated by the economic model GEM-E3 in Section 4.2.

Figure 39. Abatement cost expressed as % of GDP: yearly (left) and cumulated 2010-2050 (right)



Note: This cost is calculated as the area below the marginal abatement cost curve. The cumulated cost reported here is the average over 2010-2050, without considering discounting of future costs.
Source: JRC POLES model

A comparison of the mitigation cost between the Global Mitigation scenario and various mitigation policy projections produced in other projects is provided in Annex 2.

4.4 Low oil price variant

4.4.1 Rationale

This section considers a low oil price variant, as since the summer of 2014 the global price of crude oil shows a steep decrease which has not been seen since 2008. The maximum decrease (about -60%) took place between June 19th 2014 and January 13th 2015, with a slight recovery since (Figure 40). However this recent price drop remains below the one observed with the financial crisis in 2008 when the price plummeted by almost 75% between July and December 2008. The steep fall in price then was followed by a steady recovery to high levels that cumulated in 2012 around 120 $/bl.

Figure 40. Daily oil price, 2004-2015 (Brent, current $)

Sources: US EIA[42] and oil-price.net, latest data point: 14th May 2015.

The recent drop of the oil price raises several questions on the drivers of such a steep decrease and on the impact on the short term and long term price evolution. According to Arezki and Blanchard (2014), lower than expected demand between June and December 2014 accounts for only 20 to 35 percent of the price decline. Other explanations being put forward hint that the supply side effect is predominant. Key producing countries in Middle-East and Northern Africa, such as Libya and Iraq, show high oil production levels despite political instability. The US has become the world's largest oil producer thanks to new supply from shale oil. Gulf countries are preserving their market share, as they are facing lower than average extraction costs. Most analysts expect some rebound of prices later this year, albeit below the peak of 115 US$/bl in last June[43]. In the longer term, sustained low prices tend to be self-correcting as the incentives for investments in oil supply decline.

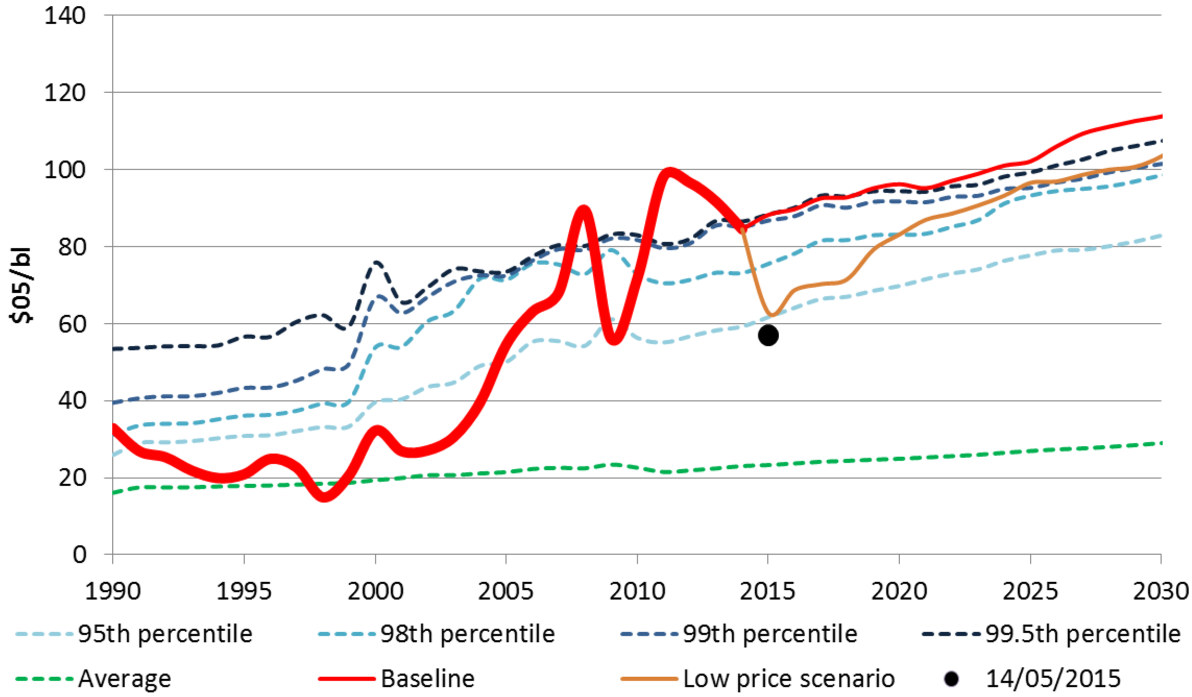
[42] http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm

[43] For instance, in its Winter 2015 European Economic Forecast (EC 2015c), DG ECFIN uses futures-based technical assumptions for Brent prices and projects an evolution to USD 53/bbl in 2015 and to USD 61.5/bbl in 2016.

4.4.2 Definition

In the absence of certainty regarding future evolution, we developed a "low oil price" variant to assess the impact on the GHG policies. Figure 41 shows that a low oil price covers in the short run *only* the production cost of the 95th percentile of the production cost curve (around 60$05/bl), a level it was close to in 1990-2005. Conversely, in the Baseline case the oil price always covers at least the top production cost (99.5th percentile). After a stabilization period the "low oil price" variant increases again due to the fast declining reserves over production ratio (R/P) for OPEC and Gulf countries[44] and thus departs from the 95th percentile of production costs.

Figure 41. Yearly oil price vs. production cost (Brent, $05)



Note: the graph shows the yearly oil price (Brent, thick red line is history 1990-2014), the average production cost and various percentiles of the production cost as calculated in the POLES model: 95th percentile, 98th, and 99.5th (being considered as the most expensive production).

Source: JRC POLES model

4.4.3 Impact on the policy cost and the energy balance

Variants of the Baseline and the Global Mitigation scenario have been developed using the "low oil price" conditions. They respect the emission constraints of respectively the Baseline case (low 2020 pledges) and of the Global Mitigation scenario (high 2020 pledges and emission trajectory beyond).

<u>Carbon price</u>

In the case of the Baseline the impact on the carbon value in 2020 for constrained countries is noticeable (Table 17): a lower oil price leads to higher carbon values to reach the same CO2 emissions: from +10% for Canada to +40% for USA. On the other hand, India, Mexico and Brazil which had no constraint, see no change. The low oil price does not change the picture for the EU, since its 2020 objective is defined by the ETS sector where the contribution of oil in energy demand and CO2 emissions is very small.

[44] In this version of the POLES model the oil price is driven by the following: the production cost, and the role of Gulf as swing producers whereby

Table 17. Effect of the low oil price on the carbon value

$05/tCO2	Low oil price scenario			Low oil price / central oil price		
	Baseline	Global mitigation		Baseline	Global mitigation	
	2020	2020	2030	2020	2020	2030
EU (ETS)	10	11	82	0%	0%	1%
USA	19	23	82	40%	21%	1%
CAN	12	18	82	10%	30%	1%
AUS	21	21	82	12%	17%	1%
CHN	3	8	82	20%	55%	1%
IND	0	8	41	0%	55%	1%
MEX	0	23	82	0%	85%	1%
BRA	0	8	82	0%	55%	1%

Source: JRC POLES model

The effect on the Global Mitigation scenario is comparable by 2020: the carbon values increase to compensate the lower oil price and the resulting higher emissions in the transport sector. Coal demand in the power sector is then further reduced to respect the same emissions level across the economy as in the central case. By 2030, though, the oil price assumption has little impact on the carbon value, given the level of constraints applied to the system.

Table 18. Effect of the low oil price on World demand and emissions (2020)

	Low oil price scenario		Low oil price / central oil price	
Primary energy Demand (Mtoe)	**Baseline**	**Global mitigation**	**Baseline**	**Global mitigation**
Total	15230	14970	1%	0%
Oil	4750	4670	4%	3%
Gas	3430	3347	1%	0%
Coal	4070	3870	-2%	-3%
Others	2980	3083	-1%	0%
Energy CO_2 Emissions ($MtCO_2$)				
Total	35540	34350	1%	0%
Power	13920	13230	-1%	-2%
Transport	8200	8020	4%	3%
Industry	6530	6420	1%	0%
Residential-Services	3460	3340	3%	1%
Others	3430	3340	0%	0%

Source: JRC POLES model

Emissions and energy balance

Table 18 shows that, in the Baseline, while the constrained countries emit the same levels with a lower oil price (by definition), the others are producing more CO_2 emissions by 2020, leading to World CO_2 emissions being slightly higher (+1%). A lower oil price leads to more oil and gas being used and less coal (affected by the higher carbon values) and less biomass (especially liquid biofuels used in the transport sector). Total emissions sectors increase at World level, most notably

transport (+4%), while emissions in the power sector are reduced (higher carbon value in the constrained countries).
In the Global Mitigation scenario total emissions remain the same, and conclusions on fuel demand remain: by 2020 slightly more oil is used (in transport) to the expense of coal (in power production).

5 Detailed country factsheets

5.1 Introduction

The country factsheets provide detailed information on country basis:

- Decomposition of the GHG emissions per key driver (model POLES)
- Evolution of GHG emissions per sector in the Baseline and the Global Mitigation scenarios, including the role of sinks in reducing past emissions, but no projections of sinks (model POLES)
- Decomposition of total GHG reductions per option from Baseline to the Global Mitigation scenario, with a focus on 2030 (model POLES)
- Decomposition of GHG reductions per option in the power sector from Baseline to the Global Mitigation scenario, with a zoom on 2030 (model POLES)
- Investments in the power sector per fuel type (model POLES)
- GDP components under Baseline, Global mitigation and Global mitigation with auctioning (model GEM-E3)
- Activity levels by economic sectors under Global mitigation and under Global mitigation with auctioning (model GEM-E3)

The numbers in these country factsheets should not be taken at face value to discuss the ambition level of the contributions that the countries will put forward for the new climate agreement, as the numbers presented here are sensitive to:

- Datasets used (e.g. historical emissions, population, GDP, energy price assumptions, levels of elasticity);
- The way policies are interpreted (e.g. policies included in the Baseline or not, differentiated convergence to a common carbon value);
- The modelling itself and the way features of the economic system and policies are represented.

The country factsheets should thus be considered as the scientific output of a modelling exercise that gives tendencies and possible evolutions of the energy system under a set of specific constraints. As such they should not be regarded as being policy prescriptive but rather as informative.

The country factsheets presented below illustrate how, under the modelling framework of a Global Mitigation scenario, all regions: 1/ converge to low levels of emissions, of emissions/cap, and significantly improve the emission intensity of their economy (see Figure 42 to Figure 44 for the major economies) and diversify their energy mix to low-emission sources (as already presented in chapter 4.1.7 and 4.1.10); 2/ whilst all countries and regions retain very diverse ways to move to such a low-emission future, relying on different mitigation options, experiencing different pace of emission reduction depending on their initially diversified energy mix and economic structure, emission profiles and growth models. Across all countries and regions, investments in the energy sector accompany the transition from the Baseline scenario to the Global Mitigation scenario, but again there is no set pattern: countries are taking up different investment options according to their national circumstances. Also specific sectors benefit of the transition to the Global Mitigation scenario depending on the assets of the countries, and national policy choices, with benefits at stake in many regions.

The factsheets of the countries and aggregate regions[45] are presented in alphabetical order.

[45] In the previous sections, aggregate regions were sometimes lumped together for presentational purposes (e.g. North Africa oil producers, North Africa non-oil producers, and Sub-Saharan Africa were aggregated)

Figure 42. GHG emission intensity vs. per capita, major economies, 2000-2010

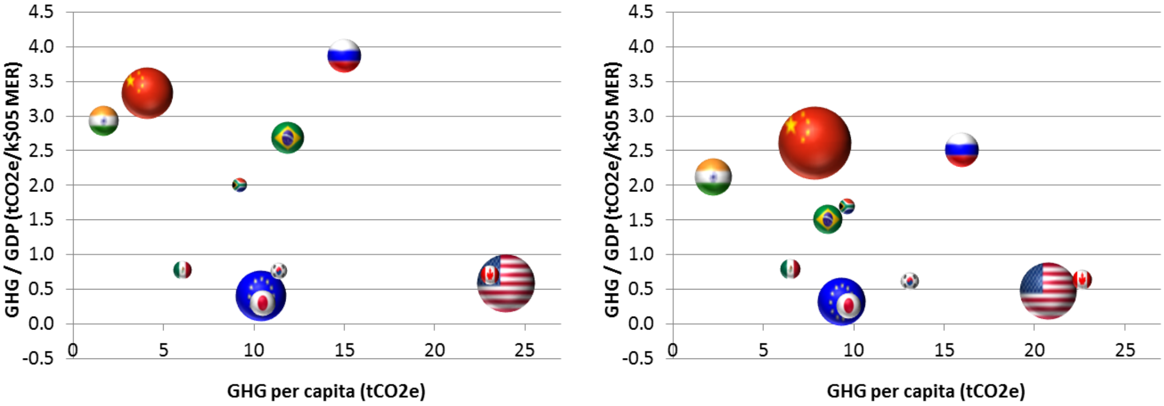


Figure 43. GHG intensity vs. per capita, major economies, Baseline 2030-2050

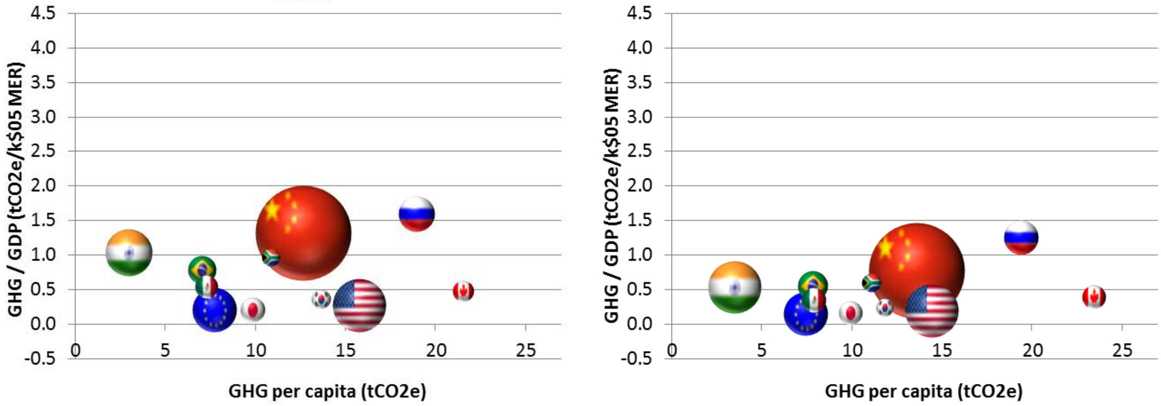
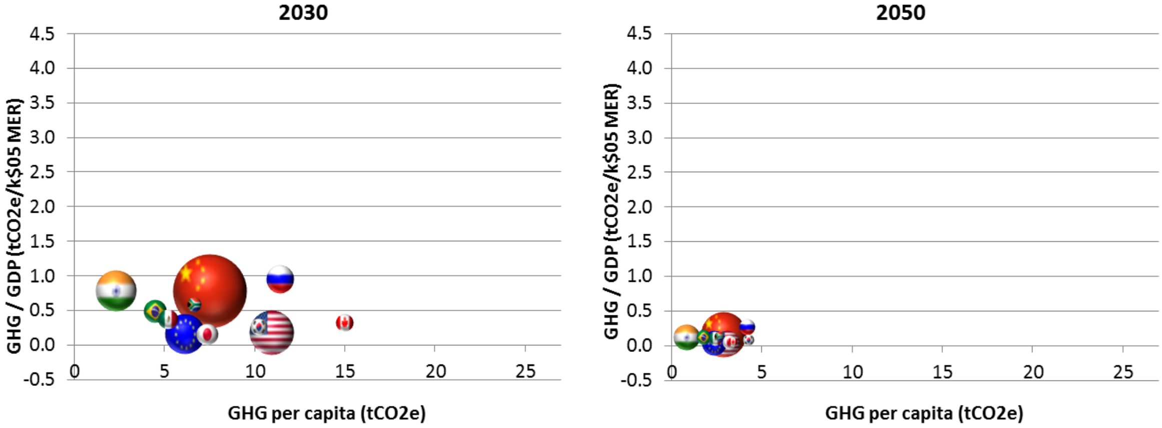


Figure 44. GHG intensity vs. per capita, major economies, Global Mitigation scenario 2030-2050



Source: JRC POLES model

5.2 Brazil[46]

In the Global Mitigation scenario, Brazil is projected to reduce emissions after 2020 while maintaining annual GDP growth rates of over 3% in total GDP (and 2.3% in GDP per capita) while reducing emissions. Excluding LULUCF, agriculture makes the single greatest contribution to the emissions reduction, with important contributions also from renewable energy, energy efficiency and from the fossil fuel production sector.

In the Baseline scenario, Brazil is projected to have total GHG emissions (excl. LULUCF) of 1.3 $GtCO_2e$ in 2020. LULUCF emissions are expected to decline fast, while the other GHG emissions are expected to triple in 2050 as compared to 1990 in absolute terms and to double in per capita terms, while the emission intensity of GDP would halve. Under the Global Mitigation scenario emissions stabilise around 2020, decreasing to 70% of 1990 levels by 2050 (46% in per capita terms).

Table 19. Brazil decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	195	211	218	223	229	231	130	141	149	153	154
GDP per capita (k$05)	10	12	14	16	21	25	140	171	225	289	355
GHG ($MtCO_2e$)											
Baseline	1056	1329	1458	1564	1731	1807	181	228	268	297	310
Global Mitigation	1056	1205	1068	991	825	403	181	207	170	141	69
GHG per capita (tCO_2e)											
Baseline	5.4	6.3	6.7	7.0	7.5	7.8	139	161	180	193	201
Global Mitigation	5.4	5.7	4.9	4.5	3.6	1.7	139	146	114	92	45
GHG / GDP (tCO_2e/M$)											
Baseline	537	514	477	434	363	307	99	95	80	67	56
Global Mitigation	537	466	349	275	173	68	99	86	51	32	13
Energy / GDP (toe/M$)											
Baseline	134	130	127	125	118	111	109	106	102	96	90
Global Mitigation	134	124	119	114	102	89	109	101	93	83	72
GHG / energy (tCO_2e/toe)											
Baseline	4.0	4.0	3.8	3.5	3.1	2.8	90	89	78	69	63
Global Mitigation	4.0	3.8	2.9	2.4	1.7	0.8	90	85	54	38	17

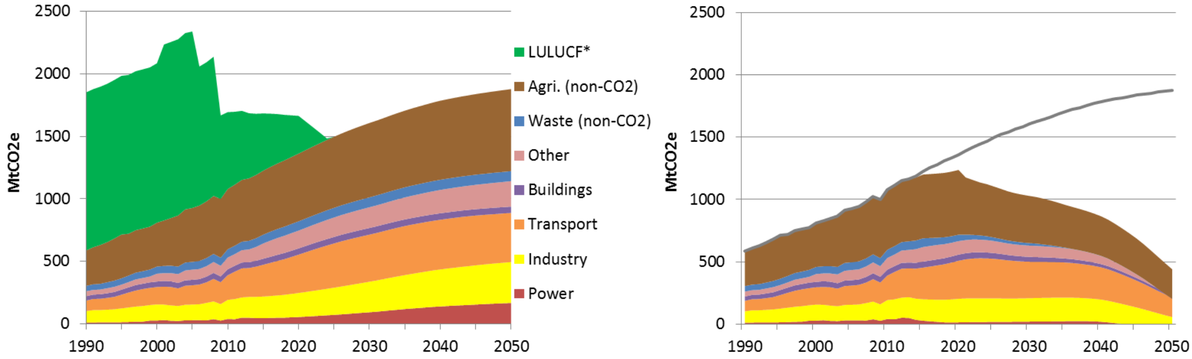
Source: JRC POLES model

As Figure 45 and Figure 46 show, agriculture accounts for large, and growing, share of Brazil's emissions in the Global Mitigation Scenario (37% in 2030, rising to 54% in 2050). However, the sector also accounts for the greatest contribution of the country's mitigation, contributing 35% of

[46] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

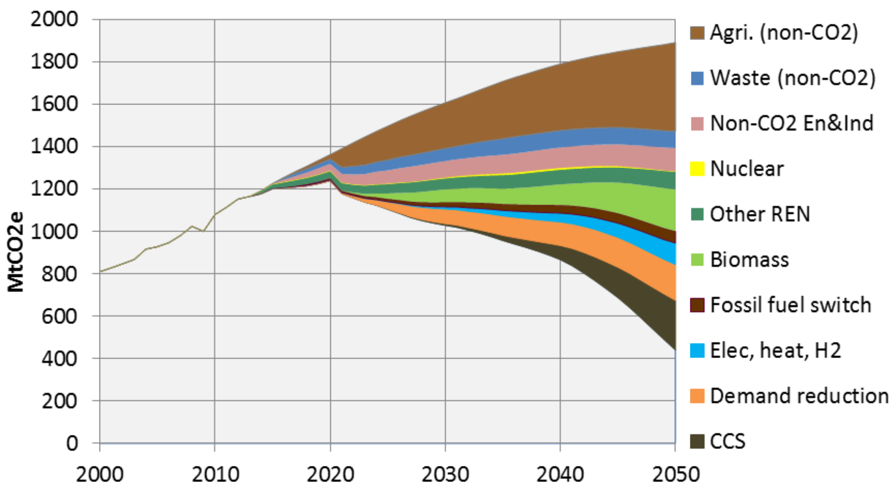
total reduction beyond 2020. The rest of the reduction is spread across a range of actions and technologies, with biomass, waste and fuel savings each contributing over 10%.

Figure 45. Brazil sectoral GHG emissions (excl. LULUCF), Baseline (left) vs. Global Mitigation scenario (right),



Source: JRC POLES model

Figure 46. Brazil emission reduction options (excl. LULUCF)



Source: JRC POLES model

In 2030 the largest reductions[47] outside agriculture and LULUCF take place in industry, with non-CO_2 emissions contributing to more than half of the reductions in 2030 (a large part linked to the fossil fuel supply sector) followed by biomass and efficiency. It is then followed by the transport sector: reduced demand contributes to more than half, followed by biofuels (greater share of compared to the Baseline) and the development of electric cars.

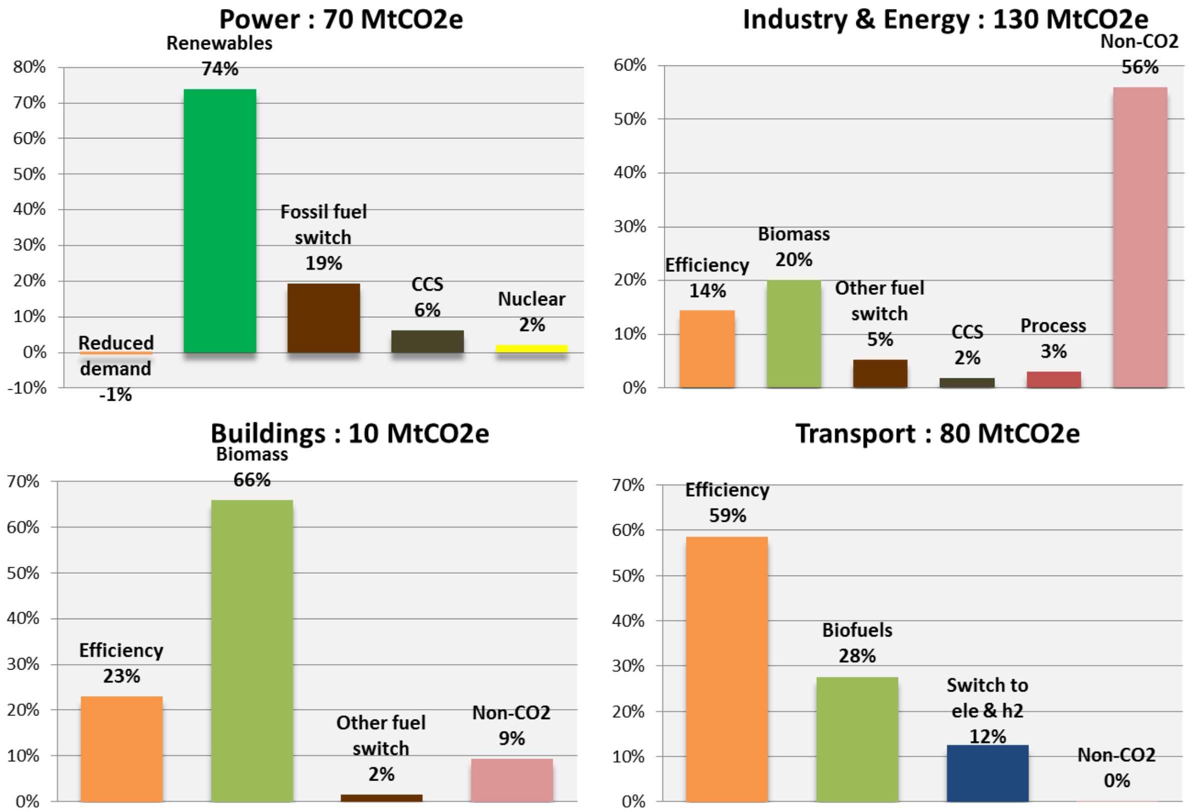
Brazil's power sector has relatively low emissions in the Baseline case, thanks to an energy mix with a relatively high share of renewable energy sources. In the Global Mitigation scenario further development of a more diversified portfolio of renewable energy sources in addition to hydro maintain emissions to low levels up to 2030 and beyond. This scenario is considered realistic as Brazil's 10 year energy plan intends to increase renewable capacity (wind, biomass and small hydro) from 9 GW in 2010 to 38 GW by 2022, bringing the share of these renewables in electricity supply to 16%. In terms of investment in the power sector, the main difference between the Baseline and Global Mitigation scenario is an even further increase in renewables (biomass, solar

[47] For further analysis on Brazil's energy system, see also Lucena et al. (2015).

and wind) at the expense of coal. CCS remains a marginal option by 2040, with biomass overtaking coal as the main CCS feedstock afterwards.

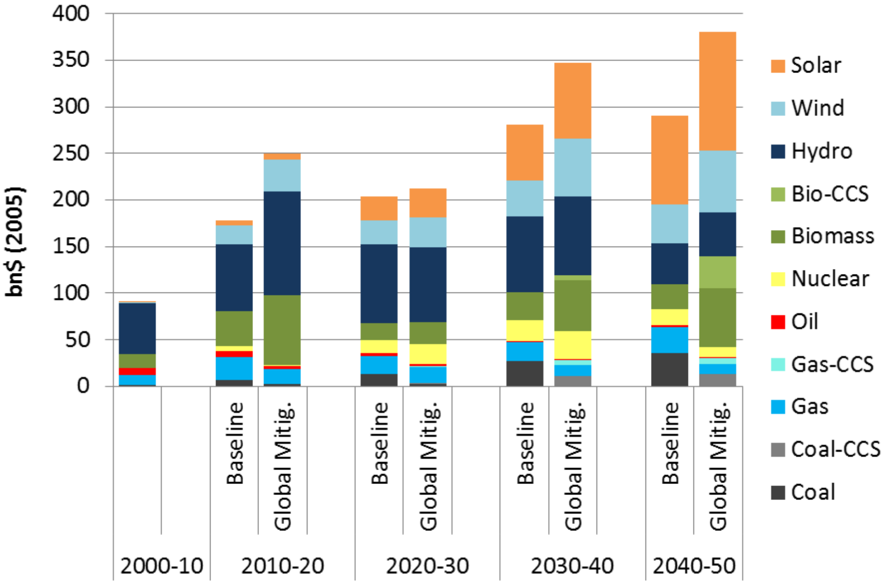
Studies focused on the impact of climate on the Brazilian energy sector identify such investment in low-emission energy system as a cost-effective strategy to make Brazil's power sector more resilient (see Schaeffer at al., 2012).

Figure 47. Brazil emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

Figure 48. Brazil investment in power (cumulative per decade)

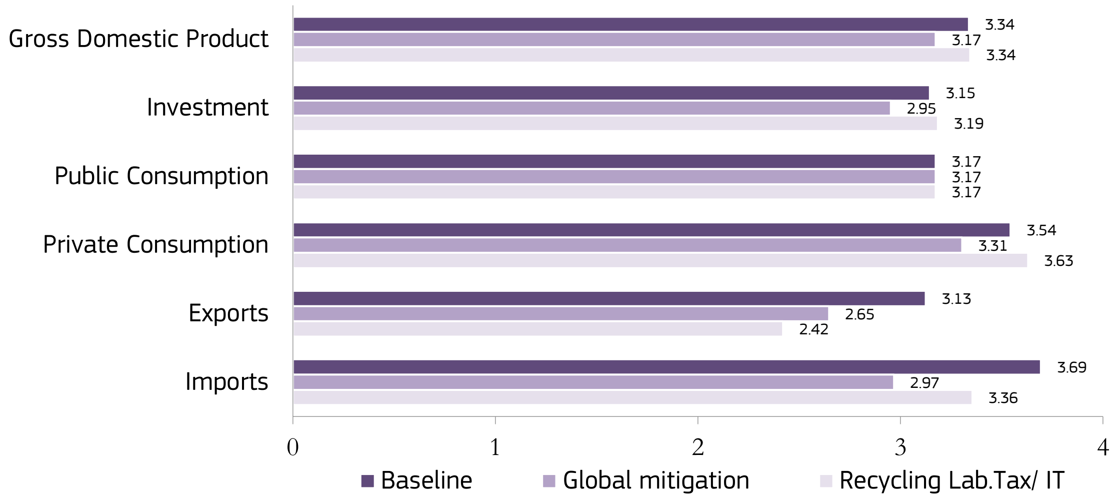


Source: JRC POLES model

The scenarios assume that Brazil is on course to meet its pre-2020 pledge and this is consistent with studies measuring a large reduction in deforestation since the mid-2000s. This reduction is partly attributable to policies such as the Action Plans for Deforestation Prevention and Control in the Amazon and Cerrado regions (Assunçao et al., 2015; Godar et al., 2014). Land-use change and forestry policies and measures are not analysed in the energy-economy modelling of this paper. In the Global Mitigation Scenario, agriculture sector contribute to emission reductions, and it seems realistic as other studies identified intensification of cattle ranching as an additional policy measure that would make a key contribution to reducing emissions and as Brazil has put in place an ABC fund for promoting low-emission agriculture (CLIMACAP, 2013). In the Global mitigation scenario, energy efficiency also contributes to reduction, and Brazil has information measures in place (e.g. labelling for vehicle fuel efficiency, or energy-using equipment performance).

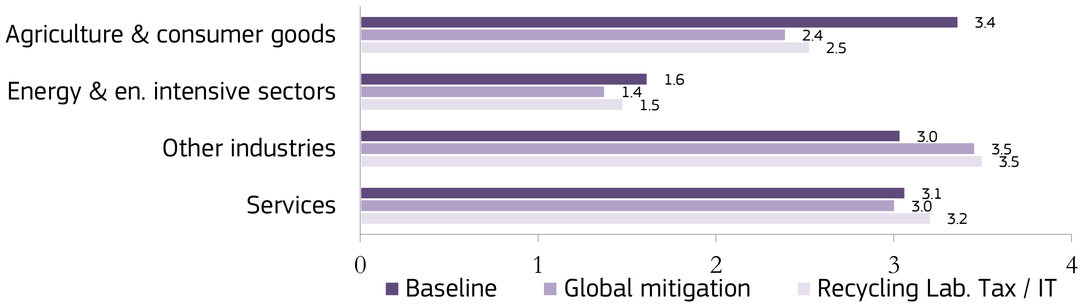
In macro-economic terms, the Global Mitigation scenario sees continued economic growth to 2030 at an annual rate of around 3.2%. The Baseline projects a GDP by 2030 that is 1.6% higher than in the Global Mitigation scenario. However, at an annualised rate, the GDP difference between the Global Mitigation scenario and the Baseline is small (Figure 49). However, it is important to note that the Baseline projection does not take into account the economic impacts of climate change and may underestimate the mitigation potential of some sectors due to lack of technological detail. Moreover, when the revenues of auctioning of carbon permits/carbon tax are recycled through a reduction of indirect tax rates, the GDP in 2030 is at the same level as in the Baseline, with employment levels about 0.8% higher. Various sectors of the Brazilian economy become more competitive in the global context and increase their exports and total domestic production (up by 3-5%), as for example the energy-intensive and the equipment goods industries. Domestic production of the largest sector of the economy, the services, also increases due to higher intermediate demand stemming from the higher economic activity and the higher disposable income (Figure 50 and Table 20).

Figure 49. Brazil, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 50. Brazil, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 20. Brazil, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	17	43	35	35
Energy & Energy Intensive Goods	18	22	25	25
Other Industries	10	27	32	32
Services	56	7	8	8

Source: JRC GEM-E3 model

5.3 Canada[48]

In the Global Mitigation scenario, Canada's emissions would fall around 34% below their 2005 level by 2030, with steeper reductions in the 2030-50 period.. Moreover, such a move to a low-emission development pathway would be feasible whilst maintaining an economic growth at a rate comparable to the Baseline. The energy-intensive sectors of the economy would have to adapt to the new global economy, however, this modelling does not represent the possible benefits of the diversification of the economy, and, this modelling shows with smart policies, other major sectors of the economy (agriculture and consumer goods) would benefit from the global transition to a low-emission future.

Alongside the USA, Canada has the highest level of GHG emissions per capita of the countries and regions considered in this paper[49]. Under current policies and projections, Canada's 2020 emissions are expected to be roughly the same as 2005 levels, making it unlikely to reach its pledge of a 17% reduction compared to 2005 levels by 2020.

Table 21: Canada decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	34	38	39	41	43	45	123	136	147	156	164
GDP per capita (k$05)	35	39	42	45	52	59	130	146	167	191	219
GHG ($MtCO_2e$)											
Baseline	688	709	740	759	833	879	120	123	132	145	153
Global Mitigation	688	664	583	514	387	152	120	116	89	67	27
GHG per capita (tCO_2e)											
Baseline	20.2	18.8	18.9	18.7	19.4	19.4	97	91	90	93	94
Global Mitigation	20.2	17.6	14.9	12.6	9.0	3.4	97	85	61	43	16
GHG / GDP (tCO_2e/M$)											
Baseline	572	477	446	413	375	328	75	62	54	49	43
Global Mitigation	572	447	351	280	174	57	75	58	36	23	7
Energy / GDP (toe/M$)											
Baseline	211	191	183	177	162	147	75	68	62	57	52
Global Mitigation	211	181	162	152	133	111	75	64	54	47	39
GHG / energy (tCO_2e/toe)											
Baseline	2.7	2.5	2.4	2.3	2.3	2.2	100	92	86	85	82
Global Mitigation	2.7	2.5	2.2	1.8	1.3	0.5	100	91	68	48	19

Source: JRC POLES model

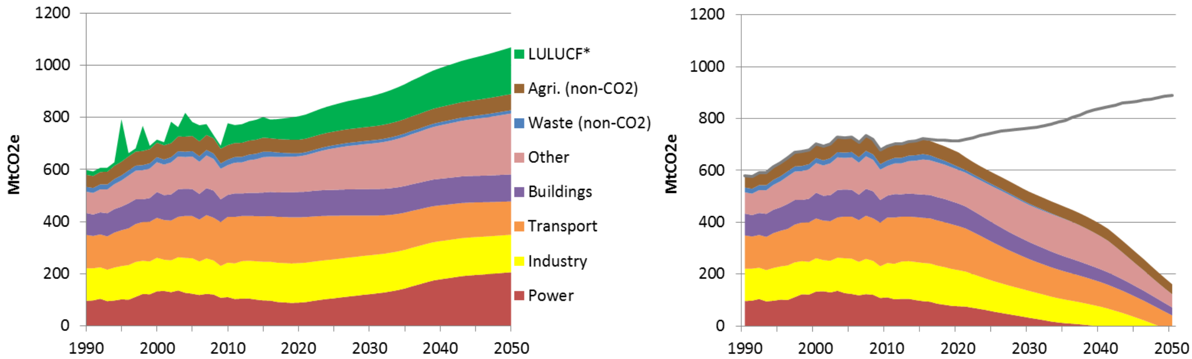
48 This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

49 Some smaller states (for instance some Middle-East oil and gas producers) have greater emissions per capita but are too small to be treated as separate regions in this paper.

Emissions are projected to increase thereafter up to 2050 considering no additional policy is implemented from 2020 onwards. This trend would reverse under the Global Mitigation scenario, with emissions projected to fall after 2020, reaching 89% and 28% of 2010 levels in 2030 and 2050 respectively (Table 21).

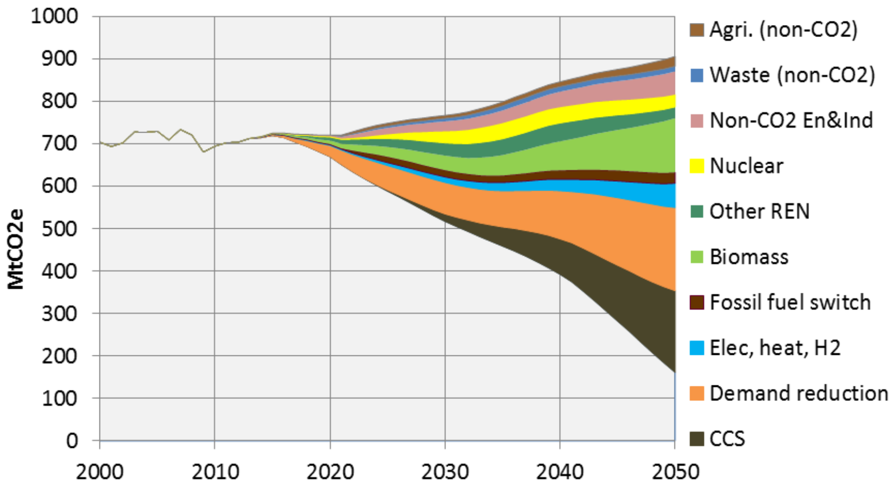
As Figure 51 and Figure 52 show, the power sector is an important contributor to mitigation (40% of the cumulative emissions reduction in 2020-2050), while energy efficiency also plays a significant role with about 30% of the total reductions in 2030.

Figure 51. Canada sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 52. Canada emission reduction options (excl. LULUCF)



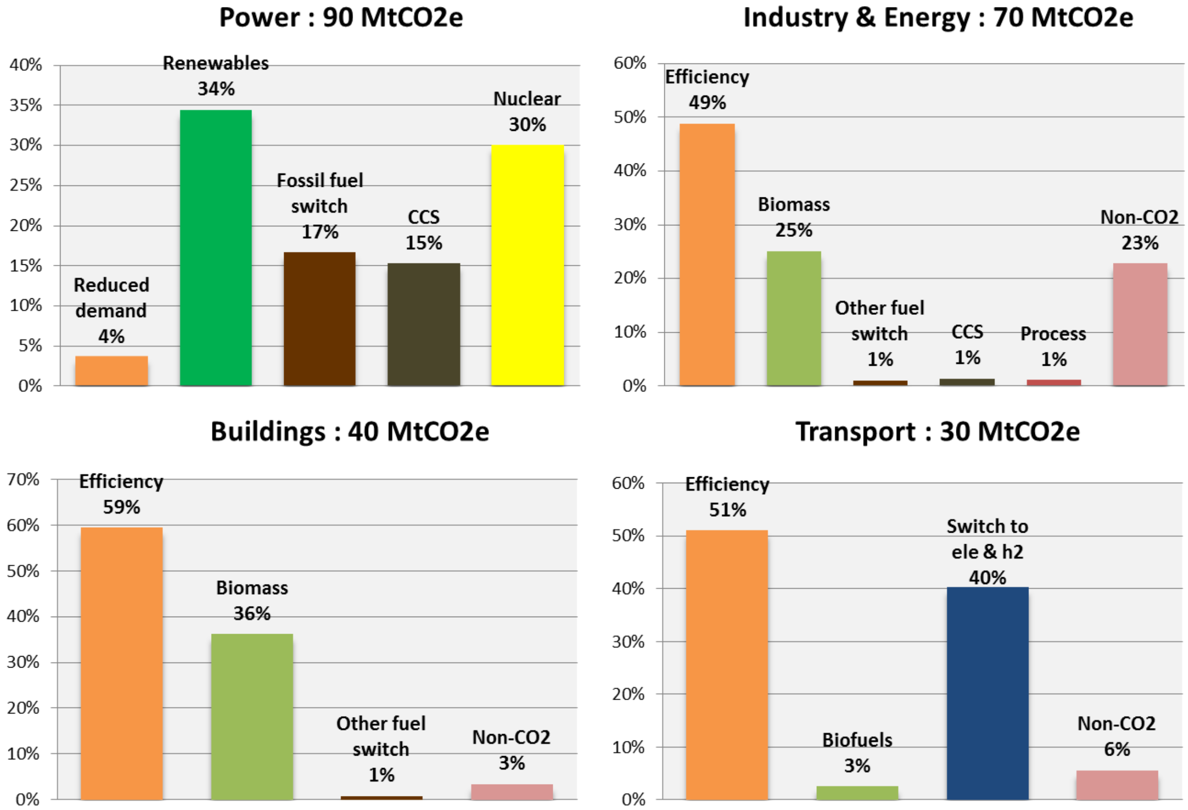
Source: JRC POLES model

Mitigation in the power sector in 2030 is a balanced mix of options: renewables (33%), nuclear (29%), fossil fuel switching to gas (17%) and CCS (15%). Beyond 2030 the contribution of CCS and biomass becomes more significant, and is sufficient to produce negative overall emissions in the power sector from 2040 onwards.

In the other sectors, energy efficiency is the largest contributor (around 50% for industry – energy, buildings and transport), ahead of biomass (in industry and buildings), non-CO_2 emission reductions form the fossil fuel industry, and a switch to alternative vehicles (electrical by 2030).

In the Global Mitigation scenario, the levels of Canada's reductions appear high compared to other regions, this is largely due to the high starting point of per capita emissions and lack of mitigation in the Baseline. Other studies have also identified a high mitigation potential, e.g. fuel efficiency standards could provide an additional reduction in emissions from cars and trucks of 13-32% by 2030 or a reduction in the production and consumption of HFCs under the framework of the Montreal Protocol[50] (Den Elzen et al., 2015).

Figure 53. Canada emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

As Figure 54 shows, transforming the power sector will require investment initially in nuclear, wind and solar, and later in CCS (both coal and biomass). This comes partly from reduced investment in conventional coal-fired generation, though additional overall investment is still needed. This is a realistic result of the Global Mitigation scenario, as Canada is already a leader with piloting the deployment of CCS technologies[51].

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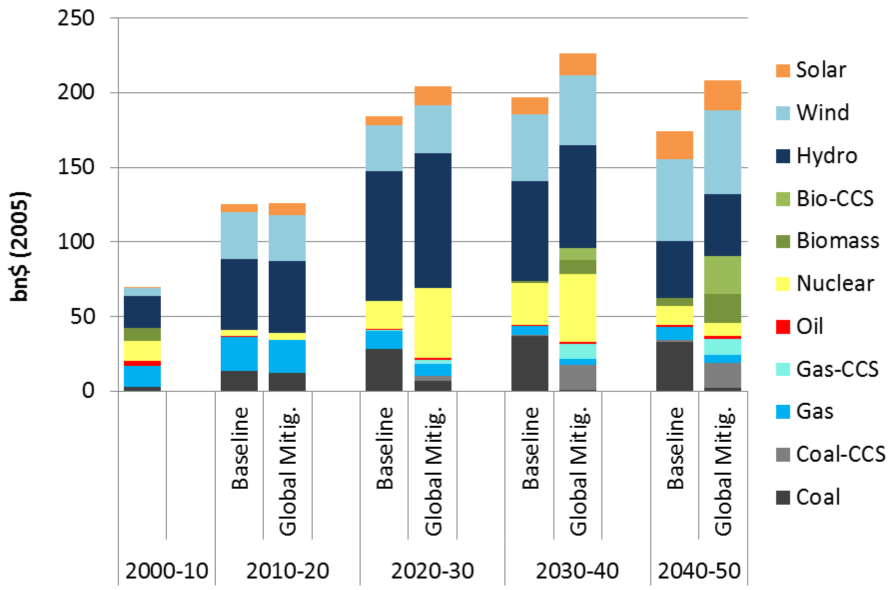
[50] http://conf.montreal-protocol.org/meeting/oewg/oewg-33/presession/PreSession%20Documents/OEWG-33-3E.pdf
[51] Canada presentation to WS2 Technical expert meetings http://unfccc.int/bodies/awg/items/8421.php

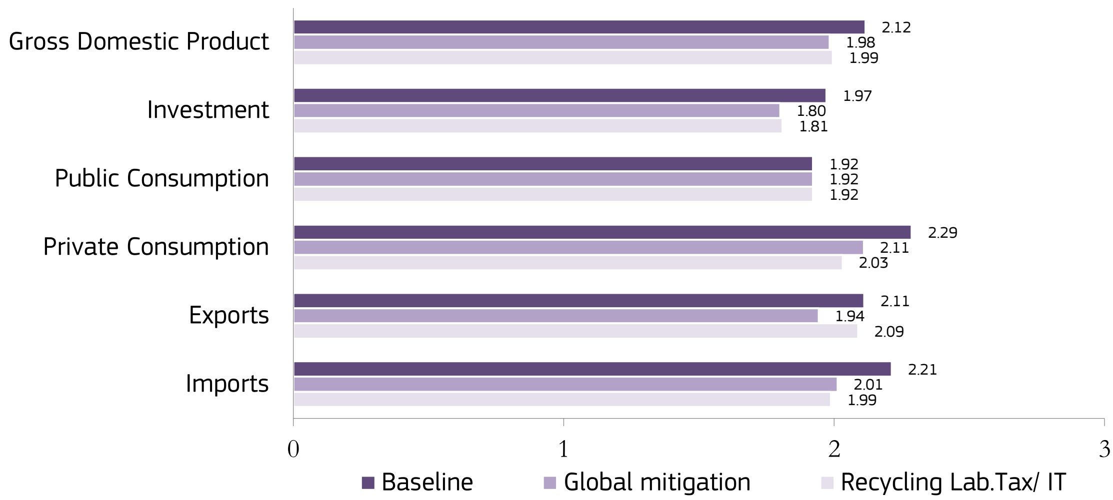
Figure 54. Canada investment in power (cumulative per decade)



Source: JRC POLES model

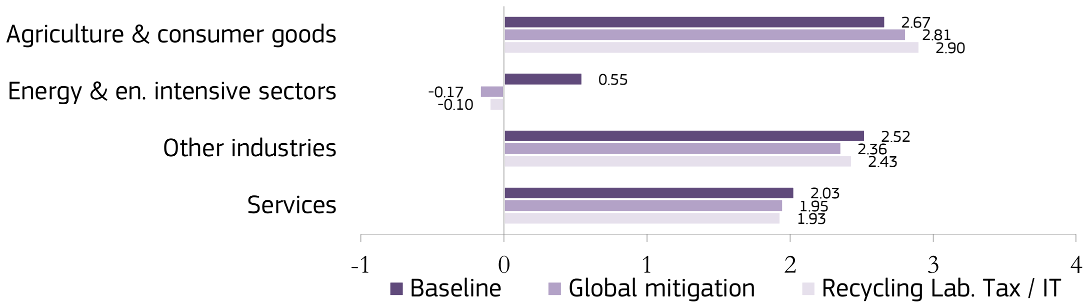
Canada's GDP growth in the Global Mitigation scenario is similar to the Baseline, with an annualised rate of 2% (instead of 2.1%) between 2020 and 2030 (Figure 55). At sectoral level, energy-intensive sectors do not show strong growth in the Baseline, and decrease their output in the Global Mitigation scenario. On the other hand, output is larger than Baseline levels in agriculture and manufactures that are less energy-intensive (consumer goods and electric goods). This increase in domestic production for certain sectors is driven by an increase in export demand (Figure 56). Despite this, overall production in the Global Mitigation scenario remains 2.5% lower than the 2030 Baseline. However, this should be considered a conservative estimate since it assumes no policy measures are taken to diversify the economy.

Figure 55. Canada, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 56. Canada, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 22. Canada, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	10	21	22	22
Energy & Energy Intensive Goods	15	23	21	21
Other Industries	11	38	38	38
Services	64	18	19	19

Source: JRC GEM-E3 model

5.4 China[52]

In the Global Mitigation scenario, China's absolute GHG emissions start to decline after 2020, but the decline is gradual, with emissions still above the 2010 level in 2030, though falling steeply afterwards. This reduction is achieved notably through investments in advanced technologies in the power sectors and energy efficiency improvements in industry, buildings and transport. The modelling identifies these reductions would go with a significant reduction of energy imports.. There could be further benefits to take into account that are not represented here: this modelling framework does not include the costs of adaptation to a warmer climate that would occur under a Baseline scenario, especially for the power sector. The modelling also identifies a significant mitigation potential from reducing non-CO_2 gases in industry.

In terms of economic impacts, GDP growth rates remain higher compared to other regions and are only marginally impacted by the mitigation policy, while a policy of recycling carbon revenues to reduce indirect taxes could provide higher welfare levels than those of the Baseline.

China's GHG emissions represented 25% of the global total in 2010 (excl. LULUCF), and this share is expected to increase over time. In terms of emissions per capita, China is a middle ranking country experiencing a fast increase under the Baseline scenario projections.

China's CO_2 emissions per capita in 2013 from fossil energy use are already estimated to have caught up with EU levels in 2013 (EC JRC-PBL, 2014); under Baseline scenario per capita emission only stabilises from 2040 at about 4 times the 1990 level. The scenarios assume that China meet its pre-2020 pledge, a target of 40-45% decrease of CO_2 intensity compared to 2005 and therefore apply a small CV of less than 5$/t$CO_2$ up to 2020. This assumption is realistic in view of recent developments, whereby the country CO_2 intensity of GDP already decreased by almost 30% in 2005-2013, and the energy intensity of GDP with -20% (Enerdata, 2015a).

In the Global Mitigation scenario China's emissions begin to fall after 2022 (similarly to other studies estimating a peaking in 2025 – see Xu Xiaojie, 2014) and stand at the 1990 level by 2050. However, this fall is more gradual than in the emission profiles of other regions with higher GDP/cap levels. In the Global Mitigation scenario in 2030 GHG emissions are falling but still above the 2010 level.

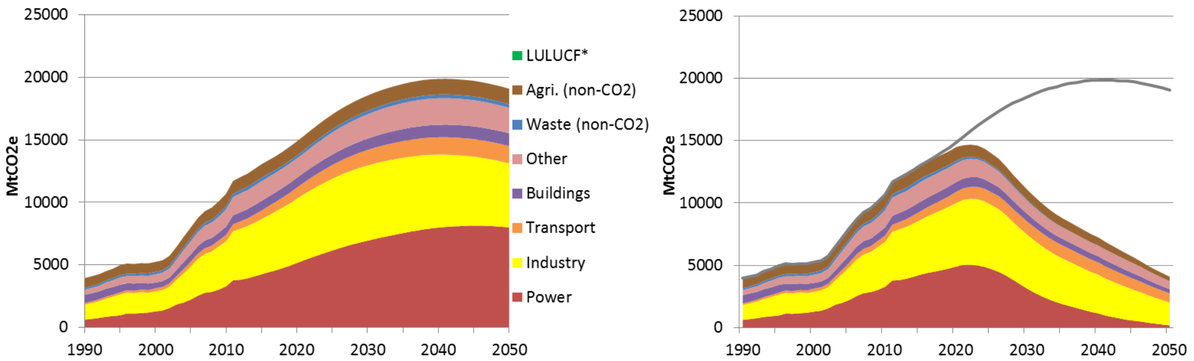
[52] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

Table 23. China decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^9)	1.4	1.4	1.4	1.5	1.4	1.4	117	123	125	123	119
GDP per capita (k$05)	7	13	18	22	32	41	582	1124	1878	2696	3453
GHG ($GtCO_2e$)											
Baseline	10.6	14.8	16.9	18.4	19.6	18.8	270	375	467	499	478
Global Mitigation	10.6	14.4	13.8	10.9	7.1	3.9	270	366	277	179	100
GHG per capita (tCO_2e)											
Baseline	7.8	10.3	11.7	12.6	13.7	13.6	232	305	374	405	402
Global Mitigation	7.8	10.0	9.5	7.5	4.9	2.9	232	298	222	146	84
GHG / GDP (tCO_2e/M$)											
Baseline	1129	771	655	566	330	330	40	27	20	23	23
Global Mitigation	1129	751	536	336	69	69	40	26	12	5	5
Energy / GDP (toe/M$)											
Baseline	255	187	165	147	118	97	41	30	24	19	15
Global Mitigation	255	186	152	119	86	68	41	30	19	14	11
GHG / energy (tCO_2e/toe)											
Baseline	4.4	4.1	4.0	3.8	3.6	3.4	98	91	85	80	75
Global Mitigation	4.4	4.0	3.5	2.8	1.8	1.0	98	89	62	39	23
Source: JRC POLES model											

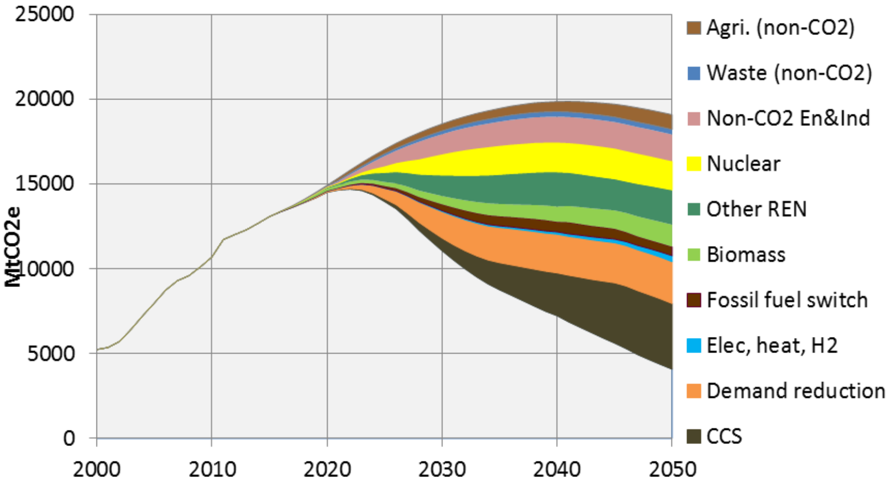
The mitigation effort after 2020 is shared across several sectors, with power emissions almost fully decarbonised in 2050. In 2030 demand reduction makes an important early contribution (24%), ahead of renewables (21%), non-CO_2 from energy & industry (16%) and nuclear (15%). CCS comes in later.

Figure 57. China sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 58. China emission reduction options (excl. LULUCF)



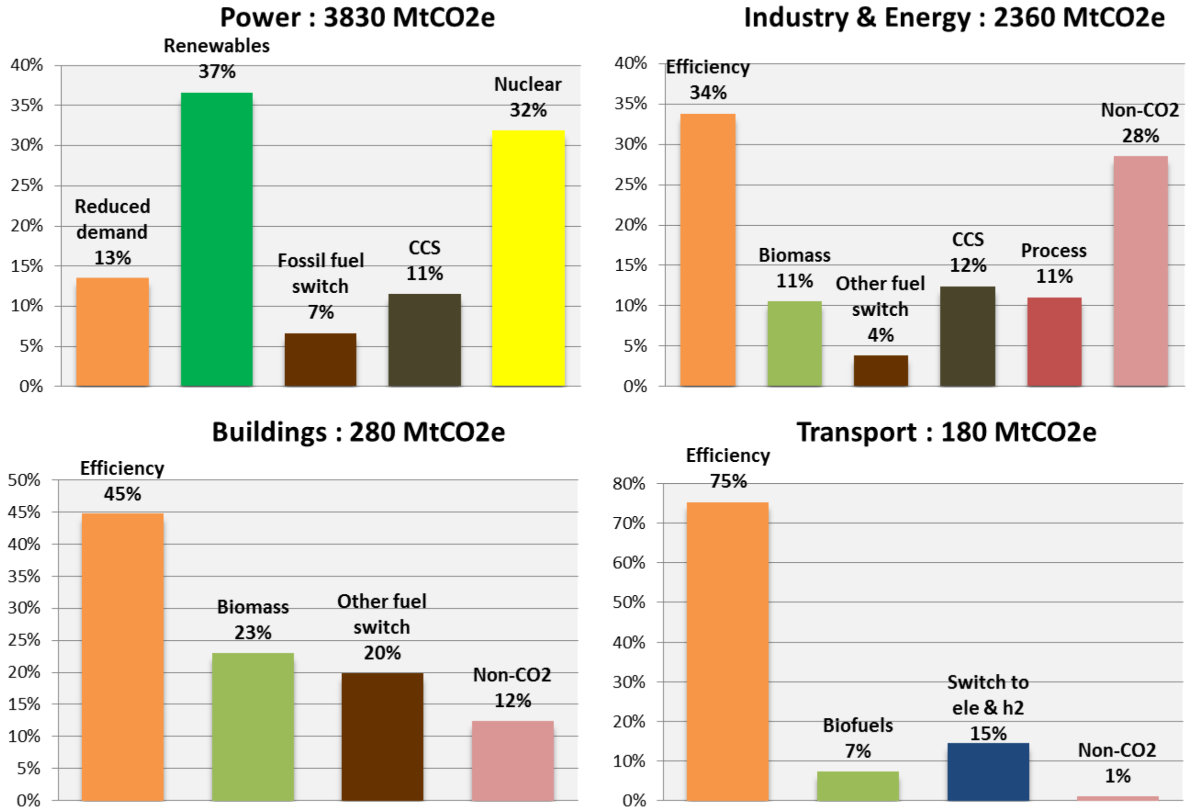
Source: JRC POLES model

Most of the GHG reductions in 2030 take place in the power sector (almost 4 $GtCO_2e$, corresponding to about half the World mitigation in the power sector) and in the industry & energy sector (almost 2.5 $GtCO_2e$, about 40% of World mitigation in these sectors). Buildings and transport represent together less than 10% of the total reductions in China.

Renewables, nuclear and reduced production (induced by reduced electricity demand) are the main options in the power sector. Post-2030 reductions entail substantial use of CCS. Non-CO_2 emissions and efficiency make together almost two-thirds of the total in the industry & energy sectors. Energy efficiency gains are also important in other sectors, accounting for about half the reductions in buildings (ahead of biomass and fossil fuel switch) and 75% in transport (ahead of switch to electricity).

In the Global Mitigation scenario, biomass, wind, solar, hydro can grow to resp. 9%, 7%, 3% and 6% of total gross energy consumption by 2030, increasing the share of low-emission energy to 25%. This is consistent with the analysis of IRENA (2014b) which estimates that it would be both technically and economically feasible to increase the share of modern renewables to 26%, and to double the share of renewables in the power sector from 20% to nearly 40% by 2030. Similarly, the fuel switch in buildings sector in the Global Mitigation scenario, is also consistent with IRENA (2014b) where the building sector is projected to transform its fuel mix to two-thirds renewables.

Figure 59. China emissions mitigation options in sectors – 2030

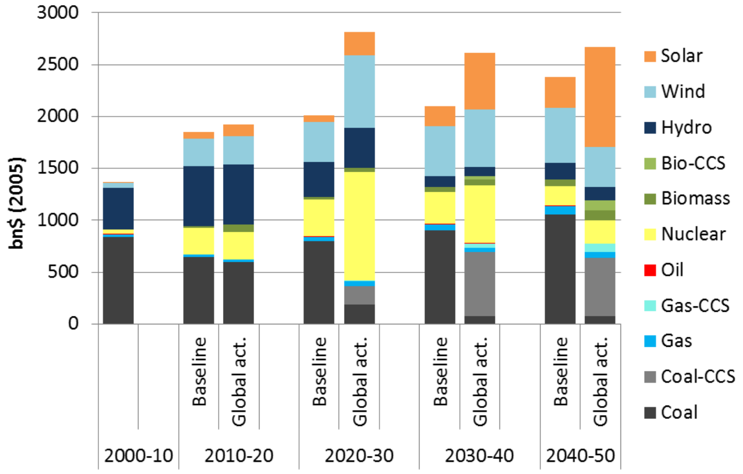


Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

The investment required in the power sector is most considerable in the period 2020-2030, with nuclear absorbing about half the total investment (Figure 60). However, some of these investments replace the investment in coal power that would have occurred in the Baseline. Large investments are already on-going, with, at the beginning of 2015, about 250 GW of capacity under construction or approved, of which 33% is nuclear and 27% is renewables (Enerdata, 2015b).

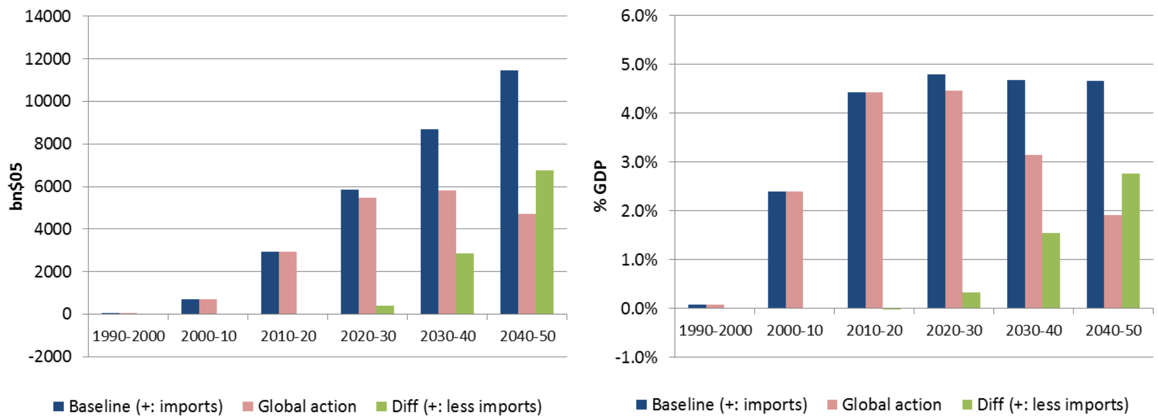
There are co-benefits to this policy, such as a smaller energy trade deficit. Figure 61 shows that by 2050 an equivalent of 3% of GDP can be saved thanks to the combined effects of reduced imports and cheaper prices. Other studies have analysed the energy security benefits of emission reductions in China taking into account the exposure of the country to the price volatility in the global energy markets (GCEC, 2014).

Figure 60. China investment in power (cumulative per decade)



Source: JRC POLES model

Figure 61. China Energy trade (cumulative per decade)

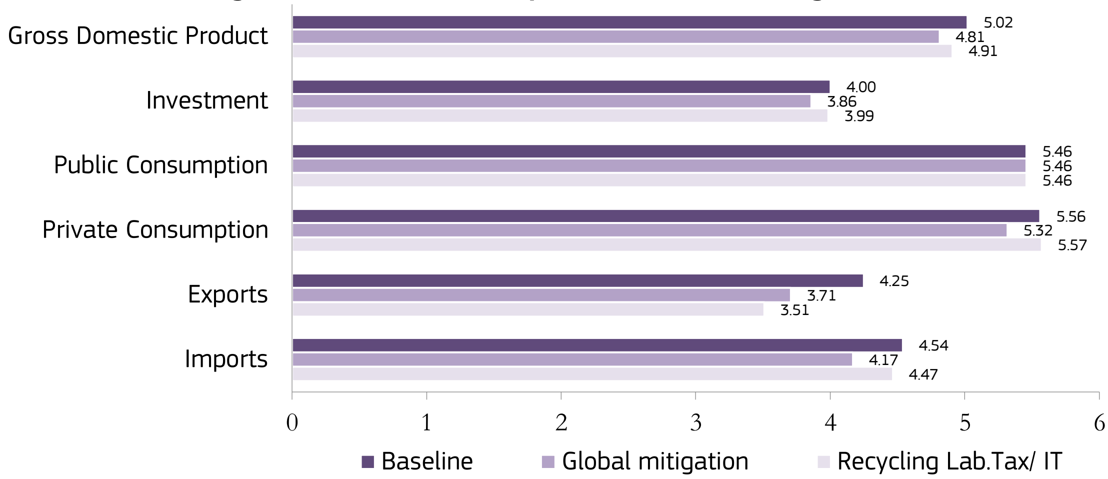


Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

Overall, GDP is expected to grow at 4.8% per year between 2020 and 2030 in the Global Mitigation scenario, compared to 5.0% in the Baseline. When the indirect taxes are reduced through recycling of auctioning revenues the GDP is 4.9% (Figure 62). In the Global Mitigation scenario, most of industrial sectors in China are able to maintain a high growth rates despite the climate change mitigation policies.

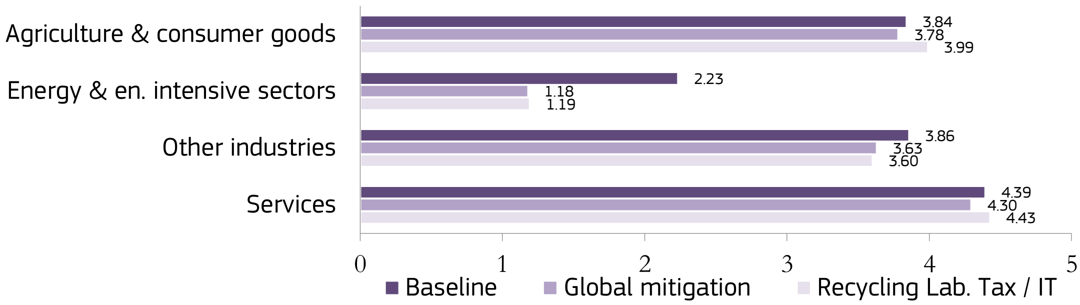
With lower indirect taxes, the total domestic production for agricultural, consumer goods and services increase beyond the Baseline levels (Figure 63). The reduction of indirect taxes through the recycling of auction revenues has beneficial effects on private consumption, which sees slightly higher levels than the Baseline thanks to lower final prices for consumption goods. Imports of energy-intensive products increase since Chinese industrial production remains less energy-efficient than in other regions, while imports in general decrease. Exports also decrease as more production is consumed domestically. This is consistent with the national objectives to diversify the economy and the sources of future economic growth in China from energy-intensive industries towards is domestic private consumption (services) (5th Five year Plan; IMF 2015).

Figure 62. China, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 63. China, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 24. China, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	17	5	6	6
Energy & Energy Intensive Goods	18	19	15	15
Other Industries	22	72	75	75
Services	44	4	4	4

Source: JRC GEM-E3 model

5.5 European Union[53]

In the Global Mitigation scenario, the emissions reductions are distributed across all sectors of the economy up to 2030 and beyond, with a key role for energy savings. Also, advanced mitigation technology options come into play in 2030 like in low-emission transport and CCS which enable to realise deep emission reductions by 2050.

In the Global Mitigation scenario, EU's economic growth is only marginally reduced as the trade balance is improved. In case EU use a smart recycling of auction revenues, EU becomes more competitive and export growth is slightly increased.

In the Baseline, we assume that the EU 2020 policy framework for emission reduction, renewable energy and energy efficiency is fully implemented (EC, 2013a). As a result the EU is one of the most emission-efficient economies amongst the regions in the model. Alongside Japan it has the lowest emissions per unit of GDP, and emissions per capita that are much lower than comparable high income regions by 2020. In the Baseline, this trend of reducing emissions is set to continue up to 2050, but not at a level sufficient for the aims of the Global Mitigation scenario.

Table 25. EU28 decomposition of GHG (excl. LULUCF)

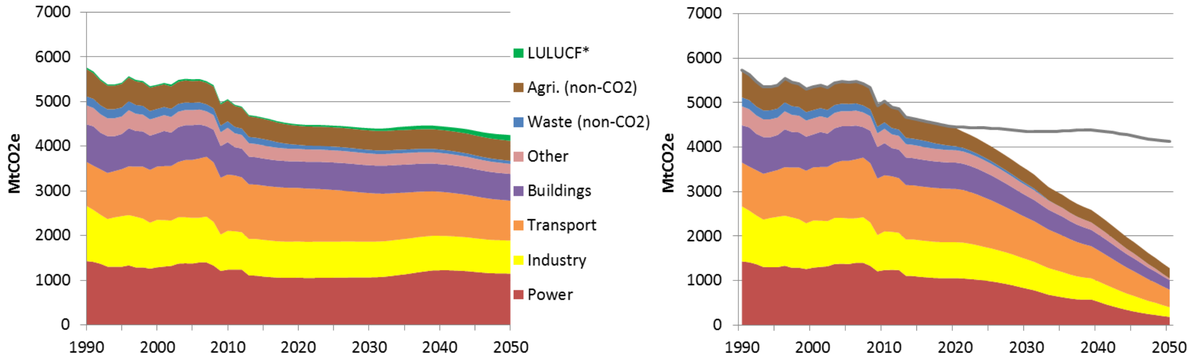
							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	507	517	519	519	518	513	106	108	109	108	107
GDP per capita (k$05)	28	31	34	37	42	49	136	155	180	208	240
GHG ($MtCO_2e$)											
Baseline	4693	4095	4042	3959	3940	3672	85	74	72	72	67
Global Mitigation	4693	4068	3657	3140	2150	1071	85	74	57	39	19
GHG per capita (tCO_2e)											
Baseline	9.3	7.9	7.8	7.6	7.6	7.2	80	69	66	66	62
Global Mitigation	9.3	7.9	7.1	6.0	4.2	2.1	80	68	53	36	18
GHG / GDP (tCO_2e/M$)											
Baseline	336	252	229	208	180	147	59	44	37	32	26
Global Mitigation	336	250	208	165	98	43	59	44	29	17	8
Energy / GDP (toe/M$)											
Baseline	125	102	96	90	79	69	74	60	53	47	41
Global Mitigation	125	102	94	84	68	56	74	60	49	40	33
GHG / energy (tCO_2e/toe)											
Baseline	2.7	2.5	2.4	2.3	2.3	2.1	81	74	69	68	63
Global Mitigation	2.7	2.5	2.2	2.0	1.4	0.8	81	74	59	43	23
Source: JRC POLES model											

In the Global Mitigation scenario, EU emissions are reduced in all sectors by 2020 and beyond, consistent with the EU decisions on its 2020 and 2030 climate and energy policy framework (European Council, 2014). Emissions reductions occur among power, industry, buildings and transport, as Figure 64 to Figure 66 show. Additional efficiency savings and reductions in demand are projected to be a key mitigation technology from 2020 onwards in buildings, transport and industry. Additional renewable deployment is also projected in the power sector, alongside

[53] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

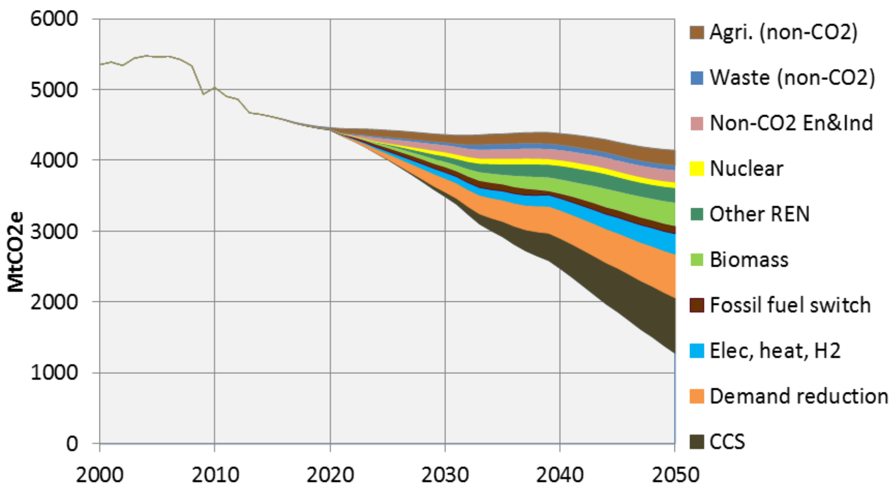
switching to cleaner fuels in both power and transport. CCS also has a vital role to play in the long-run, becoming a large emissions reduction tools in the 2040-2050 period.

Figure 64. EU28 sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



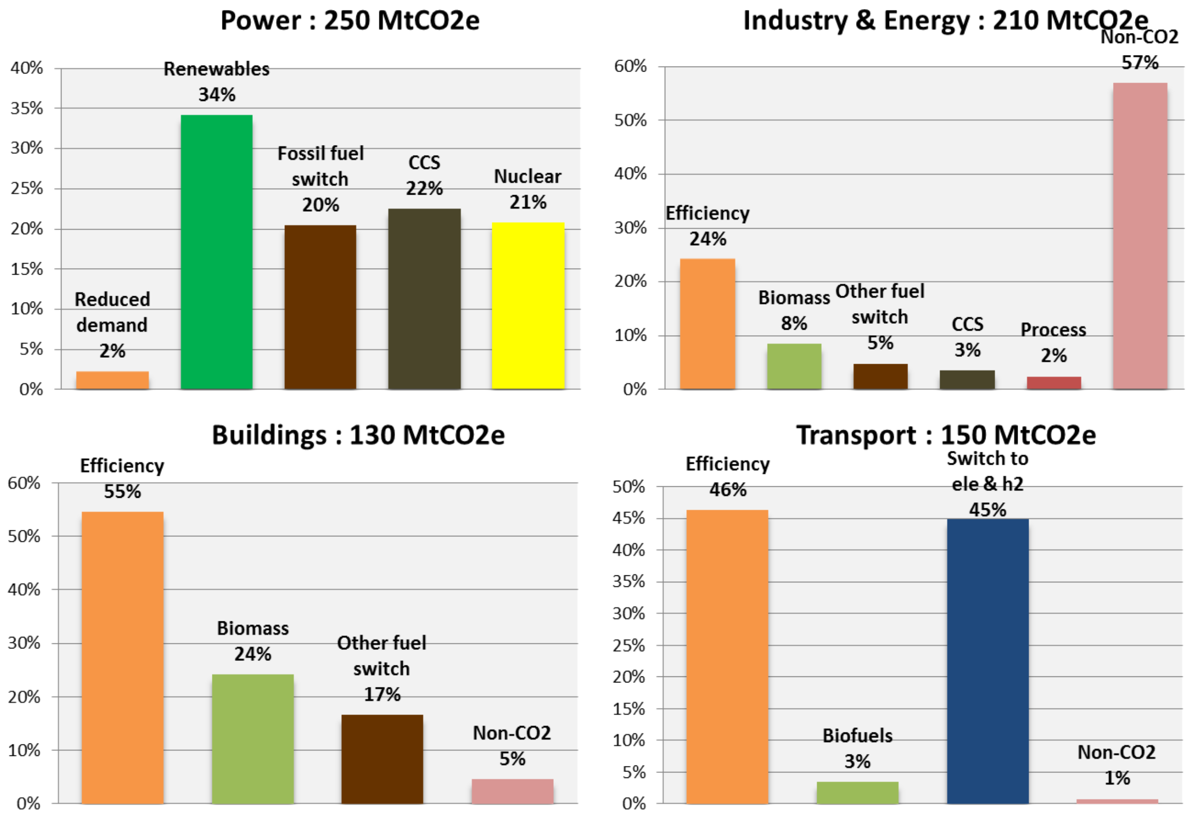
Source: JRC POLES model

Figure 65. EU28 emission reduction options (excl. LULUCF)



Source: JRC POLES model

Figure 66. EU28 emissions mitigation options in sectors - 2030

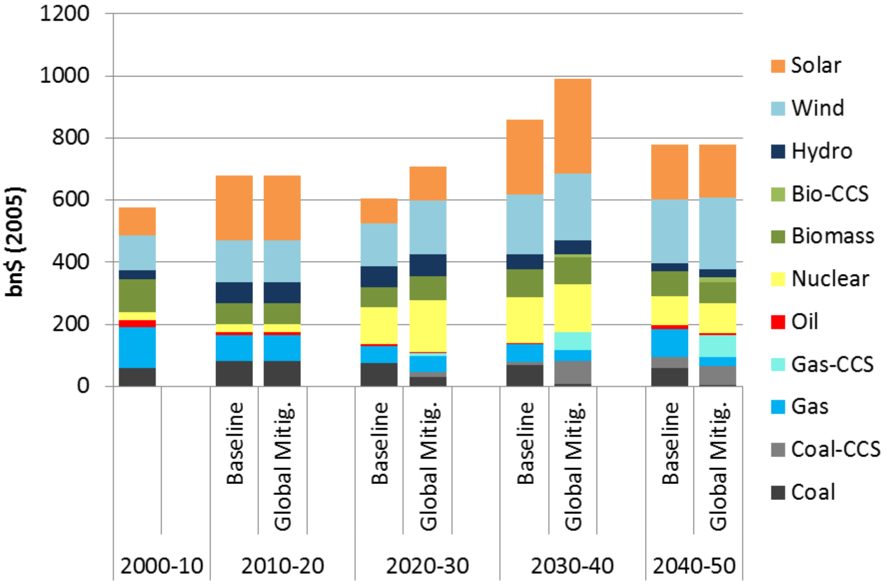


Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

In total, the additional investment required in the power sector under the Global Mitigation scenario is modest. This reflects the level of mitigation already included in the Baseline, as well as the high share of mitigation effort undertaken by final demand sectors (notably through energy efficiency). In the period 2020-2040, total investment is expected to be around 15% above the Baseline level, with greater deployment of wind, nuclear and solar, and with coal CCS and gas CCS replacing the investment that would have been made in their unabated equivalents. By 2050, the amount and composition of power sector investment is similar to Baseline levels.

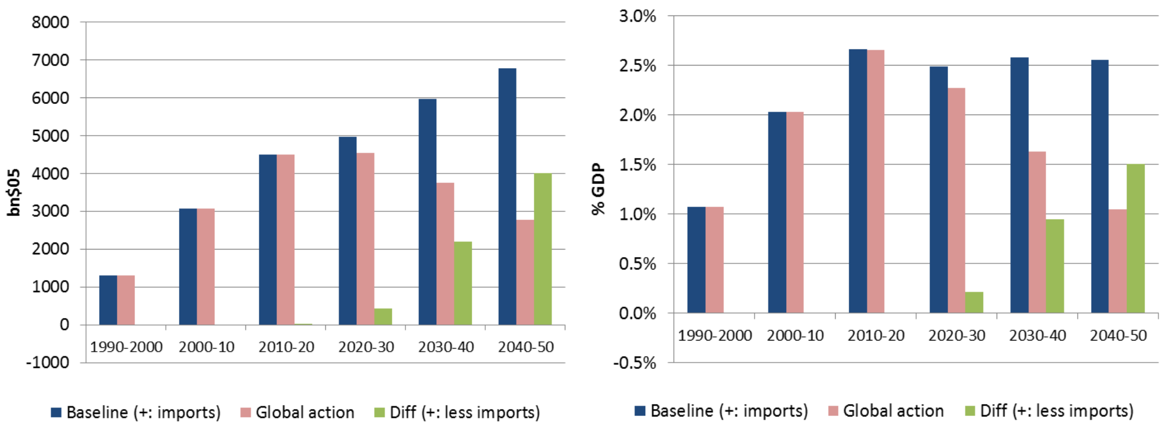
As Figure 68 shows, this increased investment brings benefits in terms of energy security and the energy trade balance. The additional mitigation analysed in the Global Mitigation scenario brings a reduction in the EU's energy trade deficit that is equivalent to 1% of GDP in 2030-2040, and over 1.5% in the following decade.

Figure 67. EU28 investment in power (cumulative per decade)



Source: JRC POLES model

Figure 68. EU28 Energy trade (cumulative per decade)

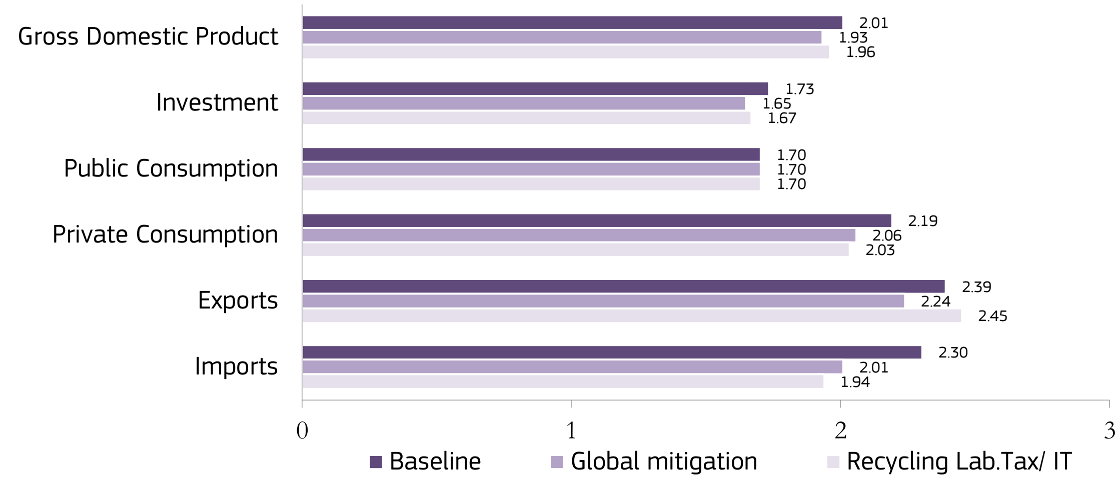


Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

The macro-economic modelling shows also an improvement of the net trade balance of all types of goods. The total net exports fall, but a stronger decrease occurs for import volumes in the Global Mitigation scenario. When the Global Mitigation scenario is combined with a reduction of labour taxes through the recycling of auction revenues, the results show an improvement of competitiveness with total exports increasing (+0.6% compared to Baseline in 2030). This insight is in line with the 2030 Impact Assessment of the European Climate and Energy Package for 2030 (EC, 2014).

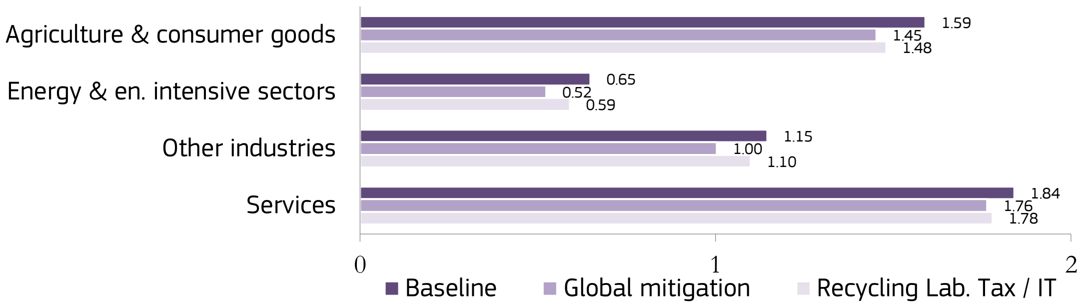
Typically, services make up a large share of the economies of the highest-income regions. The EU is a good example: services correspond to about 66% of the economy in 2030 in the Baseline. Some market and public services are not carbon-intensive, but it is important to note that transportation (included in Services in Figure 70) is an important source of emissions. The necessary transformation in the transport sector results in a small reduction in the growth rate of service sectors.

Figure 69. EU28, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 70. EU28, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 26. EU28, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	9	9	9	9
Energy & Energy Intensive Goods	13	17	18	18
Other Industries	12	29	28	28
Services	66	45	44	44

Source: JRC GEM-E3 model

5.6 India[54]

The Global Mitigation scenario translates in a late peaking in India's emissions, as this scenario is taking into account its low initial levels of income per capita. Under this scenario, India reduces its emissions through energy efficiency across all sectors and by deploying renewable energy. Such a scenario would lead to a transformation of the energy sector significantly contributing to improving India's energy trade balance.

The domestic and global mitigation efforts do not limit significantly India's potential to grow economically, despite its export dependence on energy-intensive goods. Auction revenue recycling towards the reduction of indirect taxes increases welfare and investments and leads to increased domestic production of consumption goods. The results indicate that there are also significant energy security benefits at stake.

In the Baseline scenario, we assume that by 2020 India is likely to achieve its pre-2020 pledge of a 20-25% reduction in the GHG intensity of GDP compared to 2005. After that, the Baseline projects an increase in emissions of 1.1 $GtCO_2e$ (+33%) between 2020 and 2030 with further increases thereafter. In the Global Mitigation scenario, emissions still rise after 2020 but by a lesser amount. Emissions stabilise at 6% above the 2020 level by 2025 and remain at this level until after 2030. The Global Mitigation scenario also enables an increase in emissions per capita up to 2030, since present per capita emissions, at 2.2 tCO_2e, are relatively low. However, like all countries and regions in the Global Mitigation scenario, India reduces GHG emissions in absolute and per capita terms after 2030.

Table 27. India decomposition of GHG (excl. LULUCF)

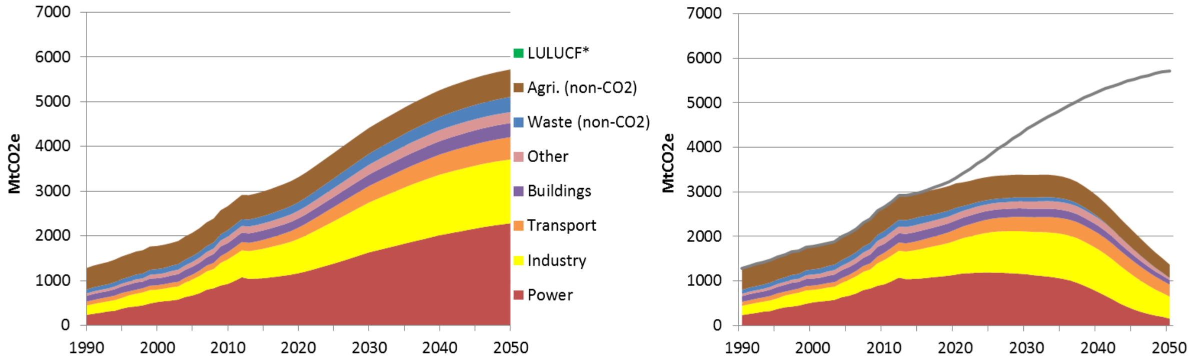
							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^9)	1.2	1.4	1.4	1.5	1.6	1.6	139	156	170	180	186
GDP per capita (k\$05)	3	5	7	9	14	20	257	412	713	1122	1612
GHG ($GtCO_2e$)											
Baseline	2.7	3.3	3.8	4.4	5.2	5.6	208	258	343	406	438
Global Mitigation	2.7	3.2	3.3	3.3	2.8	1.3	208	249	262	222	104
GHG per capita (tCO_2e)											
Baseline	2.2	2.4	2.7	3.0	3.3	3.5	150	166	202	225	235
Global Mitigation	2.2	2.3	2.3	2.3	1.8	0.8	150	160	154	123	56
GHG / GDP (tCO_2e/M\$)											
Baseline	705	485	405	341	176	176	58	40	28	18	18
Global Mitigation	705	467	352	261	42	42	58	39	22	4	4
Energy / GDP (toe/M\$)											
Baseline	187	136	117	101	75	57	64	46	35	26	20
Global Mitigation	187	136	112	93	64	42	64	46	32	22	14
GHG / energy (tCO_2e/toe)											
Baseline	3.8	3.6	3.5	3.4	3.2	3.1	92	86	82	78	75
Global Mitigation	3.8	3.4	3.1	2.8	2.1	1.0	92	84	68	50	24

Source: JRC POLES model

54 This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

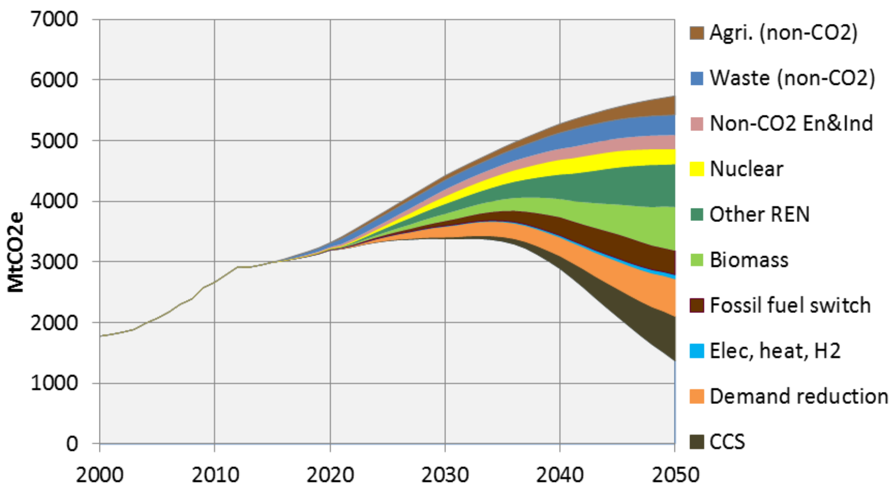
Figure 72 shows that India's GHG reductions under the Global Mitigation scenario can be met with a balanced mix of contributions from all sectors and technologies. Eight of the ten mitigation options shown in contribute between 7% and 18% of the total mitigation in 2030, with CCS still remaining marginal at this time horizon.

Figure 71. India sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 72. India emission reduction options (excl. LULUCF)

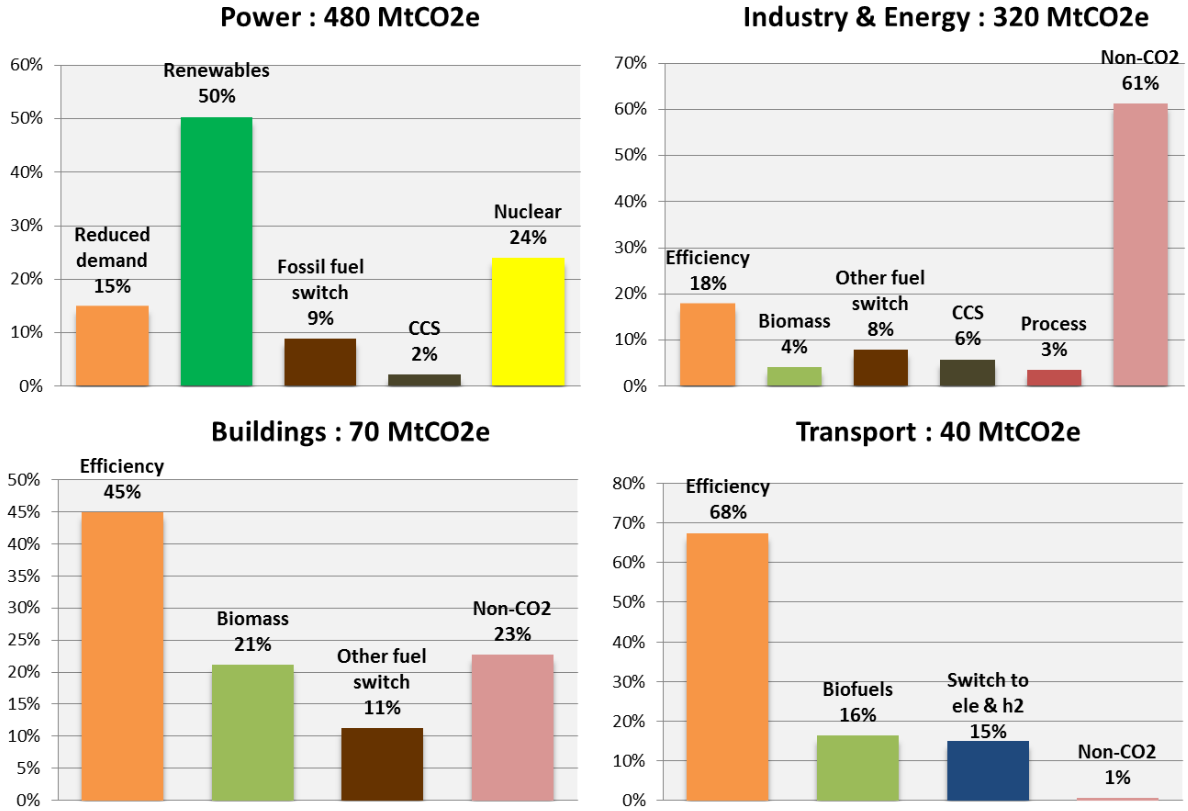


Source: JRC POLES model

Figure 73 shows that about 50% of the total reductions (excluding GHG from agriculture and LULUCF) take place in the power sector, with renewables accounting for half of this, and with major contributions from nuclear and reduced demand. The industry & energy sectors contribute 35% to the total reductions. Non-CO_2 emissions are responsible for more than 60% of this. Buildings and transport represent together only 12% of total reductions in 2030. Here, the main options are energy efficiency, followed by biomass in buildings and some switch towards liquid biofuels and electric cars in transport.

These modelling results are realistic as India has already put in place a number of energy and climate policies in some of the areas mentioned in the Global Mitigation scenario. These include the PAT scheme for energy efficiency and targets for a 15% share of renewable energy by 2020, and 100 GW of solar capacity by 2022 as part of a renewable energy target of 175 GW capacity by 2022 (a much faster rate of solar deployment than projected in the Global Mitigation scenario). Other studies also estimate a large mitigation potential in these sectors of over 1.2 $GtCO_2e$ by 2030 (Den Elzen et al., 2015), or identify co-benefits associated to these projected developments (GCEC, 2015).

Figure 73. India emissions mitigation options in sectors – 2030

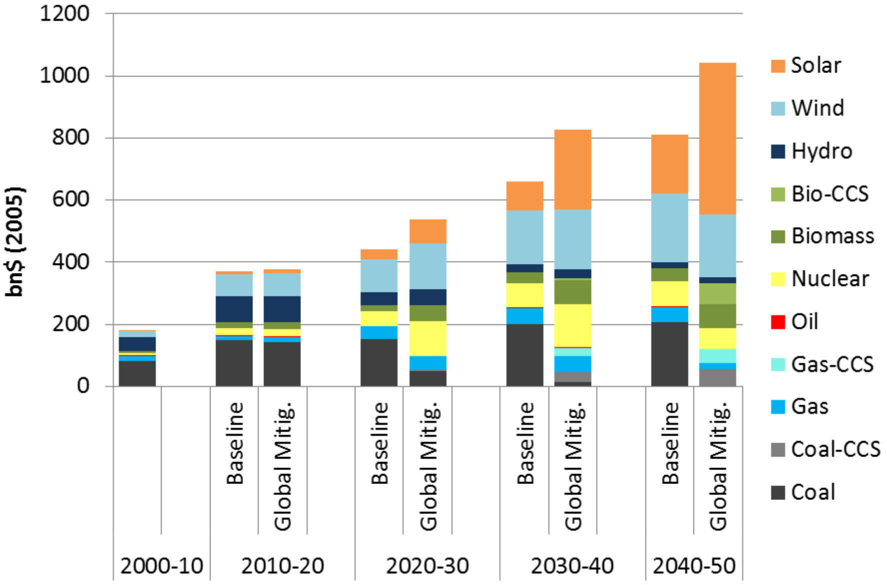


Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

Reaching the mitigation levels of the Global Mitigation scenario in the power sector requires a gradual increase in investment compared to the Baseline (Figure 74). The extra investment becomes more notable after 2030. The change in investment initially takes the form of increased nuclear deployment displacing investments in coal. By 2050 total investment remains 25% higher than in the Baseline, with a very large increase in solar capacities (more than doubling compared to the Baseline). By then, most fossil fuel and biomass investments go together with CCS.

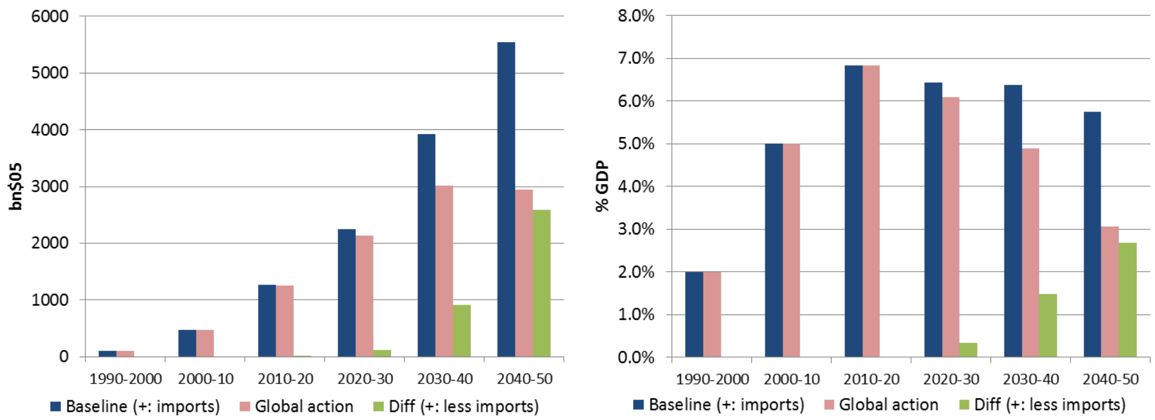
The transformation significantly contributes to the improvement in India's energy trade balance. By 2050, India's energy imports in the Global Mitigation scenario are less than half what they would be under the Baseline, a saving equivalent to 3% of GDP (Figure 75).

Figure 74. India investment in power (cumulative per decade)



Source: JRC POLES model

Figure 75. India Energy trade (cumulative per decade)



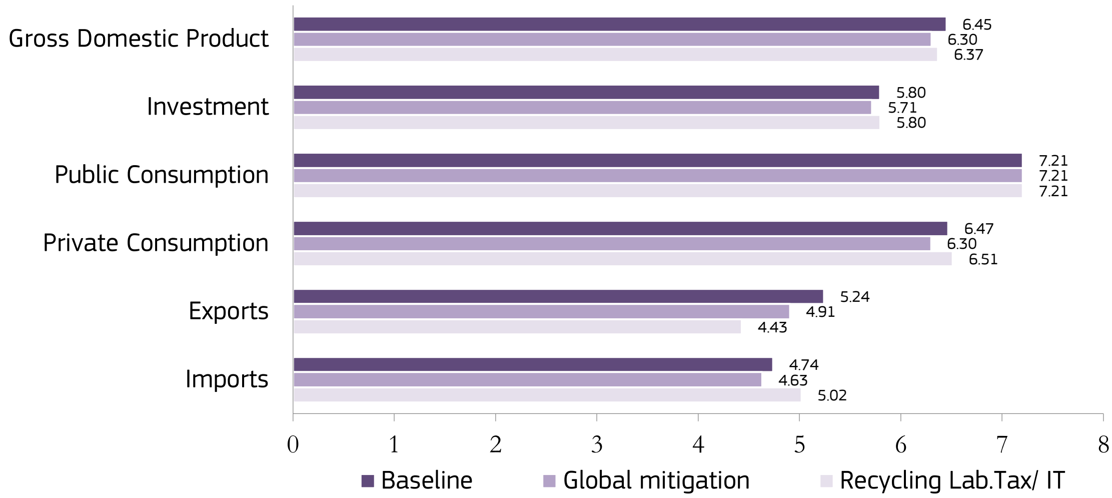
Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

Since the Global Mitigation scenario allows India to continue increasing GHG emissions up to 2030, the scenario has only a marginal effect on economic growth. The effect is felt through increased domestic production costs, which lead to a slightly lower level of private consumption and exports. The macro-economic variables improve when the Global Mitigation scenario is combined with an auctioning of the emission allowances and revenue recycling into the reduction of indirect taxes. The GDP growth rate improves almost back to the Baseline growth rate Private consumption and households' real disposable income increase slightly above Baseline levels generating additional welfare gains.

On a sectoral level, energy-intensive industrial goods (which are also export-intensive) are negatively impacted the most. However, agricultural exports increase, while with the lowering of indirect taxes, the production of agricultural, consumer goods and services is increase beyond Baseline levels.

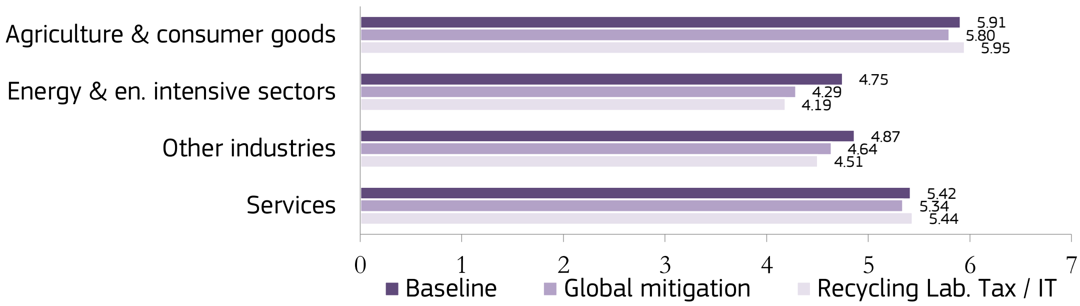
Since the important sectors for employment in India – agriculture, construction and services – are only marginally affected or even benefitting from climate and energy policies, the number of jobs is stable across scenarios compared to the Baseline.

Figure 76. India, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 77. India, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 28. India, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	24	7	7	7
Energy & Energy Intensive Goods	19	59	59	59
Other Industries	11	27	27	27
Services	46	7	7	7

Source: JRC GEM-E3 model

5.7 *Indonesia*[55]

Compared to other countries, Indonesia's national greenhouse gas emissions are influenced much more heavily by land use, land-use change and forestry (LULUCF). Per capita emissions, at around 10 tCO_2e, stand at a level similar to the EU. Yet emissions excluding LULUCF are little over 3 tCO_2e per capita.

Excluding LULUCF, Indonesia's Baseline emissions are expected to increase steadily from 700 $MtCO_2e$ in 2010 to over 1100 $MtCO_2e$ by 2030. In the Global Mitigation scenario, emissions remain at 800 $MtCO_2e$ in 2030 before falling to 480 $MtCO_2e$ by 2050. This reduction is shared fairly evenly among a wide range of sectors, from renewable energy and energy efficiency to agriculture and waste.

The GHG emissions of Indonesia are dominated by land use and land-use change (LULUCF), both in absolute terms and in terms of mitigation potential (Figure 78). Emissions per capita in 2010 reach about 10 tCO_2e when LULUCF is included compared to a low level of around 3 tCO_2e per capita when it is not. LULUCF emissions and related reductions are not further considered in this analysis since the modelling conducted concentrates on emissions from fossil fuel combustion in energy and industrial uses.

Without any specific policies, emissions per capita (excl. LULUCF) stabilise at around 4 tCO_2e per capita from 2040 onwards. In the Global Mitigation scenario emissions per capita (excl. LULUCF) decrease slowly between 2020 and 2030, and then undergo a steeper decline by 2050, thanks in particular to rapid decarbonisation of the energy sector.

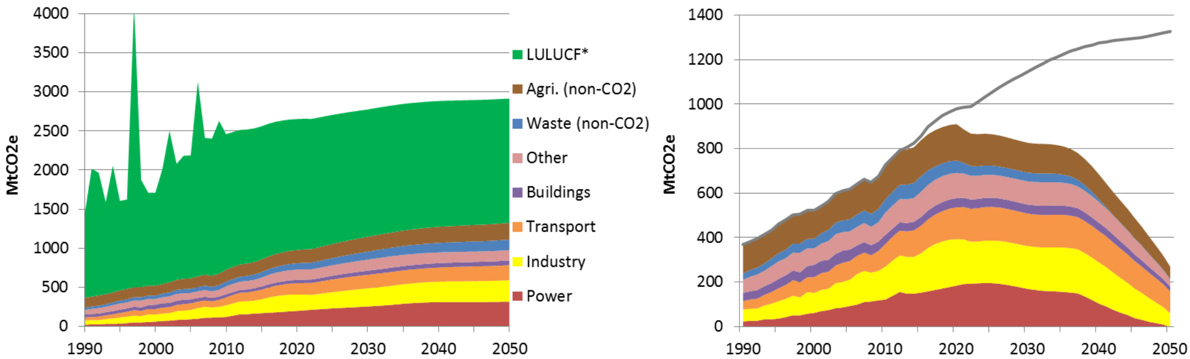
[55] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

Table 29. Indonesia decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	241	269	282	293	311	321	135	151	164	174	180
GDP per capita (k$05)	4	6	8	10	14	19	187	299	460	653	900
GHG ($MtCO_2e$)											
Baseline	723	973	1049	1141	1267	1318	198	267	313	348	362
Global Mitigation	723	906	860	821	679	263	198	249	225	186	72
GHG per capita (tCO_2e)											
Baseline	3.0	3.6	3.7	3.9	4.1	4.1	147	177	191	200	201
Global Mitigation	3.0	3.4	3.0	2.8	2.2	0.8	147	165	137	107	40
GHG / GDP (tCO_2e/M$)											
Baseline	776	583	478	408	301	220	79	59	41	31	22
Global Mitigation	776	542	392	294	161	44	79	55	30	16	4
Energy / GDP (toe/M$)											
Baseline	214	163	138	123	95	73	82	62	47	36	28
Global Mitigation	214	168	137	118	92	57	82	64	45	35	22
GHG / energy (tCO_2e/toe)											
Baseline	3.6	3.6	3.5	3.3	3.2	3.0	97	95	89	84	80
Global Mitigation	3.6	3.2	2.9	2.5	1.8	0.8	97	86	66	47	20
Source: JRC POLES model											

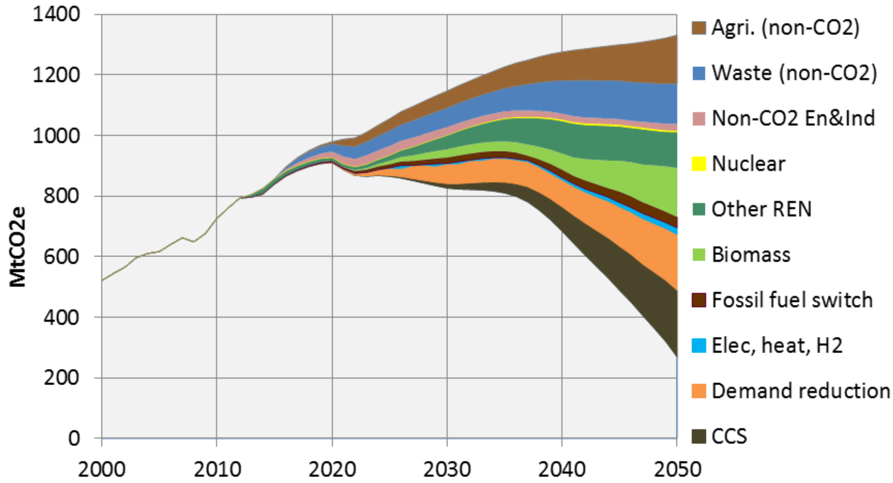
We assume Indonesia will meet its pre-2020 pledge that involves reducing 2020 emissions domestically by 26% compared to a business-as-usual scenario. Measures introduced under the National Action Plan to Reduce Greenhouse Gas emissions should contribute savings of 38-56 $MtCO_2$ in the energy and transport sectors (IEA, 2015). In our Baseline scenario, this translates into an increase of emissions by 2020 compared to 2010, which are expected to rise from around 700 $MtCO_2e$ in 2010 to almost 1000 $MtCO_2e$ in 2020, over 1100 $MtCO_2e$ by 2030 and about 1300 $MtCO_2e$ by 2050 (excl. LULUCF). In the Global Mitigation scenario, by contrast, emissions fall gradually to 800 $MtCO_2e$ by 2030 and 480 $MtCO_2e$ by 2050. The dominant mitigation options by 2030 are energy efficiency (22%), reduced emissions from waste (20%) and agriculture (17%), and increased use of renewables (9% for biomass alone, 13% for other renewables). CCS remains a limited option throughout the entire period.

Figure 78. Indonesia sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 79. Indonesia emission reduction options (excl. LULUCF)

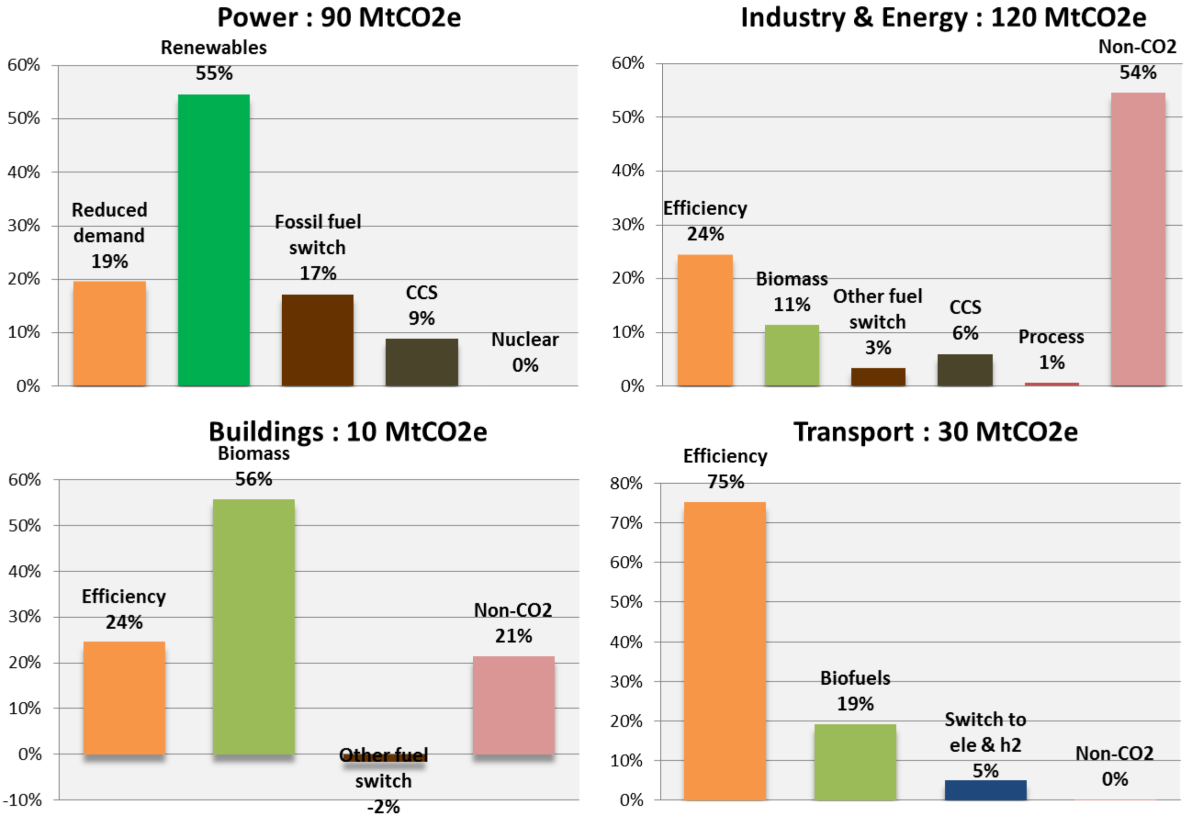


Source: JRC POLES model

The industry & energy sectors contribute most to the GHG reductions (excl. emissions from agriculture and LULUCF) with non-CO_2[56] representing more than half of the effort, ahead of energy efficiency. In the power system renewables is the first option (52%), followed by reduced electricity demand (21%) and switch to gas (18%). These results are in line with the National Energy Policy that aims at increasing the share of renewable energy to 23% (compared to 5% in 2012), including a 15% biofuel share in transport fuel (Den Elzen et al., 2015). As for many other emerging economies in the Global Mitigation scenario, energy efficiency and biomass are the main options for total GHG abatement in 2030, whereas the contributions of buildings and transport remain limited (with energy and biomass being the main options here) (Figure 80).

[56] mostly CH_4 emissions from the coal production sector

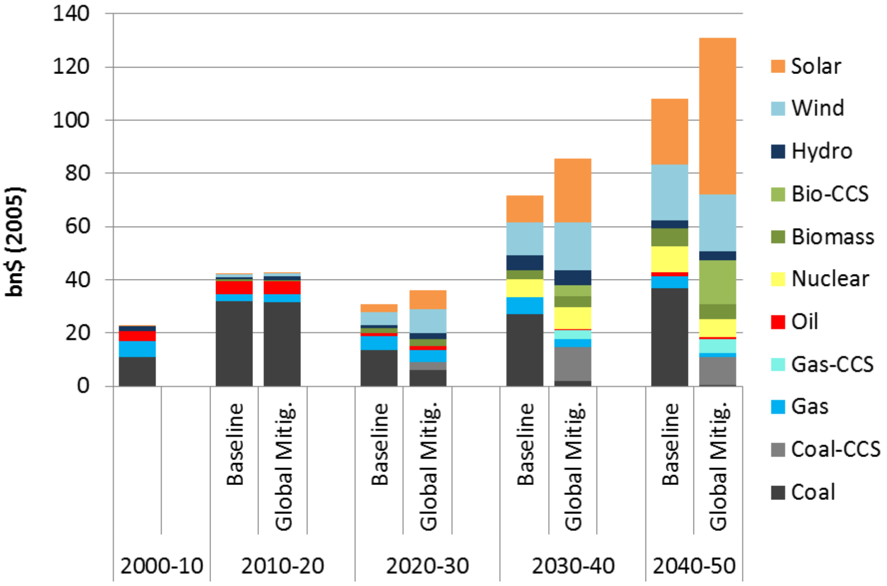
Figure 80. Indonesia emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

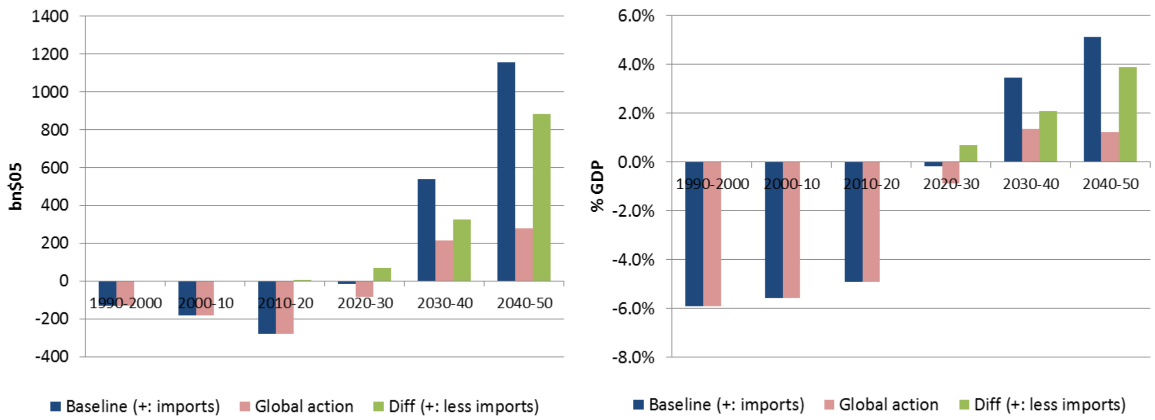
The investment pattern reflects the inflexion towards more renewables after 2020, which represent more than half the investments in the power sector from 2030 onwards, with solar alone amounting 40% in 2040-2050. Indonesia is a net importer of oil and recently started importing LNG (IEA 2013b). With increased domestic energy demand, Indonesia becomes a net energy importer (in value) by 2030. Hence, the savings associated to the mitigation policy outweigh the additional investment in the power system.

Figure 81. Indonesia investment in power (cumulative per decade)



Source: JRC POLES model

Figure 82. Indonesia Energy trade (cumulative per decade)

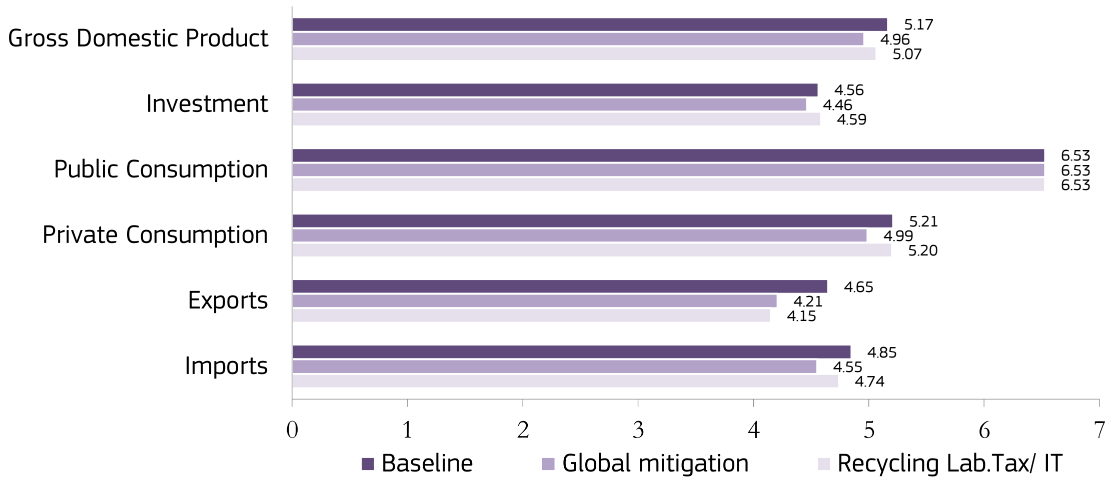


Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

In the Global Mitigation scenario Indonesia sees a decline in economic activity compared to the Baseline. The main drivers for the loss in GDP are of private consumption and exports. However, the negative impact on the economy is among the lowest among fossil fuel producing countries. This is due to the fact that Indonesia's economy is quite diversified with a relative small share of fossil fuel producing sectors and other sectors, such as consumer and agricultural goods, services and electric goods, being predominant.

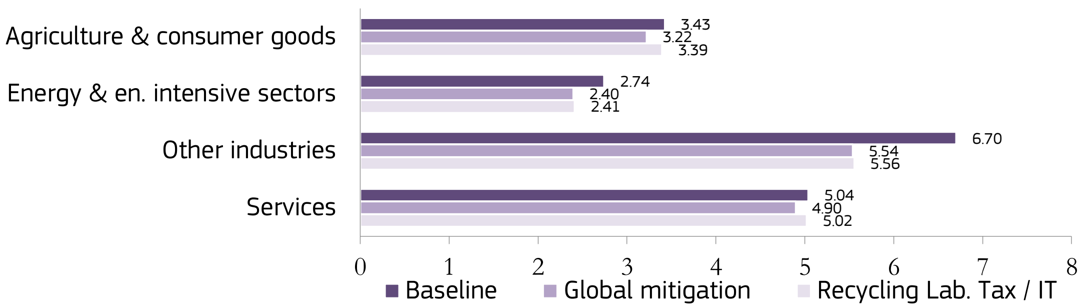
Using the auctioning revenues to lower the indirect tax rates brings back private consumption and investment to Baseline levels. On a sectoral level, the largest exporting sector is the one presenting the highest reduction in production, namely the industrial sectors and especially the electric and equipment goods.

Figure 83. Indonesia, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 84. Indonesia, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 30. Indonesia, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	19	18	19	19
Energy & Energy Intensive Goods	20	30	34	33
Other Industries	13	49	44	45
Services	48	3	3	3

Source: JRC GEM-E3 model

5.8 Japan[57]

Japan has emissions per capita standing at over 9 tCO_2e in 2010, and in the Baseline they are projected to remain at this level up to 2050. In the Global Mitigation scenario Japan lowers emissions gradually before making sharp reductions after 2030. However, both Baseline and Global Mitigation scenario assume that nuclear remains a key part of the power mix.

If nuclear generation in Japan is phased out, it is still possible to meet emissions reductions similar to the Global Mitigation scenario. In this case, nuclear is replaced by increases in the use of wind power, oil and gas, as well as reductions in energy use.

Although Japan's GDP displays an emissions intensity that was less than half the world average in 2010, emissions per capita are at 9.7 tCO_2e per capita and have actually worsened recently with the temporary suspension of most nuclear plants replaced by coal and gas power production. Under current conditions, and even with nuclear capacities back in the power mix, overall emissions will remain stable throughout the period to 2030 – we assumed Japan is respecting the pledge for 2020 of a 3.8% reduction compared to 2005.

Table 31. Japan decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	127	125	123	121	115	108	104	103	99	94	89
GDP per capita (k$05)	31	35	37	40	46	53	116	130	149	173	199
GHG ($MtCO_2e$)											
Baseline	1232	1176	1180	1176	1082	1045	103	99	98	91	88
Global Mitigation	1232	1170	1053	879	572	318	103	98	74	48	27
GHG per capita (tCO_2e)											
Baseline	9.7	9.4	9.6	9.7	9.5	9.7	99	96	100	97	99
Global Mitigation	9.7	9.3	8.5	7.3	5.0	2.9	99	96	75	51	30
GHG / GDP (tCO_2e/M$)											
Baseline	312	270	258	244	204	181	86	74	67	56	50
Global Mitigation	312	268	230	183	108	55	86	74	50	30	15
Energy / GDP (toe/M$)											
Baseline	126	111	108	103	94	85	93	82	77	69	63
Global Mitigation	126	111	105	95	82	70	93	82	71	61	52
GHG / energy (tCO_2e/toe)											
Baseline	2.5	2.4	2.4	2.4	2.2	2.1	91	90	88	81	79
Global Mitigation	2.5	2.4	2.2	1.9	1.3	0.8	91	90	71	48	29

Source: JRC POLES model

In the Global Mitigation scenario, emissions reductions (excluding LULUCF) reach 30% in 2030 compared to 2010, and 75% in 2050 compared to 1990, hence close to the -80% objective set in the national 4th Basic environment Plan[58].

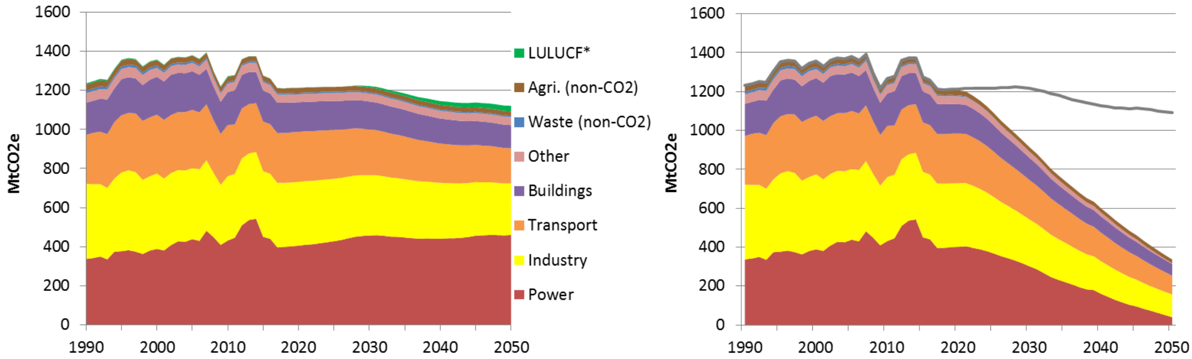
In the Global Mitigation scenario, most of the emission reductions projected for Japan come from CO_2 reductions as non-CO_2 in agriculture, waste, energy and industry contribute little to Japan's

[57] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

[58] https://www.env.go.jp/en/focus/docs/files/20120427-01_01.pdf

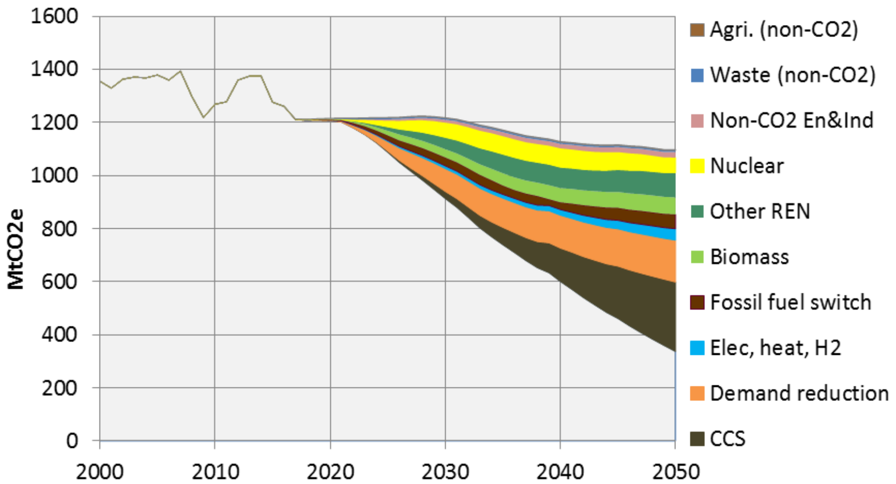
emissions. By 2030 increased energy efficiency represents about a third of the mitigation effort and renewables a fourth. CCS still plays limited role by then (9%) but could do more in the future provided all new plants are CCS-ready. Nuclear remains here an important option – see section below for an analysis of the impact of nuclear phase-out.

Figure 85. Japan sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

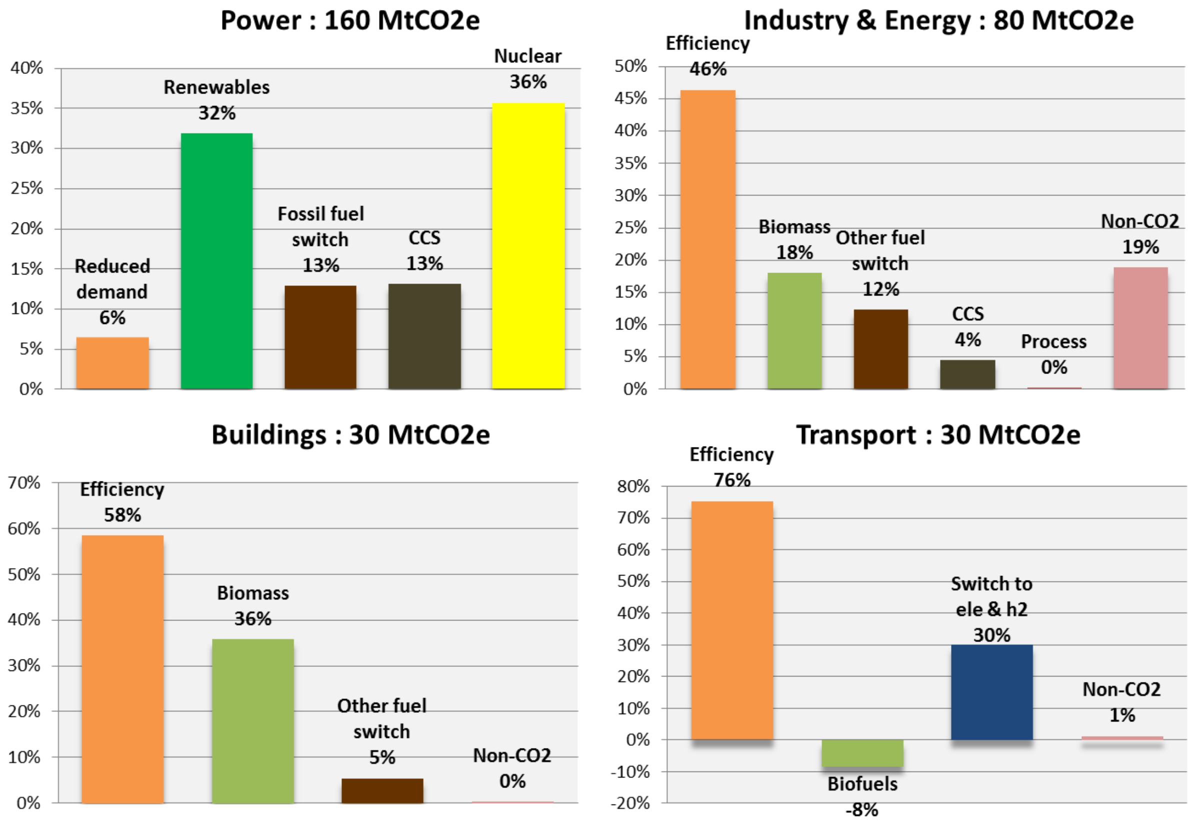
Figure 86. Japan emission reduction options (excl. LULUCF)



Source: JRC POLES model

The power sector represents more than half the total GHG reductions in 2030, with nuclear and renewables representing each about a third of the effort. Fossil fuel switch, CCS and reduced electricity demand share the last third. Other studies also identify a large mitigation potential from energy efficiency for vehicles, appliances and buildings (Den Elzen et al., 2015). In the Global Mitigation scenario, the increased use of biomass in industry and buildings comes at the expense of biofuels in transport where the switch to electric cars is predominant.

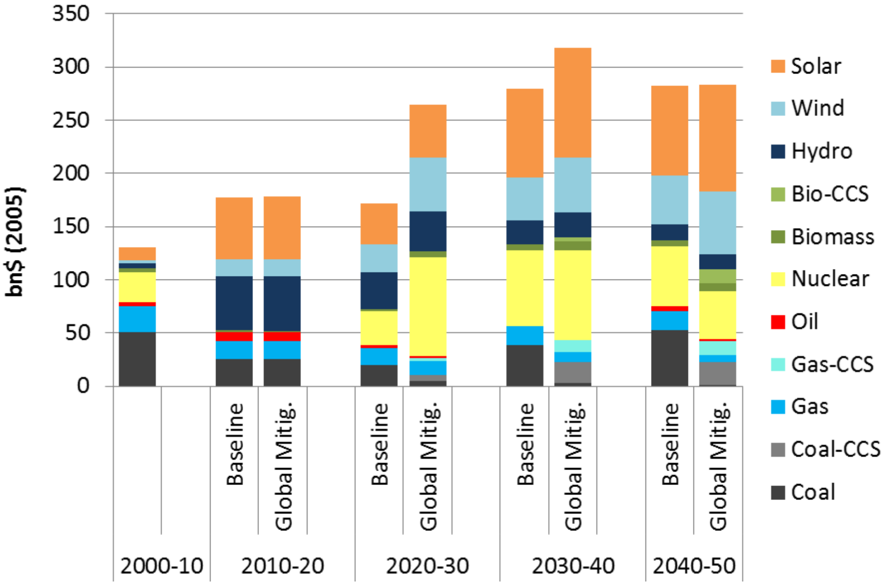
Figure 87. Japan emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

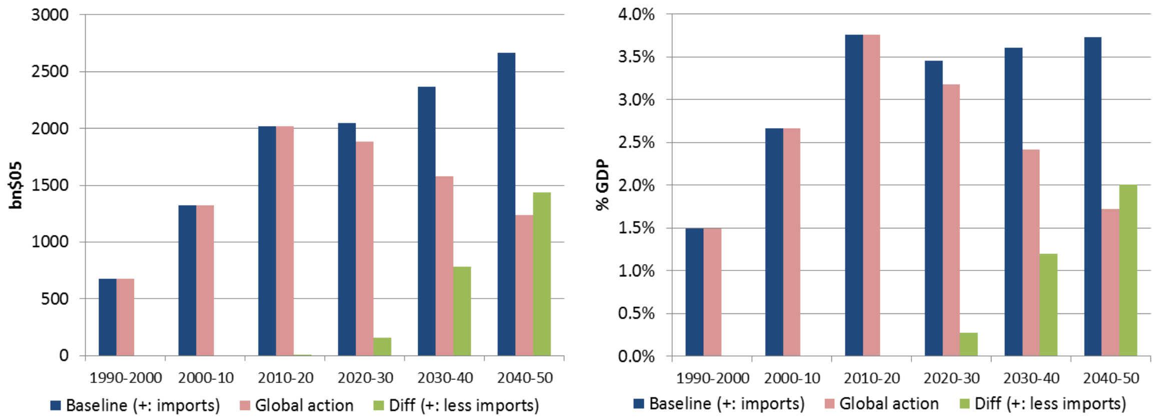
Figure 88 shows a modification of the investment pattern in the power sector of Japan towards more nuclear and more renewables. The additional investment is fully offset by reduced energy imports after 2030 that would stabilise around 3.5% of total GDP without any mitigation policy (Figure 89).

Figure 88. Japan investment in power



Source: JRC POLES model

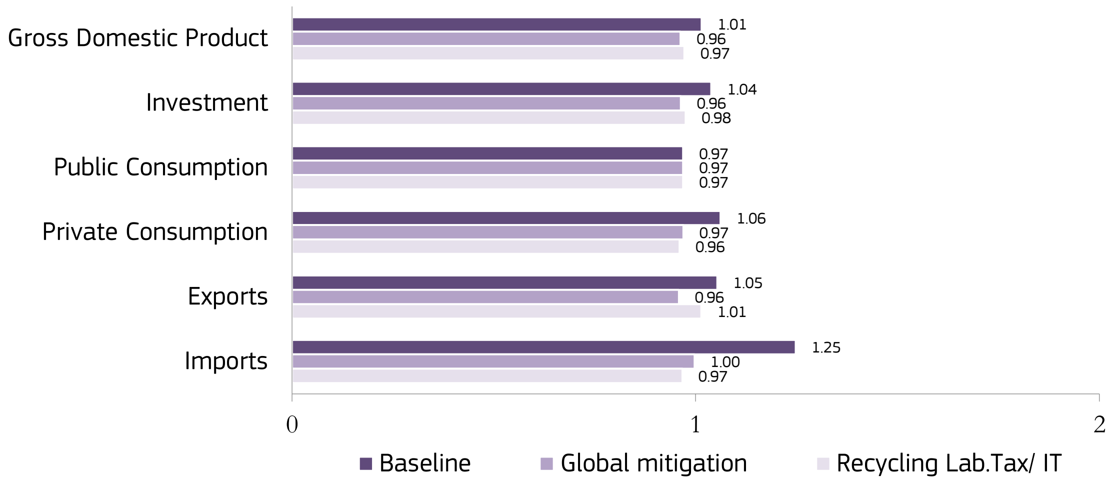
Figure 89. Japan Energy trade (cumulative per decade)



Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

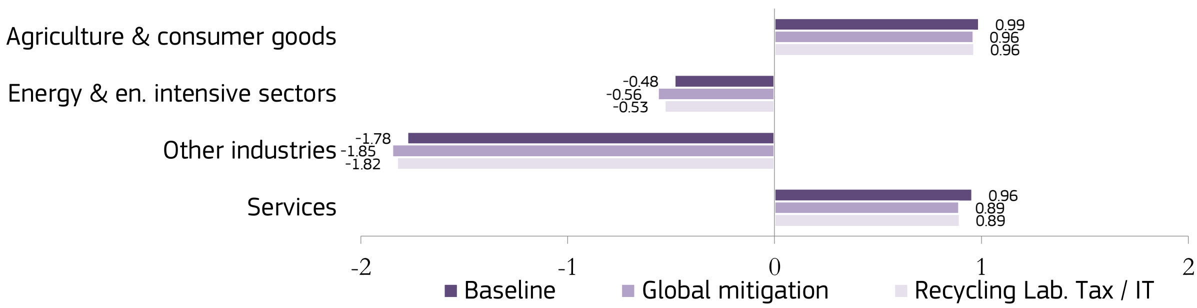
Japan undergoes an ambitious reduction of GHG emissions in the Global Mitigation scenario but since the economy is already more energy efficient than other regions of the world, the economic impacts are limited. Due to higher increase in the production cost of certain imported goods compared to the domestic cost of production, Japan decreases imports significantly to the benefit of domestic product. Thus the trade balance is slightly improved. Some energy-intensive sectors and agriculture marginally increase domestic production compared to Baseline levels, however total energy and energy-intensive production as well as the industrial sector see lower levels of output. The main exporting sectors (e.g. transport equipment and equipment goods) are impacted from the global reduction in personal transport demand, but other sectors benefit. In Japan, around three quarters of the population works in the service sectors (including transport and construction). As the service sector serves as in intermediate to the abating sectors, the output growth in this sector is slightly reduced from the Baseline. However, in general the impact is minor and the decrease in employment is among the lowest of all regions.

Figure 90. Japan, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 91. Japan, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 32. Japan, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	7	4	4	4
Energy & Energy Intensive Goods	13	16	17	17
Other Industries	11	54	54	54
Services	69	26	25	25

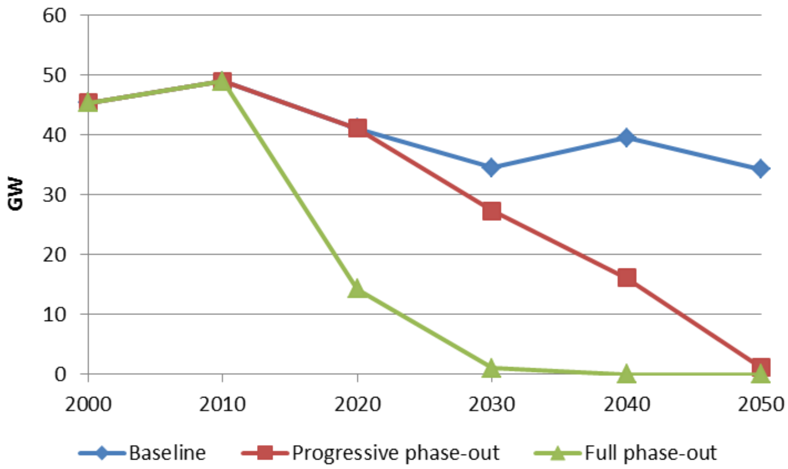
Source: JRC GEM-E3 model

Sensitivity analysis of nuclear phase-out

The evolution of emissions in Japan, and the consequent abatement effort, will depend on the future role of nuclear in its power mix (Kuramochi, 2014). The default assumption of this report (discussed in the previous section) is that the country keeps nuclear in its technological portfolio. However, given the internal debate on the matter in Japan, we also explore the following two nuclear phase-out variants:

- "progressive phase-out", where all plants (except Fukushima Daiichi) are back in operation from 2015 onwards, but are not replaced;
- "full phase-out", where most of the park is shut down with only 15 GW (a third of total existing capacity) still in operation in2020, which are not replaced over time.

Figure 92. Japan nuclear capacity: Baseline vs. phase-out scenarios

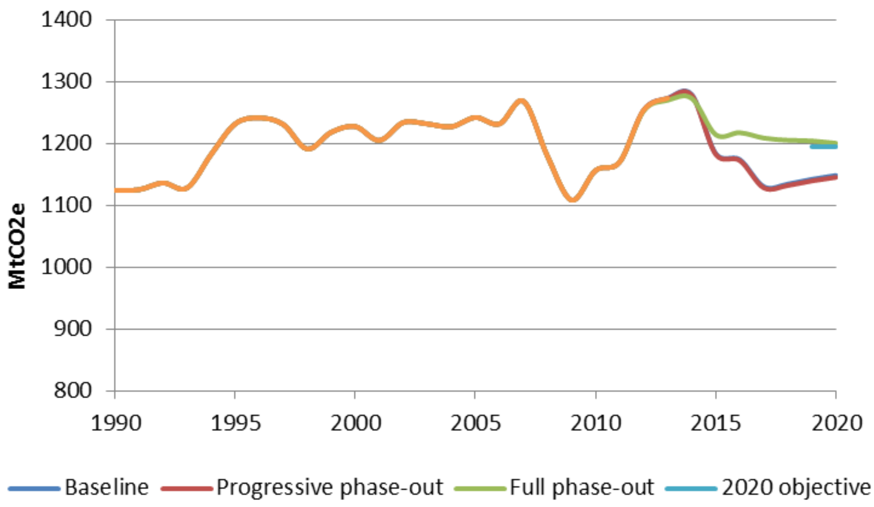


Source: JRC POLES model

As a result, 2020 GHG emissions are higher in the "full phase-out" case, as nuclear is substituted mostly by coal and gas, while in the "progressive phase-out" the emissions are affected only after 2020. To respect the 2020 pledge of -3.8% emissions compared to 2005 (Table 3) in the "full phase-out", a carbon value has been introduced that reaches 16\$05/tCO_2 in 2020, while there is no carbon value in "progressive phase-out" or the Baseline with unconstrained nuclear evolution.

The resulting emissions by 2020 are given in Figure 93. The "full phase-out" leads to total GHG emissions reaching 1200 MtCO_2e in 2020, against 1150 MtCO_2 in the Baseline and the "progressive phase-out".

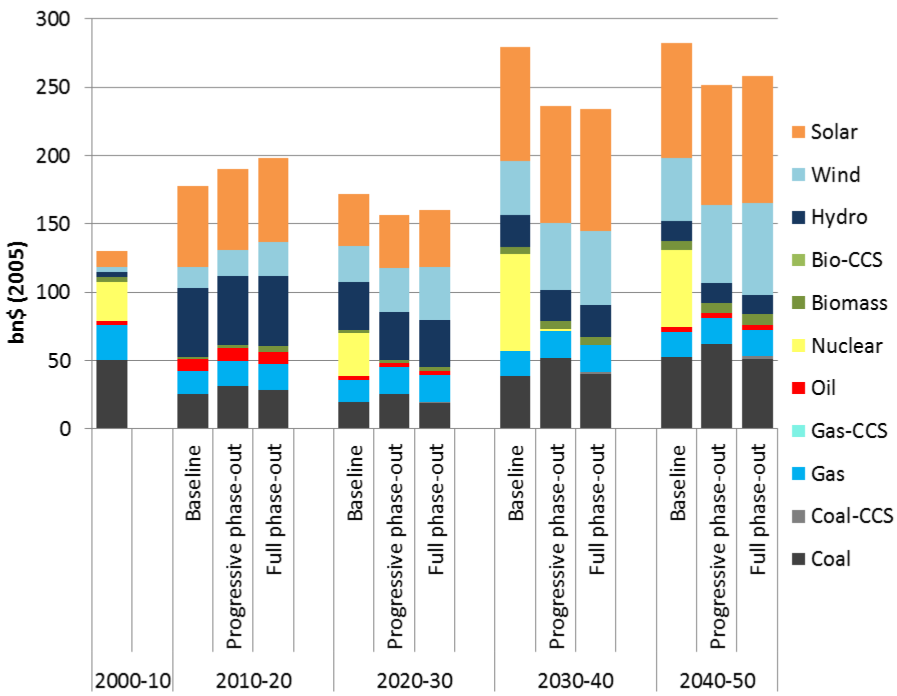
Figure 93. Japan nuclear phase-out: total GHG emissions by 2020



Note 1: include GHG emissions from all sectors
Source: JRC POLES model

Figure 94 shows that, as a consequence of the phase-out, the investment in the power system of Japan is redirected towards coal and gas capacities in the "progressive phase-out", and to coal, gas and wind in the "full phase-out" (wind is spurred by the carbon value introduced to respect the 2020 pledge).

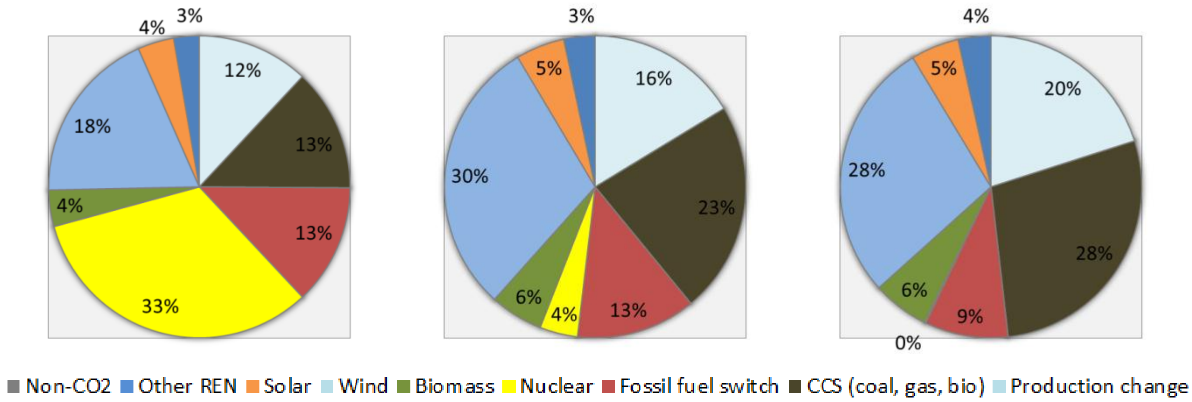
Figure 94. Japan nuclear phase-out: investment in power



Source: JRC POLES model

The absence of nuclear is, in the Global Mitigation scenario in 2030, compensated primarily by more wind, more CCS and lower demand (production change) as compared to the standard Global Mitigation scenario (Figure 95). These 3 options represent in 2030 70% of the power sector abatement effort in the "progressive phase-out", and more than 75% in the "full phase-out".

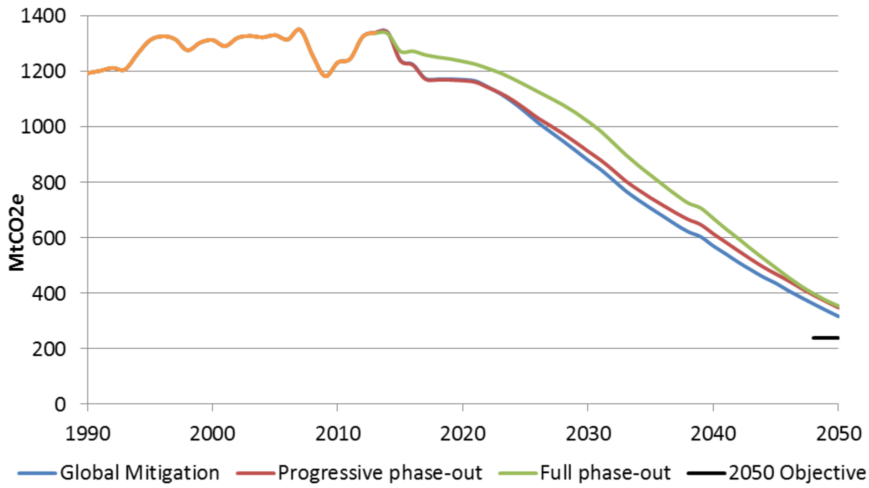
Figure 95. Japan nuclear phase-out: 2030 mitigation in power



Source: JRC POLES model

Total emission reductions in 2030 are lower in the nuclear phase-out cases, especially in the "full phase-out", as shown on Figure 96, on most of the period. However, 2050 levels appear fairly close in all three cases. For all cases, Japan will have to buy some emission credits to bridge the gap to respect its 2050 objective (-80% compared to 1990).

Figure 96. Japan nuclear phase-out: Global Mitigation emissions (excl. LULUCF) by 2050



Note1: GHG emissions excluding LULUCF CO_2
Note2: 2050 objective = -80% / 1990.
Source: JRC POLES model

5.9 Korea (Republic of)[59]

Korea, Rep. has committed to a 30% reduction in emissions by 2020 compared to the business-as-usual level. While it appears unlikely that this target will be met, Korea, Rep. has the potential to achieve the ambitious emissions reductions of the Global Mitigation scenario at relatively low cost since there is great potential for improvements in energy efficiency throughout the economy. In addition, the Global Mitigation scenario has the benefit of reducing energy imports, a saving equivalent to nearly 4% of GDP by 2050.

Korea, Rep.'s GHG emissions, at 13 tCO_2e per capita, are among the highest in the world, though notably lower than the 15-22 tCO_2e range of the highest-emitting countries. However, Korea, Rep. has also set a clear target to limit emissions in 2020 to 545 $MtCO_2e$ in its Third National Communication[60] (30% below a national "business-as-usual" projection of 776 $MtCO_2e$). Though the 2020 target is not met in either the Baseline or Global Mitigation scenario of this report, Korea, Rep. does maintain emissions below this business-as-usual level throughout the projection period. In the Baseline, emissions are projected to peak in 2030, at over 700 $MtCO_2e$, while the Global Mitigation scenario projects falling emissions from 2015 onwards.

Table 33. Korea, Rep. decomposition of GHG (excl. LULUCF)

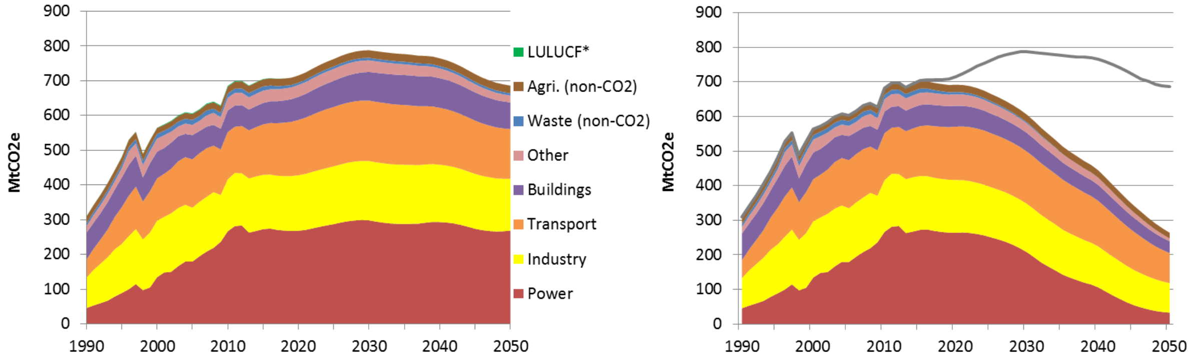
							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	48	51	52	52	52	51	113	118	121	122	119
GDP per capita (k$05)	27	37	43	49	58	64	240	325	436	513	566
GHG ($MtCO_2e$)											
Baseline	632	653	691	710	680	602	210	217	236	226	200
Global Mitigation	632	630	597	532	372	216	210	210	177	124	72
GHG per capita (tCO_2e)											
Baseline	13.0	12.9	13.4	13.6	13.0	11.8	186	184	194	186	169
Global Mitigation	13.0	12.4	11.6	10.2	7.1	4.2	186	177	145	102	61
GHG / GDP (tCO_2e/M$)											
Baseline	478	348	308	275	223	184	78	57	45	36	30
Global Mitigation	478	336	266	206	122	66	78	55	33	20	11
Energy / GDP (toe/M$)											
Baseline	191	157	146	137	121	110	102	84	73	64	59
Global Mitigation	191	153	135	123	108	98	102	81	66	57	52
GHG / energy (tCO_2e/toe)											
Baseline	2.5	2.2	2.1	2.0	1.9	1.7	76	67	61	56	51
Global Mitigation	2.5	2.2	2.0	1.7	1.1	0.7	76	67	51	35	21
Source: JRC POLES model											

In the Global Mitigation scenario, the major contributors to Korea, Rep.'s emissions reduction are efficiency improvements (reduced demand) and CCS, as Figure 98 and Figure 99 show. In 2030, demand reduction provides over 30% of the mitigation effort, ahead of nuclear, renewables and fossil fuel switching. Non-CO_2 emissions contribute very little to the emissions of Korea, Rep. and

[59] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.
[60] http://unfccc.int/resource/docs/natc/kornc3.pdf

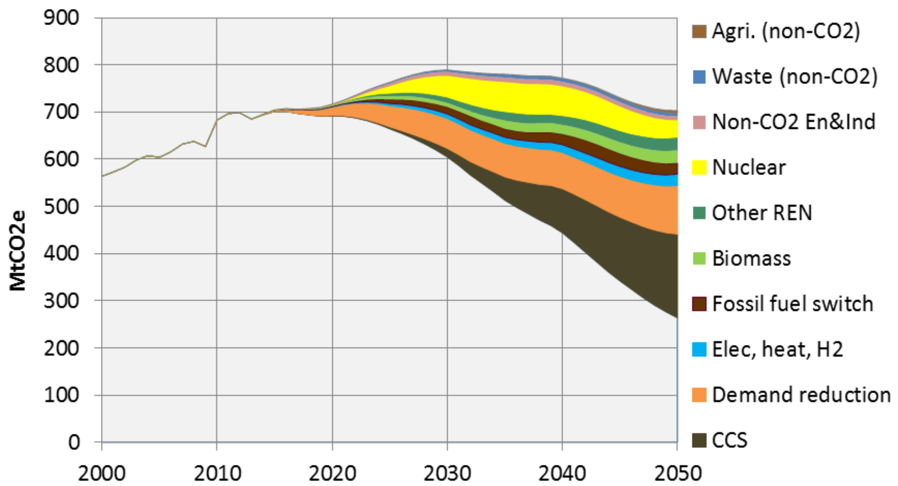
thus to reductions. CCS becomes the single largest source of mitigation from the late 2030s onwards.

Figure 97. Korea, Rep. sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

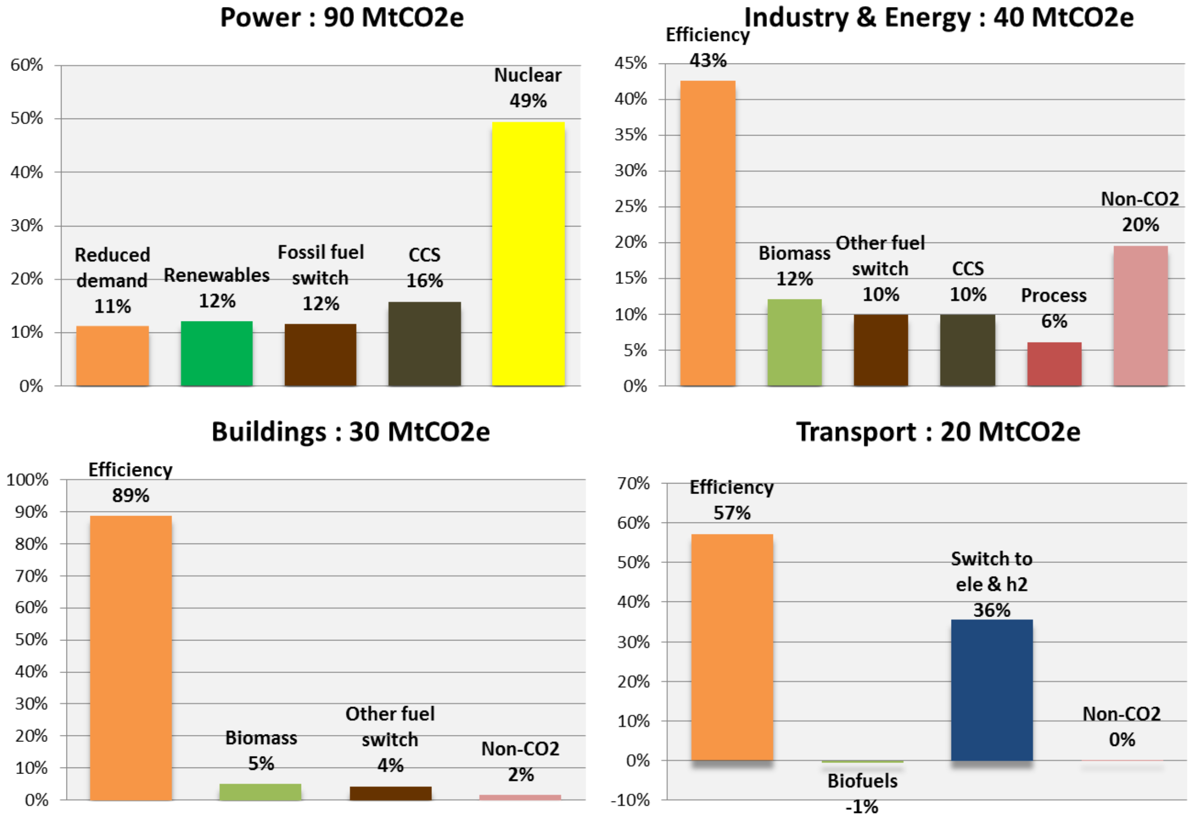
Figure 98. Korea, Rep. emission reduction options (excl. LULUCF)



Source: JRC POLES model

As Figure 99 shows, the power sector concentrates half the total reductions in 2030, with nuclear leading the effort followed by a balanced mix of options. In the final demand sectors, improvements in efficiency appear as the key option for all groups of users (industry, buildings, transport).

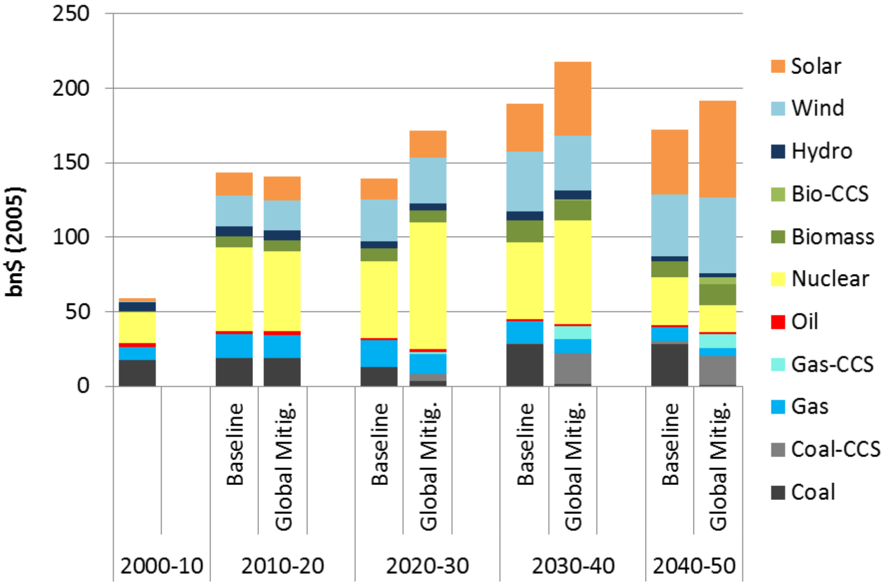
Figure 99. Korea, Rep. emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

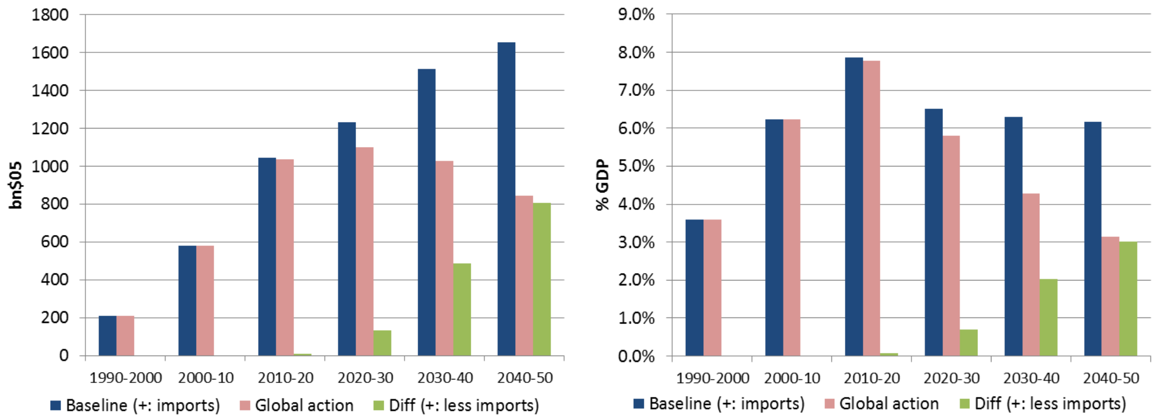
The Global Mitigation scenario's requirements for additional investment Korea, Rep.'s power sector are fairly modest compared to some countries. In part this is due to the country's ability to limit emissions through reductions in demand. The main requirement is to increase investment in nuclear generation in the period 2020-2030, as well as increasing solar and wind investment in the period beyond 2030 and replacing conventional coal generation with CCS. The combination of reduced consumption and increased renewables also has the benefit of reducing the country's energy trade deficit, a saving that amounts to almost 3% of GDP by 2050.

Figure 100. Korea, Rep. investment in power (cumulative per decade)



Source: JRC POLES model

Figure 101. Korea, Rep. Energy trade (cumulative per decade)



Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

Domestic mitigation targets in Korea, Rep. include the aim of achieving a renewable energy supply rate of 11% by 2030[61], an objective supported by a Renewable Portfolio Standard that obliges large utilities to meet a renewable generation target climbing to 10% by 2022[62]. However, this target is below the 18% projected in the Global Mitigation scenario (or even the 17% projected in the Baseline). In addition to this, Korea, Rep. has established an emissions trading scheme which is initially scheduled to run from 2015 to 2026 and achieve a total emissions reduction of 236 $MtCO_2e$ from the industrial, electricity, building and transportation sectors[63].

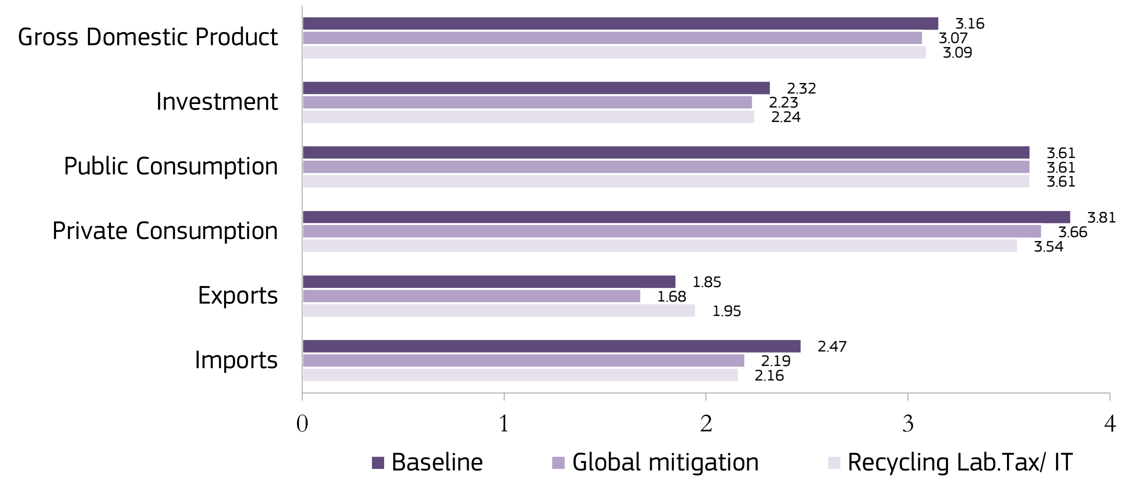
[61] http://unfccc.int/resource/docs/natc/kornc3.pdf

[62] Ministry of Knowledge Economy, Korea Power Exchange (2010), The 5th Basic Plan for Long-term Electricity Supply and Demand (2010 ~ 2024) https://www.kpx.or.kr/english_new/plan/pdf/The_5th_Basic_Plan_of_Long-Term_Electricity_Supply_and_Demand_final_print.pdf

[63] EDF and IETA (2013) South Korea, The World's Carbon Markets: A Case Study Guide to Emissions Trading http://www.ieta.org/assets/Reports/EmissionsTradingAroundTheWorld/edf_ieta_korea_case_study_september_2013.pdf

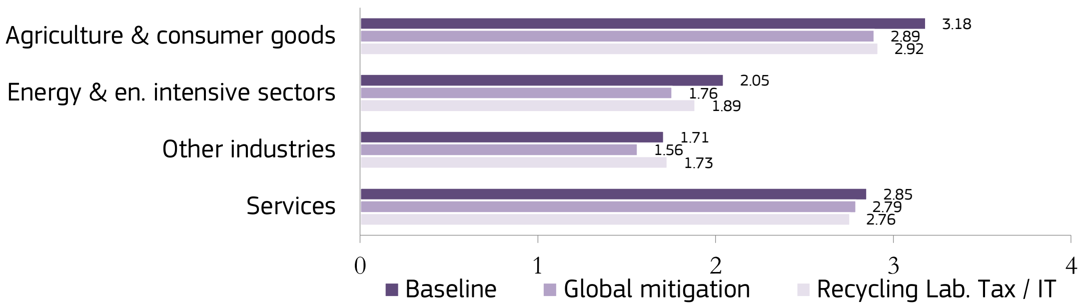
In macro-economic terms, mitigation results in a slight fall in Korea, Rep.'s GDP, though the annual growth rate is still above 3%. The switch to cleaner power generation in Korea brings about a reduction of fossil fuel imports in Korea. As a result, the net trade position of Korea improves, despite a fall in exports. The main driver of lower GDP growth is a decrease in private consumption. This can be explained mainly by lower real wages, induced by an overall reduction in production levels and labour demand due to the increased production cost of mitigating sectors. The production of the transport equipment sector, one of the most important one in Korea, Rep., is particularly affected due to lower private transport demand worldwide. Other consumer goods industries and energy-intensive sectors also see some decline, although exports of energy-intensive sectors and electric goods rise due to a relative increase of competitiveness of the already resource–efficient industries of the country. If labour taxes are reduced through the recycling of auction revenues, Korea, Rep.'s competitiveness largely improves and total exports increase beyond Baseline levels, improving the country's trading position.

Figure 102. Korea, Rep., GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 103. Korea, Rep., yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 34. Korea, Rep., Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	9	9	8	8
Energy & Energy Intensive Goods	17	23	23	23
Other Industries	19	54	54	54
Services	55	15	15	15

Source: JRC GEM-E3 model

5.10 Mexico[64]

Mexico has taken up a leadership role in international climate action and the General Law on Climate Change and the National Climate Change Strategy constitute a solid basis for long-term action.

In the Baseline, emissions continue increasing, with per capita emissions overtaking those of EU by 2030. However, meeting Mexico's existing policy objectives on renewables development, accompanied by reductions of non-CO_2 emissions in the oil and gas sector and in waste, would put the country well on track towards the Global Mitigation scenario. GHG emissions would first stabilise and then fall after 2030. In particular, the national renewable electricity targets appear consistent those projected in this paper's mitigation analysis.

Over the long run, the GHG mitigation policy would also decrease the future cost of energy imports, which would start appearing in the 2030's due, in particular, to the decline of oil production.

Mexico's GDP per capita, at $12000-16000 is well above the global average but still barely half the level of the EU and other high-income regions. In per capita terms, emissions are low compared to other middle and high income countries but, in the Baseline, would overtake those of the EU by 2030.

Table 35. Mexico decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	118	132	138	144	152	156	137	153	167	176	181
GDP per capita (k$05)	12	16	18	21	27	34	124	158	207	269	344
GHG ($MtCO_2e$)											
Baseline	727	888	960	1045	1134	1186	156	190	224	243	254
Global Mitigation	727	789	773	743	567	309	156	169	159	121	66
GHG per capita (tCO_2e)											
Baseline	6.2	6.7	6.9	7.3	7.5	7.6	114	124	134	138	140
Global Mitigation	6.2	6.0	5.6	5.2	3.7	2.0	114	110	95	69	36
GHG / GDP (tCO_2e/M$)											
Baseline	497	425	384	351	277	221	92	79	65	51	41
Global Mitigation	497	378	309	250	139	57	92	70	46	26	11
Energy / GDP (toe/M$)											
Baseline	122	108	104	99	85	71	89	79	73	62	52
Global Mitigation	122	103	96	90	74	60	89	76	66	54	44
GHG / energy (tCO_2e/toe)											
Baseline	4.1	3.9	3.7	3.5	3.3	3.1	103	99	89	83	78
Global Mitigation	4.1	3.7	3.2	2.8	1.9	1.0	103	92	70	48	24

Source: JRC POLES model

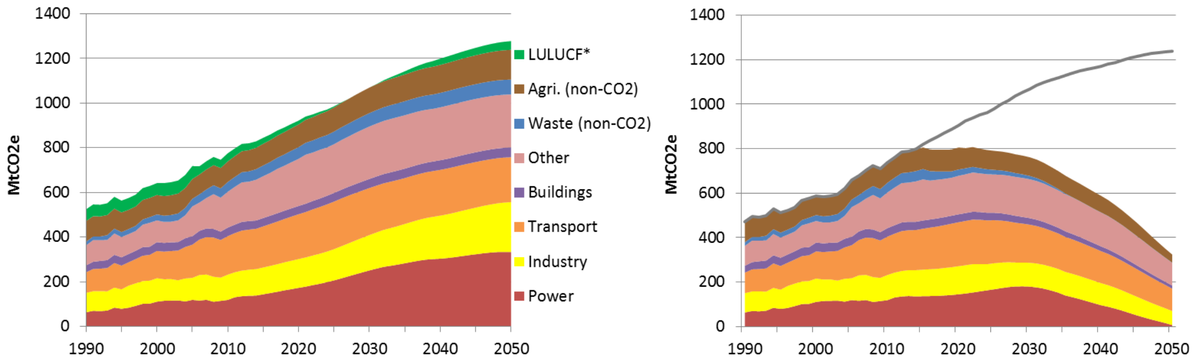
In the Baseline, the assumption is that Mexico's pre-2020 pledge of a 30% emissions reduction compared to business-as-usual (which translates into 2020 emissions of 670 $MtCO_2e$) is not fully met, consistently with other analysis (Den Elzen et al., 2015). In the Baseline, emissions rise from 727 $MtCO_2e$ in 2010 to nearly 900 $MtCO_2e$ in 2020 and over 1000 $MtCO_2e$ by 2030. The Global

[64] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

Mitigation scenario, by contrast, sees a stabilisation of emissions between 2010 and 2030, followed by reductions in the period up to 2050 when they are 30% lower than their 1990 level.

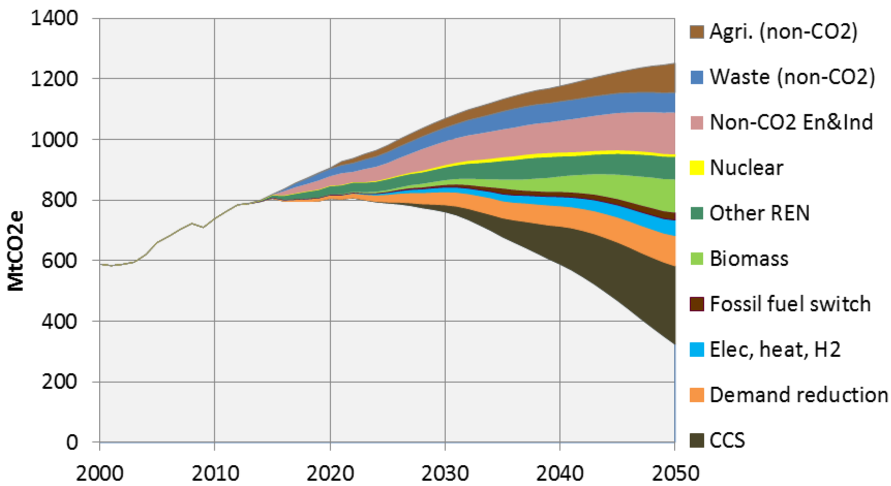
As Figure 105 and Figure 106 show, in 2030 half the reductions are actually done by non-CO_2 gases in agriculture (CH_4), waste (CH_4), industry (F-gases) and in the energy supply sector (CH_4). By 2050 the power sector becomes decarbonized, while final demand sectors see their emissions reduce.

Figure 104. Mexico sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

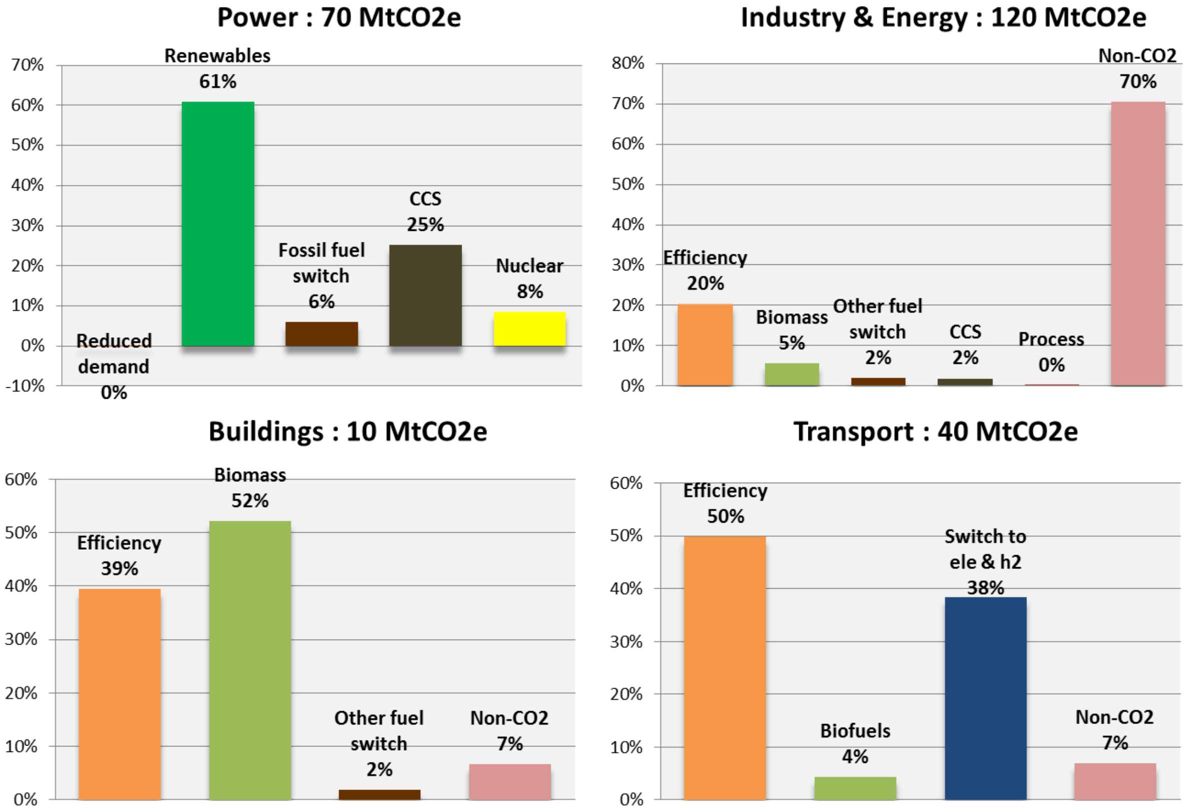
Figure 105. Mexico emission reduction options (excl. LULUCF)



Source: JRC POLES model

A closer look at the sectoral level (excl. agriculture, waste and LULUCF) shows the large role of non-CO_2 gases (including from fossil fuel supply) that exceed 80 $MtCO_2e$ in 2030, (in comparison, total abatement in the power system is 70 $MtCO_2e$). Renewables play an important role in the power production as well as in buildings, while efficiency is the first option in transport (50%), and comes second in industry (19%) and in buildings (39%). The contribution of biomass is mostly under solid form, with fuel switch in the transport going primarily to electricity rather than to liquid biofuel. In 2030 nuclear remains a limited option.

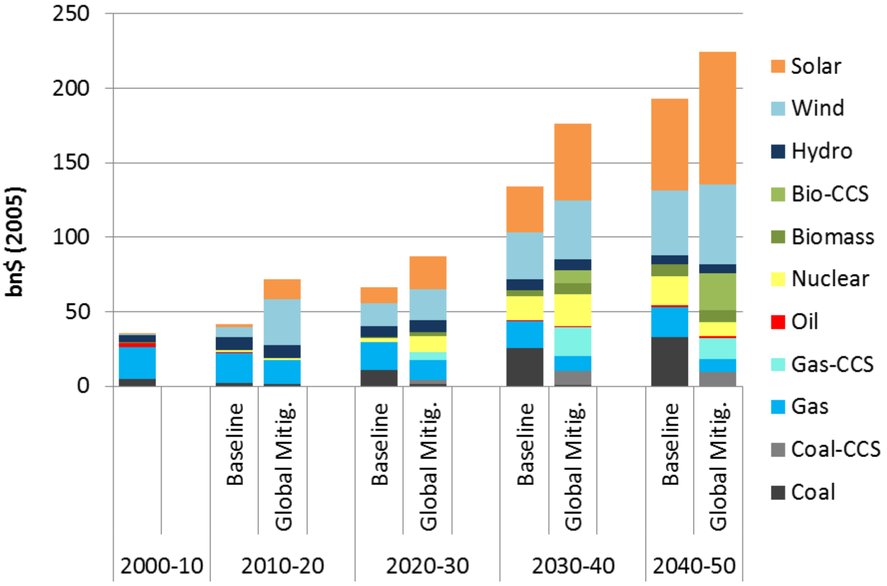
Figure 106. Mexico emissions mitigation options in sectors - 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

The Global Mitigation scenario requires increased investment in the power sector. Compared to Baseline, the greatest increase in investment occurs in the period 2030-2040, with the additional deployment consisting predominantly of greater solar deployment, as well as increased nuclear and biomass and the switching of gas and coal to their with-CCS equivalents. This pattern continues after 2040, with notable increases in biomass CCS and wind, though in this period increase in total investment created by the mitigation scenario is smaller, since even in the Baseline Mexico's power investment needs would be substantial. The development of the Mexican power system in the Global Mitigation scenarios is consistent with the various targets put forward by the National Climate Change Strategy (NCCS, 2013): 35% of electricity generated from clean energy sources by 2024, 40% of renewable electricity generated to be reached in 20 years and of 50% of renewable electricity in 40 years; but also by the Special Renewable Energy Programme (Gobierno de México, 2014) that also introduces renewable electricity targets in terms of increasing the share of renewables in energy production from 22.8% in 2018 to 26.5% in 2027.

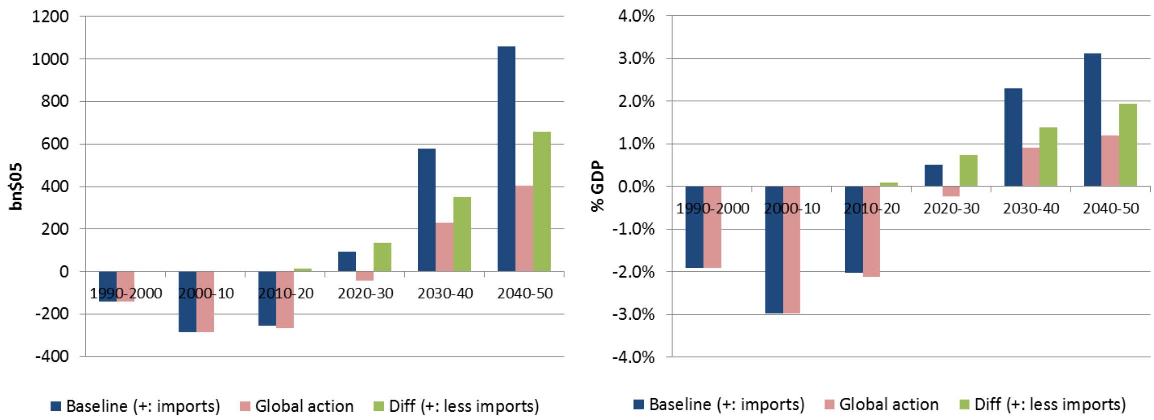
Figure 107. Mexico investment in power (cumulative per decade)



Source: JRC POLES model

One benefit of these investments is to reduce the future Mexico's trade deficit in energy, which is expected to grow towards 2050. As Figure 108 shows, Mexico is expected to become a net energy importer in the 2030s in the Baseline. In the Global Mitigation scenario this import requirement is reduced substantially, with the avoided imports in 2050 equivalent to 2% of GDP.

Figure 108. Mexico Energy trade (cumulative per decade)

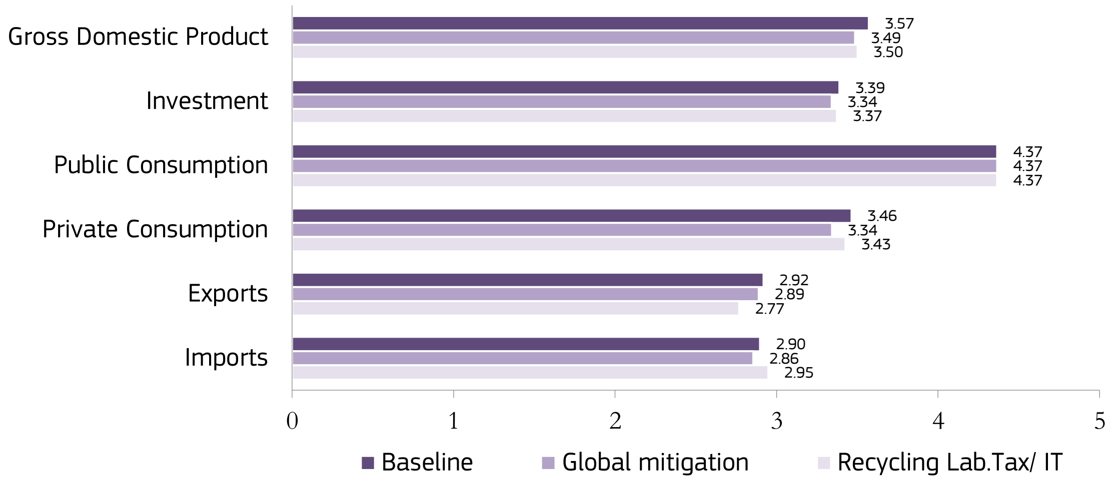


Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

Finally, it must be mentioned that Mexico's policy on forests (Gobierno de México, 2010) aims at achieving zero net carbon loss which, if achieved, would provide additional reductions to those shown above, thus allowing greater flexibility in how the country's emissions reductions are achieved.

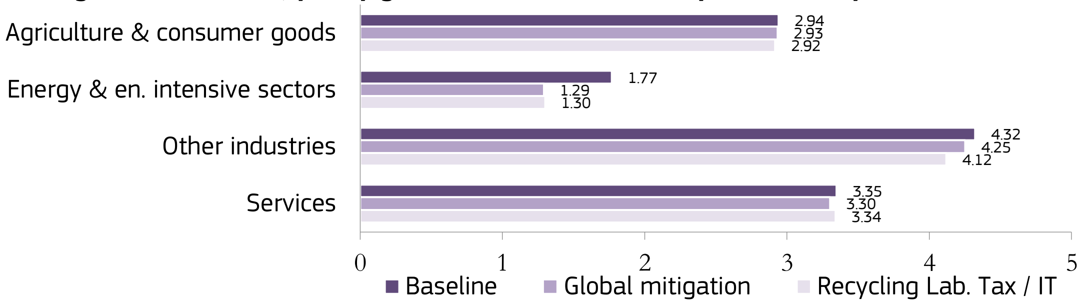
In macroeconomic terms, Mexico maintains a growth rate of around 3.5% per year in the Global Mitigation scenario, only slightly less than in the Baseline. A significant share of the burden falls on the energy sectors, in particular on the fossil fuel producing industries, since demand of carbon-intensive energy resources falls. Certain industries like consumer and electric goods increase their production due to an increase in export demand and thus employment levels are sustained. Other industrial sectors remain relatively competitive, such that sector growth rates do not differ much from Baseline levels. Overall, the net trading position remains unchanged in the Global Mitigation scenario, but deteriorates in the case of indirect tax reduction where higher private consumption and higher welfare levels leads to more imports.

Figure 109. Mexico, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 110. Mexico, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 36. Mexico, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	12	12	13	13
Energy & Energy Intensive Goods	14	18	17	17
Other Industries	14	62	62	62
Services	59	8	8	8

Source: JRC GEM-E3 model

5.11 Russian Federation[65]

In the Baseline, Russia's GHG emissions, which are among the highest in the world in per capita terms, show no decrease up to 2050. In the Global Mitigation scenario, Russia begins to reduce emissions from 2020. Russia's existing targets for 2020 already reflect the Global Mitigation scenario's level of ambition, for example in renewable energy, energy efficiency and reducing methane emissions associated with the petroleum industry. However, continued effort will be needed to ensure existing targets are met, and that future policies consistent with global mitigation are adopted.

The Russian economy depends largely on fossil fuel exports, which are significantly reduced in the global climate change mitigation effort. Diversification of the current economic activity would enable a smoother transition to a low-carbon world. Agricultural and consumer goods gain marginally from reduced factor input prices. Moreover, auction revenue recycling to reduce indirect taxes is beneficial for private consumption and investments.

GHG emissions per capita in Russia are among the highest in the world, over 50% higher than EU levels for example. Despite this, Russia's 2020 goals, which involve reducing GHG emissions by 25% compared to 1990 levels in 2020, are projected to be met without difficulty considering the high emission levels of this base year.

Beyond 2020, emissions are projected to rise in the Baseline, even though the population is projected to fall. In the Global Mitigation scenario, Russia reduces GHG emissions from 2020, though even in this scenario emissions per capita remain above the current levels of other countries until after 2030.

[65] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

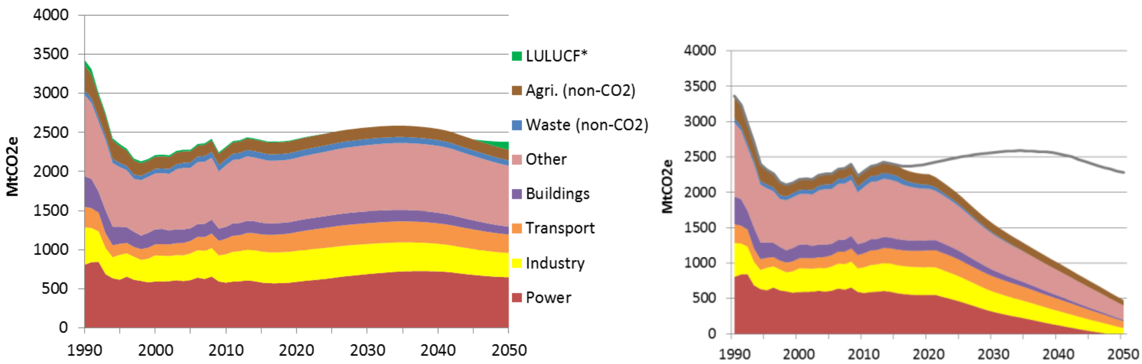
Table 37. Russia decomposition of GHG (excl. LULUCF)

							1990 = 100				
	2010	'20	'25	'30	'40	'50	2010	'20	'30	'40	'50
Population (10^6)	144	140	137	134	127	121	97	95	90	86	82
GDP per capita (k$05)	14	19	23	26	33	34	111	150	209	257	270
GHG ($MtCO_2e$)											
Baseline	2275	2375	2465	2527	2503	2231	68	71	76	75	67
Global Mitigation	2275	2225	1908	1520	975	461	68	67	46	29	14
GHG per capita (tCO_2e)											
Baseline	15.8	17.0	18.0	18.9	19.7	18.5	70	75	84	88	82
Global Mitigation	15.8	15.9	13.9	11.4	7.7	3.8	70	71	51	34	17
GHG / GDP (tCO_2e/M$)											
Baseline	1126	892	799	717	606	540	63	50	40	34	30
Global Mitigation	1126	836	619	431	236	112	63	47	24	13	6
Energy / GDP (toe/M$)											
Baseline	346	276	251	230	197	176	74	59	49	42	38
Global Mitigation	346	271	226	182	138	120	74	58	39	29	26
GHG / energy (tCO_2e/toe)											
Baseline	3.3	3.2	3.2	3.1	3.1	3.1	86	85	82	81	81
Global Mitigation	3.3	3.1	2.7	2.4	1.7	0.9	86	81	63	45	25

Source: JRC POLES model

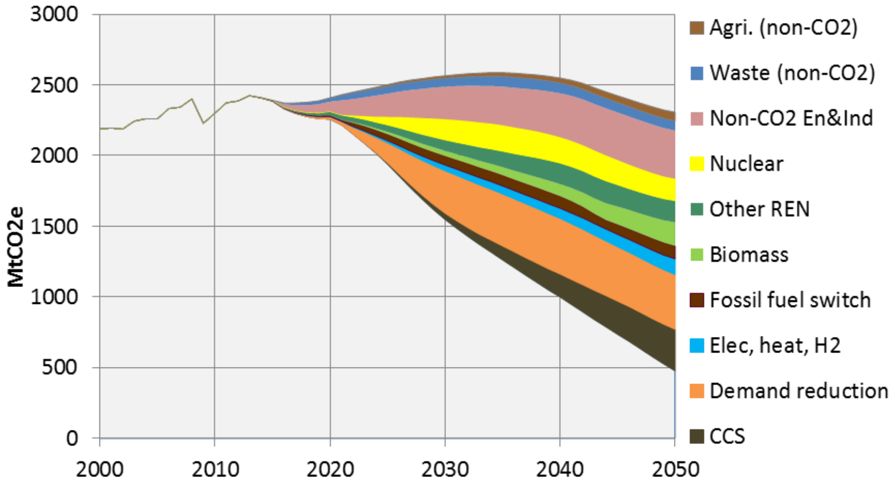
More than half of the reductions in Russian emissions in the Global Mitigation scenario in 2030 come from demand reduction and action on non-CO_2 emissions, as Figure 112 and Figure 113 show. The rest come from a mix of options in the energy system: nuclear (14%), renewables (12%), waste (6%) and fuel switch (10%, including 6% of switching away from coal). CCS still has a limited role in 2030 (4%), but becomes more important afterwards (10% of the entire period 2010-2050).

Figure 111. Russia sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 112. Russia emission reduction options (excl. LULUCF)



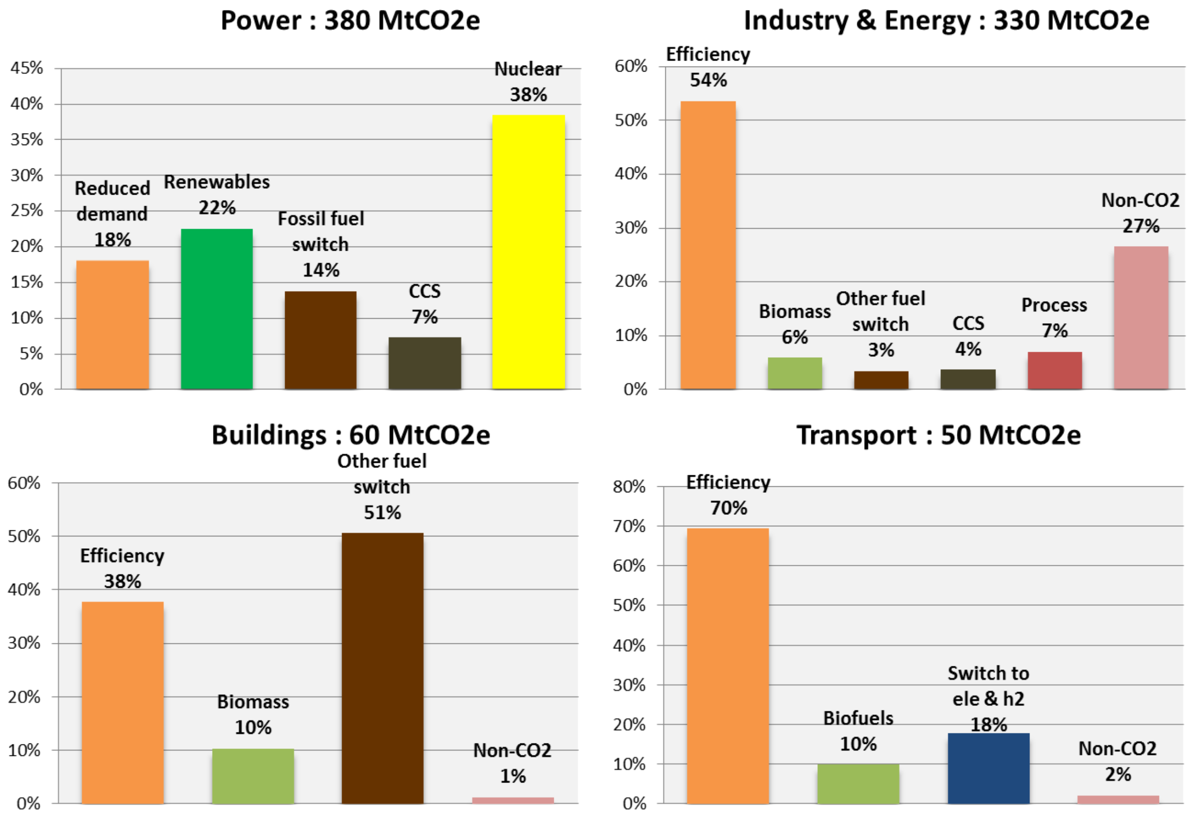
Source: JRC POLES model

In terms of sectoral contribution, most mitigation takes place in the power production and in the industry & energy, representing together 85% of the total (excluding GHG emissions from agriculture and LULUCF). Compared to other countries the role of renewables remains limited in all sectors, while efficiency and switch to less carbon-intensive fuels play an important role. In energy intensity, Russia has domestic targets that are similar to the Global Mitigation scenario in the short term: a 40% reduction in energy intensity of GDP by 2020, compared to 2007, which is actually reached in 2025 in the Global Mitigation scenario (-26% in 2020 compared to 2007), and that goes very much in line with the evolution by 2030. Russia also has a target for utilising 95% of gas associated with petroleum production which would make an important contribution to the non-CO_2 reductions shown in Figure 113.

Renewables (excluding large-scale hydro) reach 4% of the power production in 2020, which is close to the target of 4.5% stated in the 2009 Decree for Enhancing Energy Efficiency (Den Elzen et al., 2015; Ministry of Natural Resources Russian Federation, 2010[66]). However, significant additional renewable energy investment takes place after 2030.

[66] http://unfccc.int/resource/docs/natc/rus_nc5_resubmit.pdf

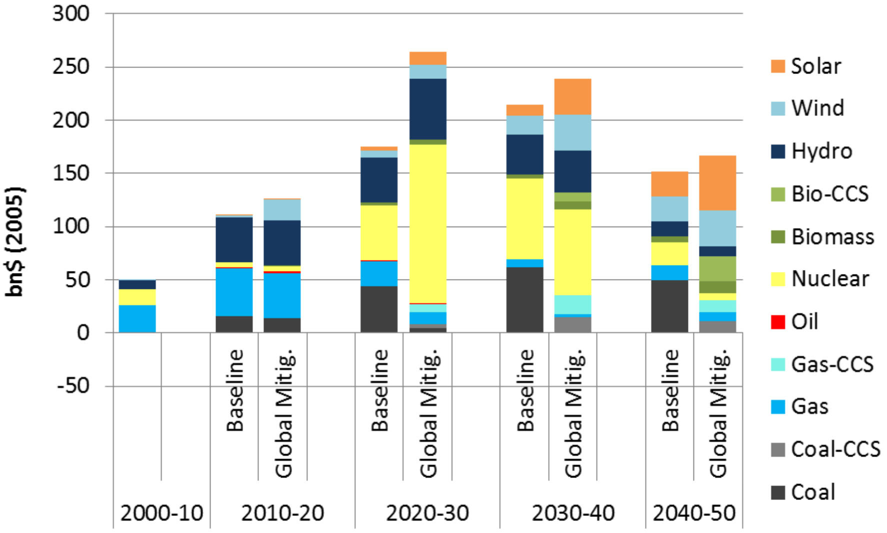
Figure 113. Russia emissions mitigation options in sectors – 2030



Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

In both the Baseline and Global Mitigation scenario, Russia needs to increase investment substantially in order to modernise the power sector during the period 2020-2040 (Figure 114). It is only in the period 2020-2030 where the investment requirements of Global Mitigation scenario are substantially higher than the Baseline. In this period, investment in nuclear is more than double the Baseline projection, alongside increased investment in renewables (notably hydro) and lower investment in gas and coal technologies. After 2030 investments in renewable technologies and CCS continue, partly at the expense of oil and gas and partly through an increase in total investment (though lower increase over Baseline levels than in the pre-2030 period).

Figure 114. Russia investment in power (cumulative per decade)



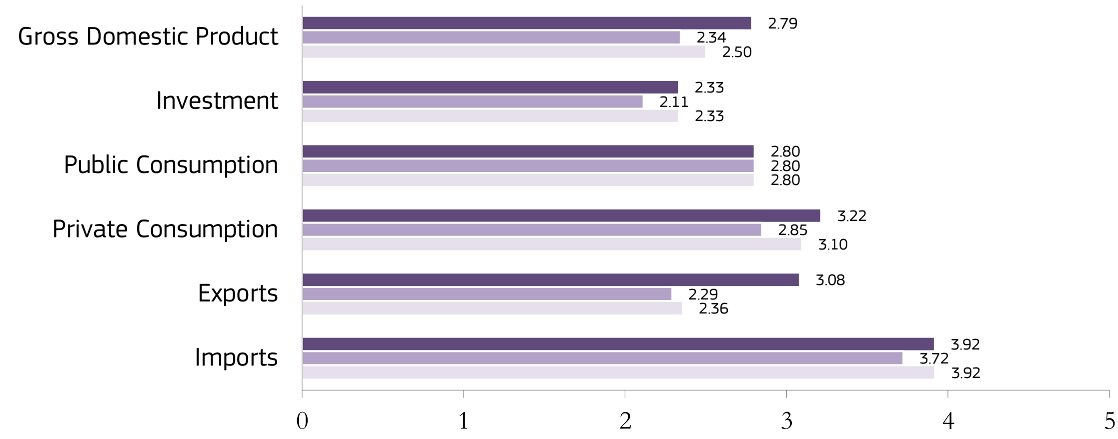
Source: JRC POLES model

In macro-economic terms, the global effort to mitigate climate change has a negative effect on GDP, though this can be softened somewhat through using the proceeds of climate policies to reduce taxes elsewhere. The largest deviation from the Baseline in terms output growth rate occurs in the energy supplying and energy-intensive sectors. On the positive side, the agricultural and consumer goods do slightly better due to increasing competitiveness that benefits export demand while the growth rate of the services sector only falls moderately. Employment losses are evident and lead to the loss of disposable income. The sectors mainly contributing to the loss of jobs is the extracting sectors, the refineries, and chemical sectors.

The lion's share of Russian Federation's exports is energy products such as gas and refined and crude oil. Due to a decreasing world demand for fossil fuels in a carbon constrained world, both the value and volume of Russia's exports fall substantially. This is the reason why the net trade position deteriorates by 1/3. The trading position of the country would be worse if imports did not fall due to the reduced disposable income of the export-led Russian economy that leads to a reduction in total private consumption. Since capital requirements are decreased substantially due to the reduction of capital-intensive production of energy goods, investment demand falls. It should be noted that in the Baseline scenario, no effort of the region to diversify economic activities has been taken into consideration, which would make the Russian economy more flexible and resilient to different energy and climate change policies.

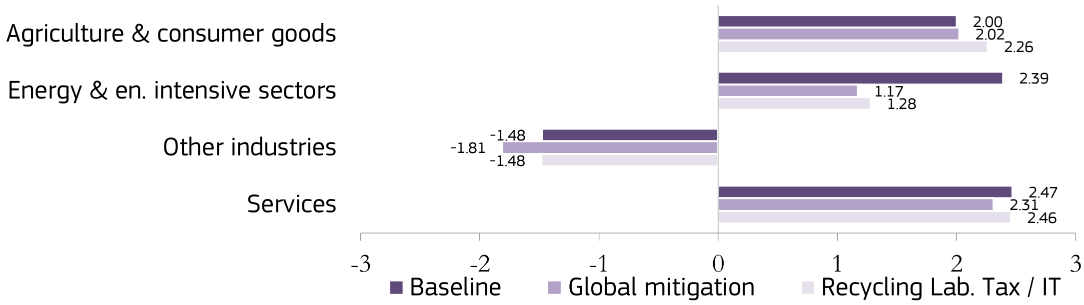
The reduction of indirect taxes through revenue recycling leads to lower final prices of consumer and investment goods and thus private consumption sees only slight reductions compared to the Baseline, while investment and imports are sustained to Baseline levels. Investment recuperates since the intermediate price of investment goods is now lower than the price of capital and thus total investment demand is increased. Increased domestic production is met mainly by agricultural and consumer goods, whose production growth rate increases more than in the Baseline.

Figure 115. Russian Federation, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 116. Russian Federation, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 38. Russian Federation, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	12	6	7	7
Energy & Energy Intensive Goods	35	83	81	81
Other Industries	3	2	2	2
Services	49	9	10	10

Source: JRC GEM-E3 model

5.12 South Africa[67]

South Africa is currently one of the most emissions-intensive economies in the world because of the coal base of its energy system, with emissions per capita that are high compared to countries at similar income levels. Current government policy features a 'peak, plateau then decline' trajectory which, while controlling emissions in the long term, is not consistent with global mitigation.

The Global Mitigation scenario is more ambitious. It illustrates a pathway for transition to a low emission economy with more diversified energy sources to substitute for coal. This transition is also gradual, with South Africa retaining higher emissions per capita than the EU right up to 2030.

South Africa undertakes an ambitious reduction of emissions under the Global Mitigation, where coal production, ferrous metals and non-metallic minerals contribute largely to the abatement effort. The impact on the total economic activity is minimal in terms of growth rates of GDP and is mainly driven by exports and private consumption reduction. Reduction of indirect taxes through recycling of auction revenues brings back consumption and investment to the Baseline levels.

South Africa is currently a middle-ranking country in terms of GHG emissions. Its GDP per capita is below that of Mexico and Russia, similar to that of Brazil and higher than that of China and India. However, the emissions intensity of the economy (emissions per dollar of GDP) is among the highest in the world, and GHG emissions per capita are already above the EU level. In the Baseline, South Africa's emissions continue to climb to 2020 and beyond, reaching over 600 $MtCO_2e$ by 2030. In the Global Mitigation scenario, by contrast, emissions begin to fall from 2015, though emissions per capita remain above EU levels right up to 2030. By 2050 emissions fall to 36% of their 1990 level.

[67] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

Table 39. South Africa decomposition of GHG (excl. LULUCF)

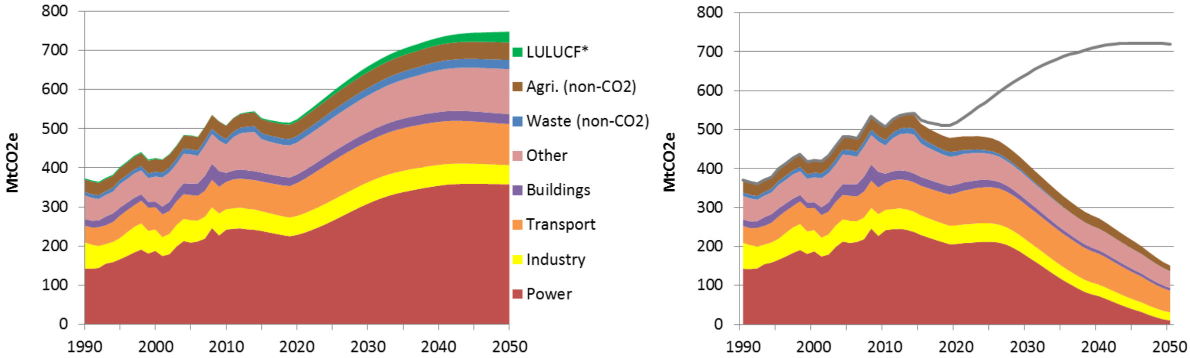
							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	51	55	57	58	61	63	140	150	158	166	172
GDP per capita (k$05)	9	12	15	18	25	30	121	155	242	329	397
GHG ($MtCO_2e$)											
Baseline	493	500	561	616	673	673	136	138	170	186	186
Global Mitigation	493	463	456	386	242	128	136	128	107	67	35
GHG per capita (tCO_2e)											
Baseline	9.6	9.1	9.9	10.6	11.0	10.6	98	92	108	112	108
Global Mitigation	9.6	8.4	8.0	6.6	4.0	2.0	98	85	68	40	21
GHG / GDP (tCO_2e/M$)											
Baseline	1037	768	659	574	440	350	81	60	45	34	27
Global Mitigation	1037	711	536	360	158	67	81	55	28	12	5
Energy / GDP (toe/M$)											
Baseline	309	225	195	172	136	114	100	73	55	44	37
Global Mitigation	309	220	183	150	114	99	100	71	48	37	32
GHG / energy (tCO_2e/toe)											
Baseline	3.4	3.4	3.4	3.3	3.2	3.1	81	82	81	78	74
Global Mitigation	3.4	3.2	2.9	2.4	1.4	0.7	81	78	58	33	16
Source: JRC POLES model											

In terms of domestic policy, South Africa released the National Climate Change Response White Paper[68] in 2011. This states the country's ambition for GHG emissions to follow a 'peak, plateau and decline' trajectory featuring an emissions peak in 2020-2025, followed by a decade where annual emissions are flat, with decline thereafter. This trajectory is more ambitious than the Baseline scenario of this report, but less ambitious than the Global Mitigation scenario.

The early mitigation action comes mostly from deployment of renewable energy that represents 25% of the total mitigation in 2030. Demand reduction comes second, with 18%, followed by nuclear (16%) and non-CO_2 reductions (13%, mostly abatement of CH_4 emissions in the coal industry). Over the entire 2021-2050 period, CCS becomes a significant contributor, linked to the important coal resource in the country that is used in the power sector. The power sector is by far the largest contributor to GHG mitigation, with almost 70% of the total (excluding GHG emissions from agriculture and LULUCF) in 2030.

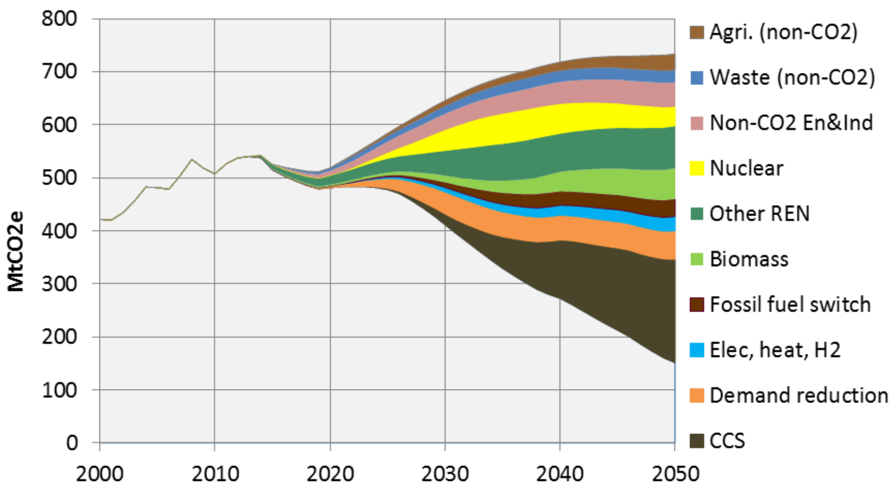
[68] http://cer.org.za/wp-content/uploads/2011/10/White-Paper-on-Climate-Change-Response-Oct-2011.pdf

Figure 117. South Africa sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



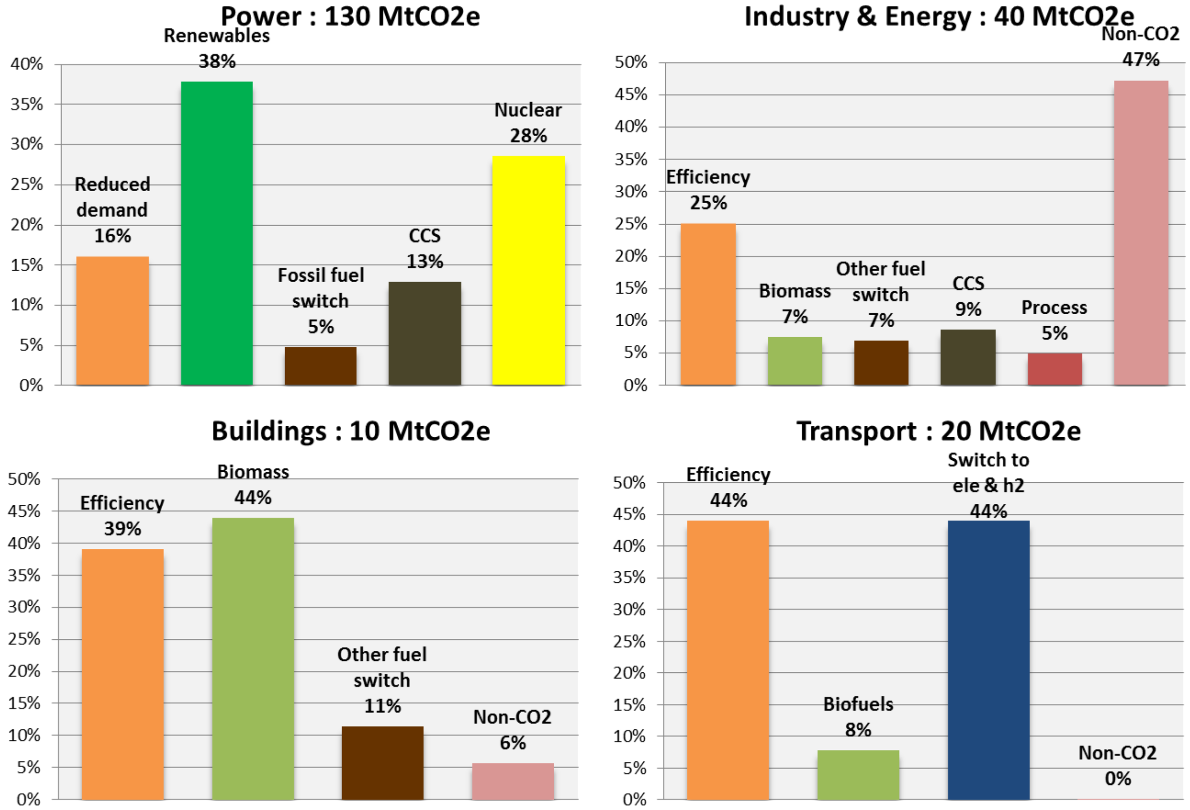
Source: JRC POLES model

Figure 118. South Africa emission reduction options (excl. LULUCF)



Source: JRC POLES model

Figure 119. South Africa emissions mitigation options in sectors - 2030



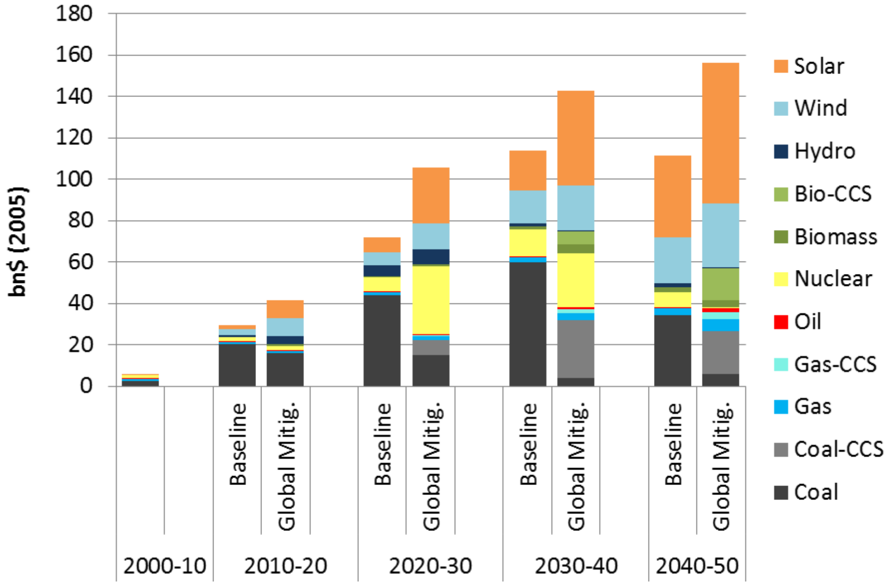
Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

Whichever mitigation path is chosen, it appears that coal will play a significant role in South Africa's energy future. The Integrated Resource Electricity Plan[69] foresees that 37 GW of generation capacity will continue to be provided by existing coal plants in 2030. The Global Mitigation scenario also projects similar capacity for 2030, with coal generating 49% of electricity, but with non-fossil fuels generating a further 40%, and with a rapid decline in the use of coal without CCS thereafter. In addition, the plan foresees renewable capacity (wind, solar and CSP) reaching 17.8 GW by 2030, which is 40% more than the Baseline projection but only half the capacity of the Global Mitigation scenario.

Decarbonising South Africa's power sector will require additional investment compared to the Baseline right up to 2050. The major destinations for this investment in the Global Mitigation scenario would be nuclear in the period 2020-2030 that substitute for coal in base load, a substantial increase in solar investment throughout the period, and CCS (biomass and coal) after 2030-2050. From 2030 onwards only residual investment in conventional coal technology remains.

[69] http://www.doe-irp.co.za/content/IRP2010_promulgated.pdf

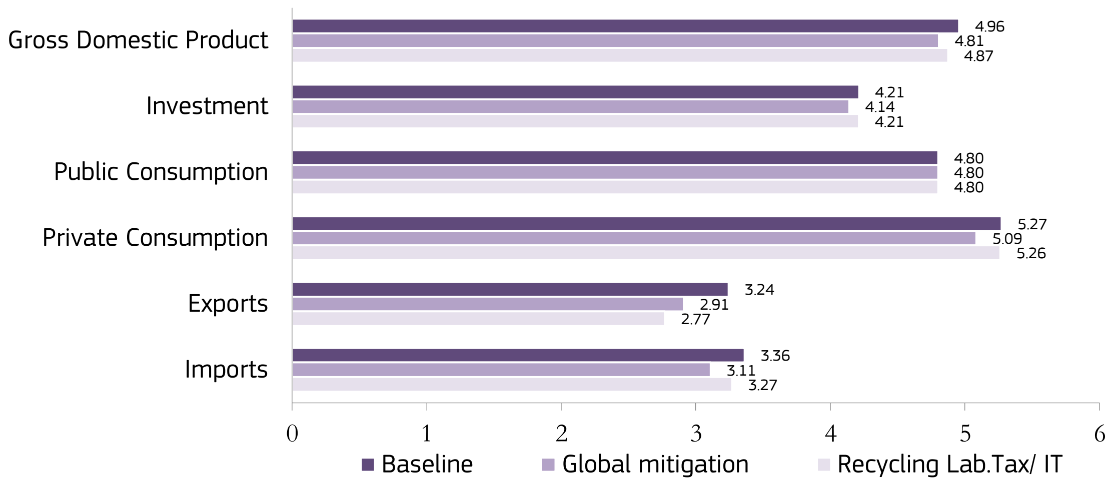
Figure 120. South Africa investment in power (cumulative per decade)



Source: JRC POLES model

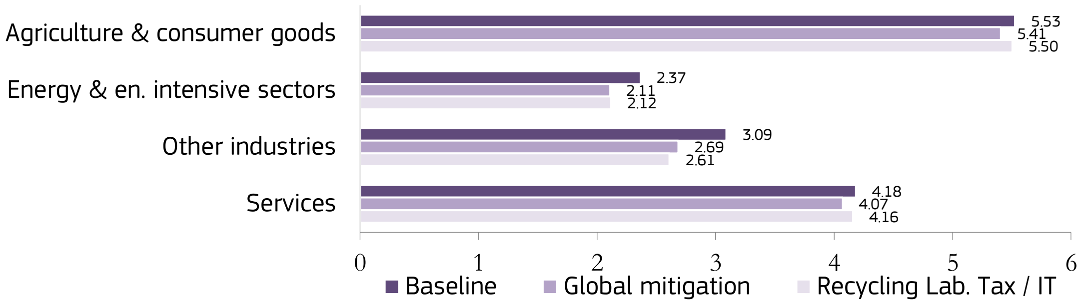
The impact on the total economic activity is minimal in terms of growth rates of GDP, but is not amongst the lowest since the South African economy is not yet carbon efficient. Investment is only marginally reduced, as is private consumption but exports seem to decrease more compared to the Baseline. However, the net trading position of the region remains positive despite the reduction in exports, since imports are also reduced. The reduction of indirect taxes through recycling brings private consumption and investment back to Baseline levels and maintains a slightly worse but positive net trading position.

Figure 121. South Africa, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 122. South Africa, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 40: South Africa, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	16	20	20	20
Energy & Energy Intensive Goods	16	33	35	35
Other Industries	13	40	38	38
Services	56	7	7	7

Source: JRC GEM-E3 model

5.13 USA[70]

The USA is a major emitter of GHGs, both in absolute and per capita terms, accounting for around 10% of global GHG emissions (excl. LULUCF) in 2010. These emissions are projected to decline slightly to 2020 and beyond, with further reductions possible if proposed initiatives (such as the Clean Power Plan) are implemented. However, in the Baseline GHG per capita, at 14 tCO_2e, remain extremely high.

In the Global Mitigation scenario, emissions per capita fall gradually, remaining above current EU levels in 2030. Nevertheless, this scenario achieves a substantial reduction (of almost 1 $GtCO_2e$ per year by 2030) through a balanced mix of increases in renewable energy, nuclear, efficiency savings and non-CO_2 reductions. This scenario highlights the ambition that will be needed if the USA is to meet its aspirational goal of 83% emission reductions by 2050. However, it also demonstrates economic benefits from global mitigation – notably an improvement in competitiveness of export sectors.

The USA accounted for around 10% of global GHG emissions (excl. LULUCF) in 2010, with emissions per capita that are among the highest in the world. Total GHG emissions have been declining since 2010 and this trend is expected to continue up to 2020. However, emissions are expected to stabilise after that, while reductions in 2020 are not expected to be sufficient to meet the pre-2020 pledge of a 17% reduction below 2005 levels.

In the Baseline, GHG do not continue to grow in the long-term, though reductions are small, with 2050 emissions remaining at 95% of the 1990 level. In the Global Mitigation scenario, a reduction of 35% is achieved in 2030 compared to 1990 levels, increasing to around 80% by 2050. At these levels, the USA would come close to meeting its stated long-term target of an 83% compared to 2005 by 2050 (US Department of State, 2010[71]).

[70] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

[71] Fifth National Communication of the United States of America Under the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/natc/usa_nc5.pdf

Table 41. USA decomposition of GHG (excl. LULUCF)

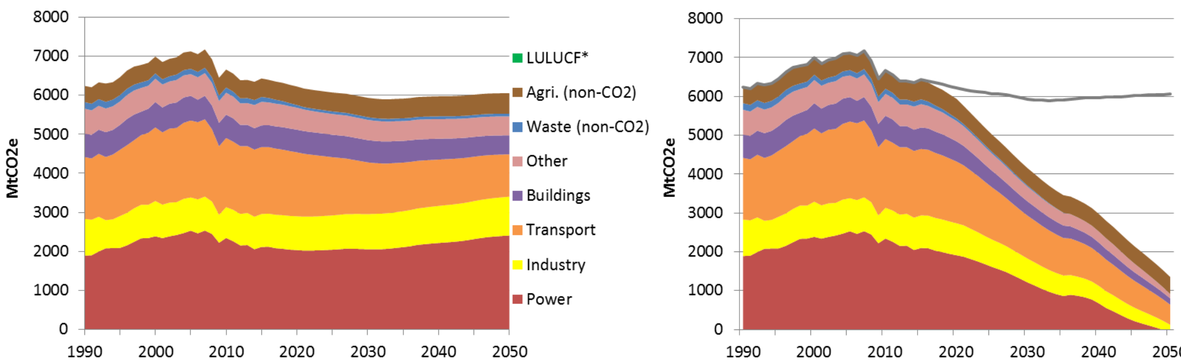
							1990 = 100				
	2010	*'20*	*'25*	*'30*	*'40*	*'50*	*2010*	*'20*	*'30*	*'40*	*'50*
Population (10^6)	312	338	351	363	383	401	123	133	142	151	157
GDP per capita (k$05)	44	52	55	59	66	74	135	160	182	206	229
GHG ($MtCO_2e$)											
Baseline	6485	6022	5859	5716	5726	5778	107	99	94	94	95
Global Mitigation	6485	5740	4820	3960	2785	1223	107	94	65	46	20
GHG per capita (tCO_2e)											
Baseline	20.8	17.8	16.7	15.8	14.9	14.4	87	75	66	63	60
Global Mitigation	20.8	17.0	13.7	10.9	7.3	3.0	87	71	46	30	13
GHG / GDP (tCO_2e/M$)											
Baseline	477	345	302	267	225	195	65	47	36	30	26
Global Mitigation	477	329	249	185	109	41	65	45	25	15	6
Energy / GDP (toe/M$)											
Baseline	165	130	117	107	92	82	69	54	45	38	34
Global Mitigation	165	126	107	94	79	67	69	52	39	33	28
GHG / energy (tCO_2e/toe)											
Baseline	2.9	2.7	2.6	2.5	2.4	2.4	94	87	81	79	77
Global Mitigation	2.9	2.6	2.3	2.0	1.4	0.6	94	85	64	45	20

Source: JRC POLES model

Like other countries with high per capita emissions, the USA has the potential to make substantial reductions by increasing the ambition of existing policies such as emissions trading, emissions standards and energy efficiency measures. For example the USA is expected to generate around 17% of its electricity from renewable sources (including hydro) in 2020, compared to over 30% in the EU. Further reductions could also come from accelerating efficiency improvements in industry and transport (for example converging towards European vehicle fuel economy standards).

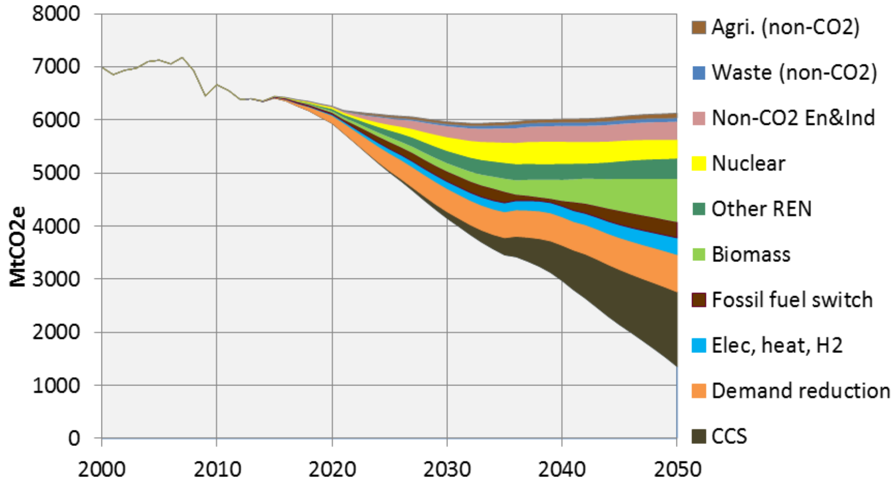
Indeed, the Global Mitigation scenario sees a diversified portfolio of technologies contributing to the USA's emissions reductions in 2030: a significant contribution from improvements in energy efficiency, ahead of renewables (21% all together), nuclear, non-CO_2 and fossil fuel switch towards gas. CCS, which plays a limited role by 2030, then develops and ends accounting for around 20% of the cumulated mitigation in the 2021-2050 period.

Figure 123. USA sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 124. USA emission reduction options (excl. LULUCF)



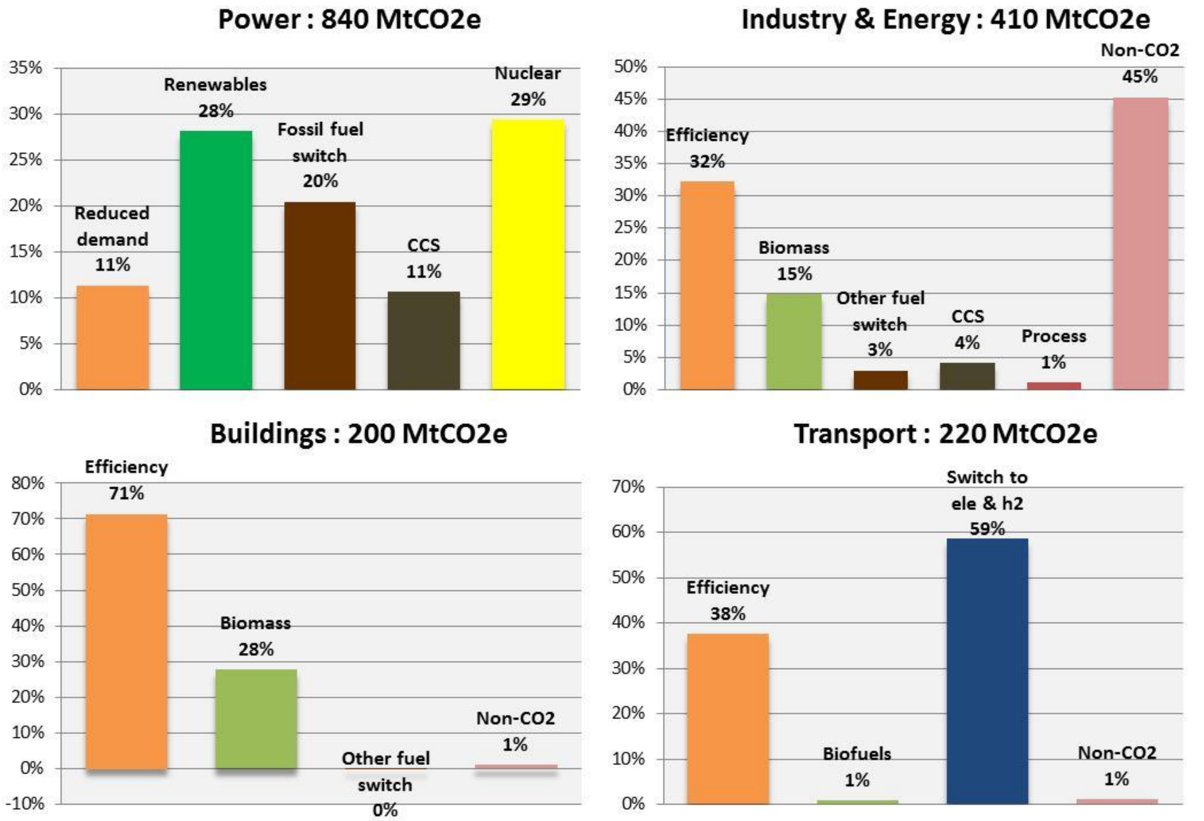
Source: JRC POLES model

The total mitigation (excluding GHG emissions from agriculture and LULUCF) in the USA amount to 1.7 $GtCO_2e$ in 2030, about 11% of the World total. Half is undertaken in the power sector, 25% in industry & energy supply and the rest evenly split between buildings and transport.

In the power sector, mitigation initially comes mainly from a very balanced mix of options: nuclear, renewables and fossil fuel switching (to gas) all contribute to the roughly same levels, while CCS and production change remain smaller. While the contribution from all these technologies is maintained in later years, CCS becomes the main contributor after 2035, accounting for 45% of mitigation in 2050. Other studies have extensively studied the transition to low-emission growth in the US and options for the US energy sector to take up new technologies (EMF, 2013).

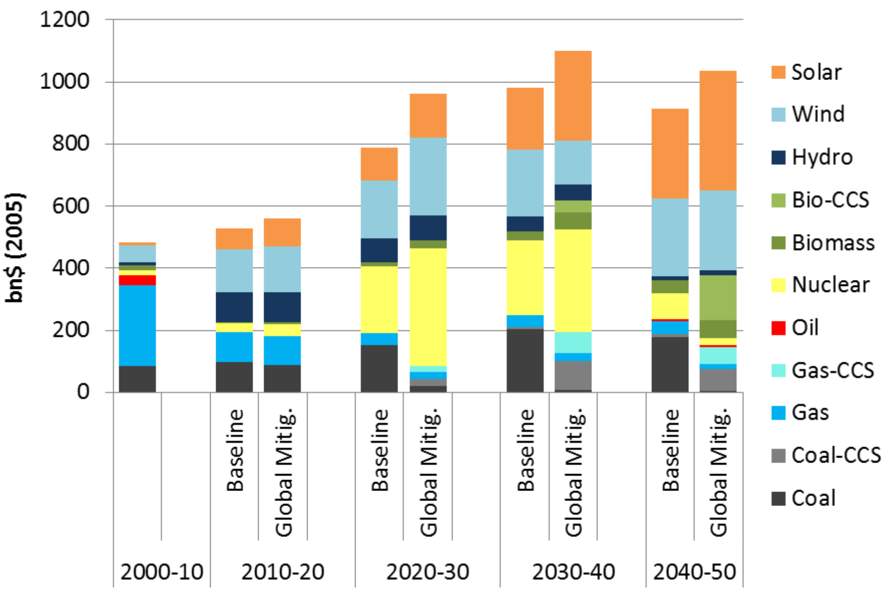
Energy efficiency plays an important role in all other sectors, as do non-CO_2 abatement in the oil and gas sector (CH_4) and in industry (F gases), biomass in buildings and a switch towards electrical vehicles in transport.

Figure 125. USA emissions mitigation options in sectors – 2030



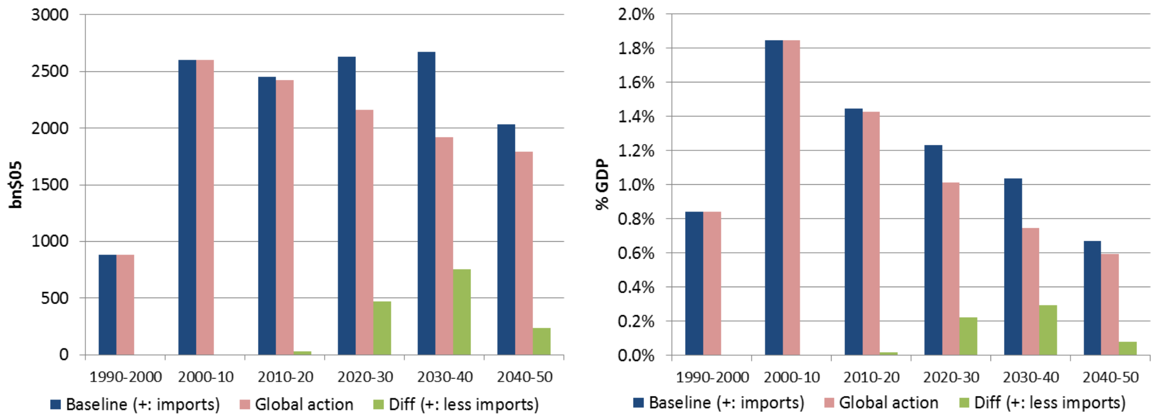
Note: the graphs show the contributions to reductions compared to the Baseline situation. A 0% reduction does not mean that the technology/option does not exist in the energy mix; it means that it does not add reductions in the Global Mitigation scenario.
Source: JRC POLES model

Figure 126. USA investment in power (cumulative per decade)



Source: JRC POLES model

Figure 127. USA Energy trade (cumulative per decade)



Note: includes oil, gas, coal, and biomass; Source: JRC POLES model

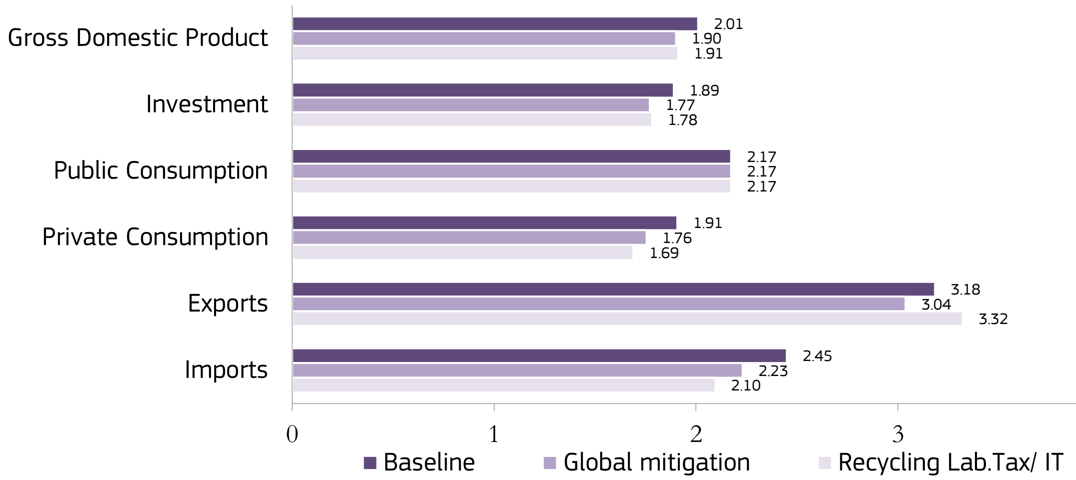
In terms of additional investment in the power sector, the period 2020-2030 is most important as the USA invests less in coal-fired generation and more in nuclear. After 2040, CCS (coal and biomass) and solar are the largest investments, partly replacing the coal investments that would have been made in the Baseline but also adding around 10% to overall investment.

The USA maintains annual GDP growth at around 2% per year under the Global Mitigation scenario (1.9% compared to 2.0%). The costs could be overestimated since some of the specific policies in the Climate Action Plan that refer to improvements in energy and resource efficiency and other structural changes of the economy may not have been considered in the GEM-E3 Global Mitigation scenario. For example, it is estimated that a 40% reduction in methane emissions from the oil and gas industry could be achieved at a net saving of over $100m per year to the US economy (ICF International, 2014).

The driver of this small decline of economic activity is lower private consumption and less demand for investments. However, the trading balance of USA is slightly improved due to a reduction of imports. The reduction of labour taxes through the auction revenue recycling largely improves competiveness so that total exports are higher than in the Baseline and since imports are further reduced due to lower domestic production costs, the trading balance of the country is further improved. The sectors that see an increase in exports in the latter case are the equipment industries and the agricultural and consumer goods. As in other countries, macro-economic modelling shows that energy-intensive sectors are likely to be most heavily affected by mitigation, though the modelling framework used does not take account potential future policies and innovations that could transform the economy away from the status quo and towards a low carbon growth.

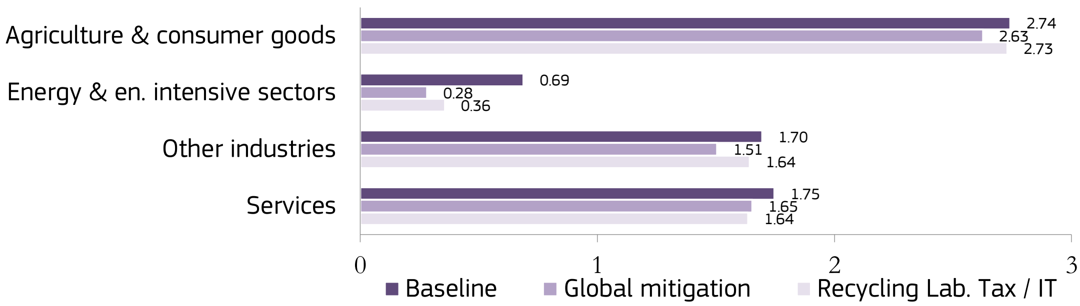
The cost estimates relative to the Baseline should also be considered conservative since the Baseline does not include several policy initiatives that are under development but whose entry into force is not certain at this time. For example, the proposed Clean Power Plan would reduce power sector emissions by 30% in 2020 compared to 2005 levels (compared to the 20% reduction foreseen in the Baseline). Similarly, the US administration has proposed tighter emissions standards for new and existing power plants and methane emissions from oil and gas production.

Figure 128. USA, GDP components in 2020-2030 growth rates



Source: JRC GEM-E3 model

Figure 129. USA, yearly growth rates of domestic production by sector (2020-2030,%)



Source: JRC GEM-E3 model

Table 42. USA, Production and Export Shares of Domestic Sectors (2030)

	Share of Production (%)	Share of Exports (%)		
	Baseline	*Baseline*	*Global mitigation*	*Recycling Lab. Tax/IT*
Agriculture & Consumer Goods	8	24	24	24
Energy & Energy Intensive Goods	11	18	18	18
Other Industries	10	31	31	31
Services	71	27	27	27

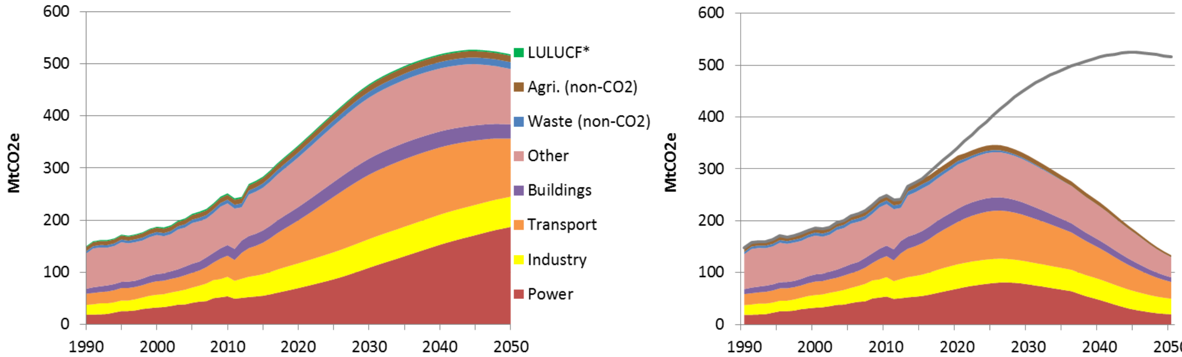
Source: JRC GEM-E3 model

6 Simplified country factsheets

6.1 Algeria and Libya (North Africa Oil & Gas producers)[72]

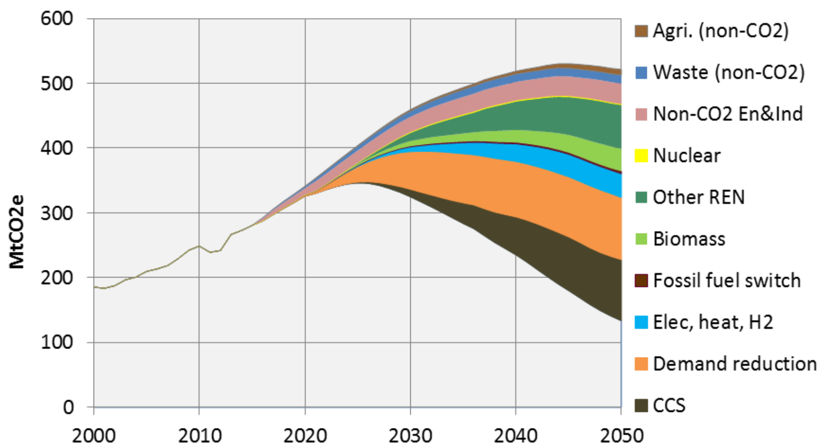
Under a Global Mitigation scenario, Algeria and Libya have opportunities to avoid a soaring in their emissions by reaping their significant potential for energy efficiency. The Global Mitigation scenario suggests that ensuring the fast growing population has access to energy efficient appliances, or improved buildings would deliver significant mitigation benefits. Industrial emissions could also be avoided by reducing emissions in the oil and gas production. Finally, the Global Mitigation scenario identifies for Algeria, Libya as well as other North African countries major opportunities to develop renewable energy production, for satisfying their growing domestic energy demand and for export. This modelling seems realistic as these countries are already working on the policy framework to reap this potential, with high environmental and economic benefits associated. For instance, Algeria aims for a 40% share of renewable electricity generation by 2030, and is already experimenting new technologies, operating one of the first hybrid solar/combined cycle plants (see IRENA 2014c).

Figure 130. Algeria and Libya sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 131. Algeria and Libya emission reduction options (excl. LULUCF)



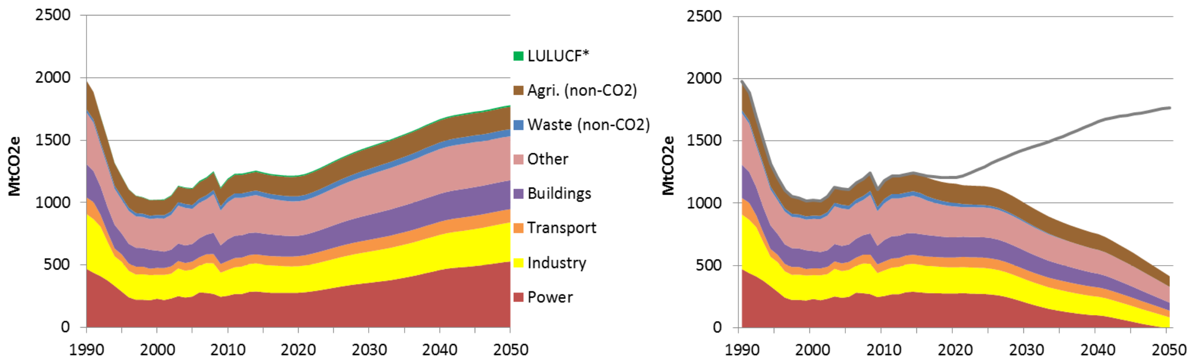
Source: JRC POLES model

[72] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.2 CIS (excl. Russian Federation)[73]

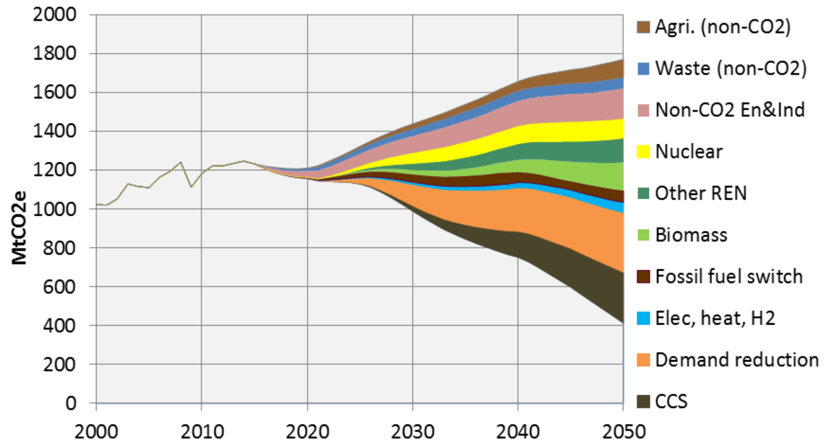
Under a Global Mitigation scenario, Ukraine, Belarus, Moldova, Caucasus, and Central Asian countries have opportunities to avoid an increase in their emissions back to their 1990 levels that are inconsistent with global action in line with staying below 2°C. Along a Global Mitigation scenario, the transition would be gradual: first countries would stabilise and decrease their emissions by 2030, before undertaking deeper cuts by 2050. Current policy goals like Belarus' carbon intensity improvements target by 2020 would not be sufficient to move on such pathway and to reap the diversified mitigation benefits of the Global Mitigation scenario (from reducing non-CO_2 emissions to developing clean energy to improved energy efficiency). The Global Mitigation scenario seems nonetheless realistic as Kazakhstan has taken a target for reaching 50% of alternative and renewable energy in the country's energy mix by 2050 by phasing out ageing infrastructure, increasing the use of alternative fuels and installing efficient and environmentally sound energy technologies (IEA 2014b). Further, Kazakhstan is deploying wind energy and district heating technologies with international support (World Bank 2014a).

Figure 132. CIS (excl. Russia) sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 133. CIS (excl. Russia) emission reduction options (excl. LULUCF)



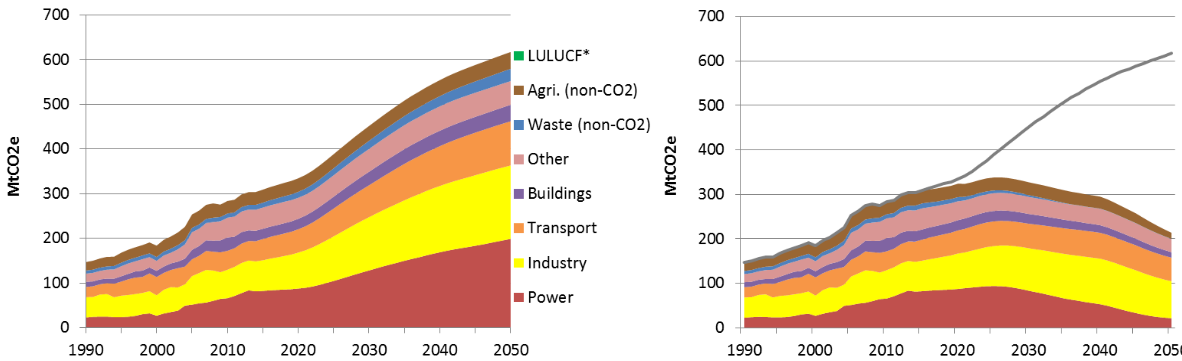
Source: JRC POLES model

[73] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.3 Egypt[74]

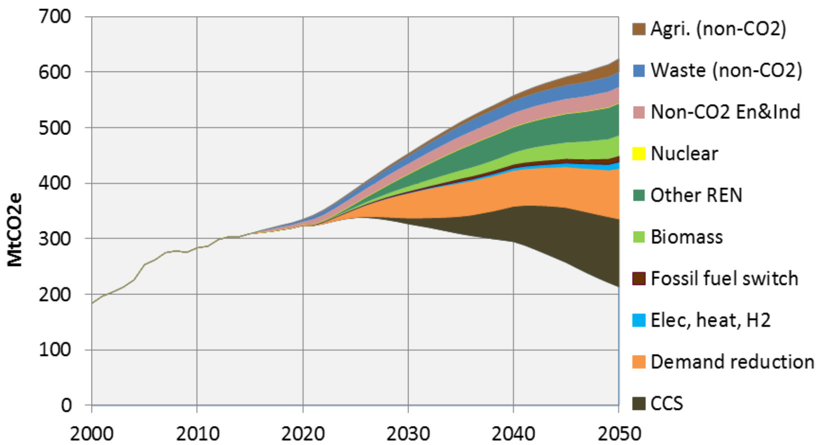
Under a Global Mitigation scenario, Egypt would control the growth in its emissions that would otherwise double compared to 2010 levels by 2050 under the Baseline scenario. The transformation of the power sector and improvements in the emission intensity of the industry sector would deliver such stabilisation of emissions in the period 2020-2040. It is likely that co-benefits would be associated to this transformation in terms of productivity and competitiveness. This modelling scenario seems realistic as Egypt has already started to improve the emission intensity of its economy and has put in place a National Low-Carbon Economy Strategy and energy targets in the National Energy Policy that aim investing in clean technologies (see IRENA 2014c). This policy framework promotes the enhanced use of natural gas, the reform of inefficient subsidies to fossil fuel consumption, an increased use of renewable energy (solar, wind and biomass) to supply 20% of national electricity demand by 2020 and to reduce 10% of future energy consumption through energy efficiency. The modelling indicates delivering such measures will go a long way to realising the transition to a low-emission future.

Figure 134. Egypt sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 135. Egypt emission reduction options (excl. LULUCF)



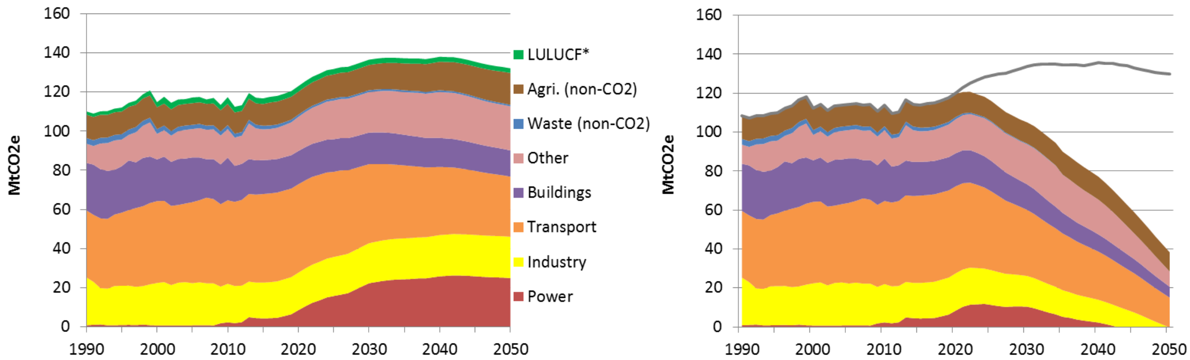
Source: JRC POLES model

74 This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.4 European Free Trade Association[75]

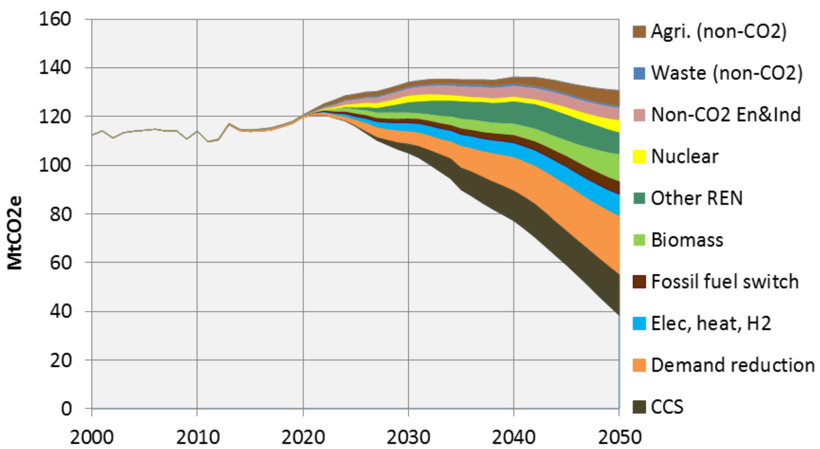
Under the Global Mitigation scenario, the European Free Trade Association (EFTA) countries (Iceland, Norway, Switzerland)[76] reduce domestic GHG emissions by 61% below 1990 levels by 2050. Together Norway and Switzerland account for over 95% of the region's GHG emissions. The region features a low level of emission intensity (38-50% lower emissions per unit of GDP compared to the EU level, which is below the levels of all other G20 economies) with its high levels of GDP and high use of renewable energy (esp. hydro). In the Baseline, power sector emissions rise along with increased demand. The region's emissions remain above the global average in the Baseline up to 2050. In the Global Mitigation scenario, the region realise emission cuts balanced across different renewable energy and fuel switching options, though the largest saving comes from energy savings. Each EFTA country has pledged 2020 emissions reductions of 15-40% that are comparable to the Global Mitigation scenario levels of domestic emission reductions (Figure 137)[77].

Figure 136. EFTA sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 137. EFTA emission reduction options (excl. LULUCF)



Source: JRC POLES model

75 This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

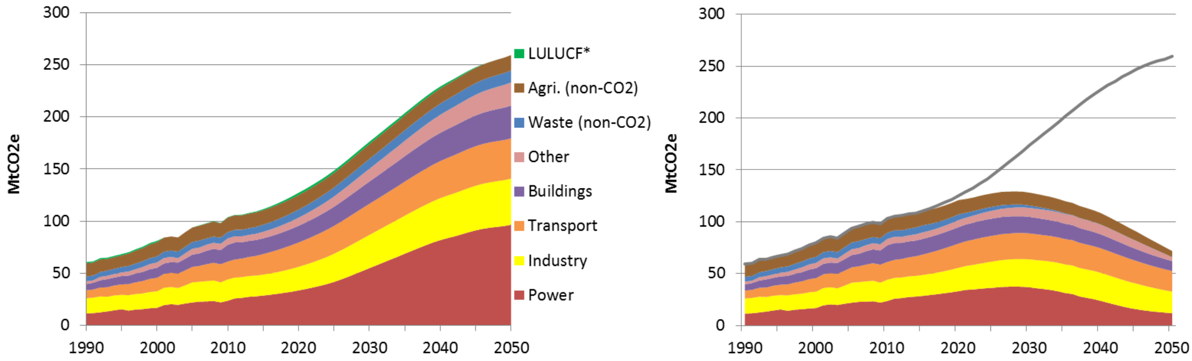
76 Liechtenstein is not part of the modelling.

77 2020 pledges are reductions of 15%, 30-40% and 20-30% for Iceland, Norway and Switzerland respectively.

6.5 Morocco and Tunisia (North Africa non-Oil & Gas producers)[78]

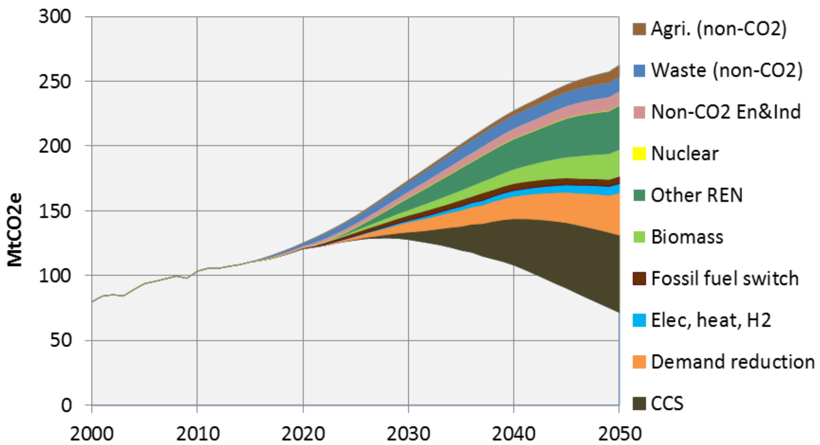
Under a Global Mitigation scenario, Morocco and Tunisia would peak their emissions by 2030 and decline afterwards, instead of experiencing a fast growth in their emissions, more than doubling their emissions from 2020 to 2050 in the Baseline. The most significant mitigation option for these countries relates to the development of renewable energy sources, as well as enhanced waste management. There would be benefits associated for the local industry from reaping this potential. Moreover, Morocco is currently importing a sizeable share of its electricity and would get energy security benefits from diversifying its energy mix with more reliance on abundant renewable energy sources. This modelling result seems realistic as Morocco is currently aiming for 42% of its electricity capacity to come from renewable sources by 2020, and working in the context of the Climate and Clean Air coalition on policy experiences to address emissions from waste. Tunisia aims for 30% of its electricity generation from renewable sources by 2030 (see IRENA 2014c, World Bank 2014a).

Figure 138. Morocco and Tunisia sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 139. Morocco and Tunisia emission reduction options (excl. LULUCF)



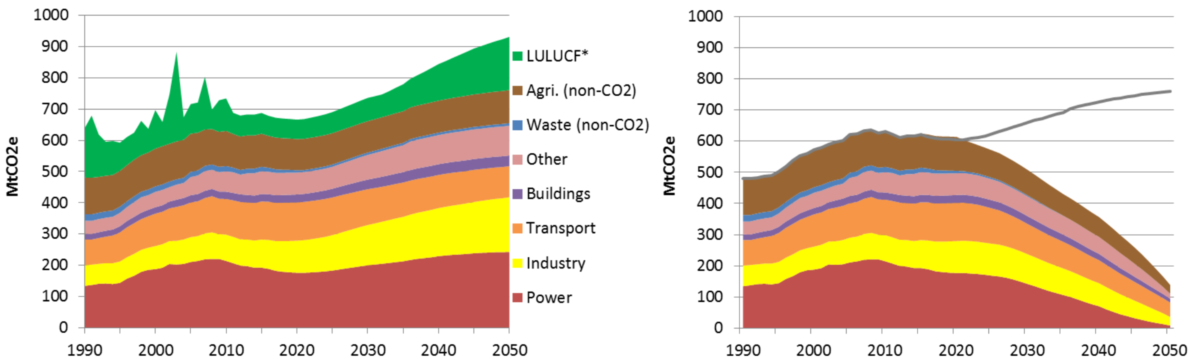
Source: JRC POLES model

78 This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.6 Oceania[79]

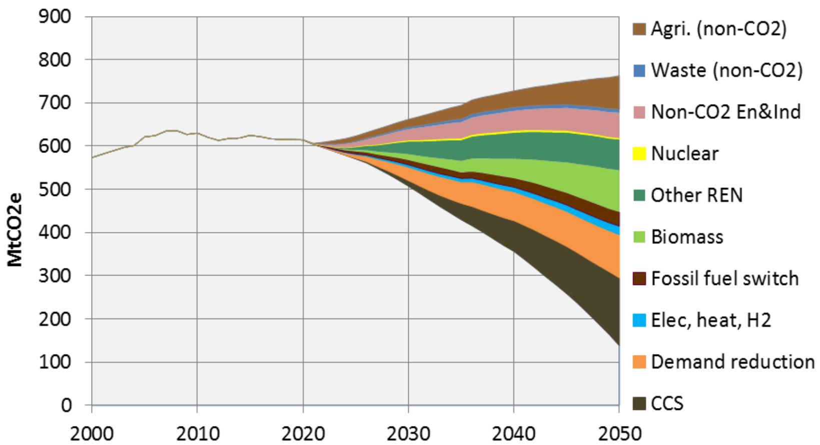
In the Global Mitigation scenario, the emissions from Australia, New-Zealand, Papua New Guinea and Pacific Islands rapidly go down after 2020 driven mostly by the largest economies in the region: Australia and New Zealand. The main emission reductions occur in the power sector, but they are also distributed in industry, agriculture and services. These cross-cutting emission reductions enable the region to come down from currently high levels of emission per capita and per unit of GDP towards the level of other regions by 2030, and to reach by 2050 low absolute levels. This modelling seems realistic, as in 2015 Australia's national projections indicate an improvement in emission intensity per unit of GPD. The modelling shows the switch to renewable energy sources to realise the transition to a low-CO_2 future; countries are putting in place policies in this direction: Australia is relying on the Emission Reduction Fund, small islands states are setting ambitious targets. Other options to cut emissions rapidly minimising overall costs come from agriculture, developing bioenergy, and reducing non-CO_2 emissions in industry (IDDRI 2014, World Bank 2014a).

Figure 140. Oceania sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 141. Oceania emission reduction options (excl. LULUCF)



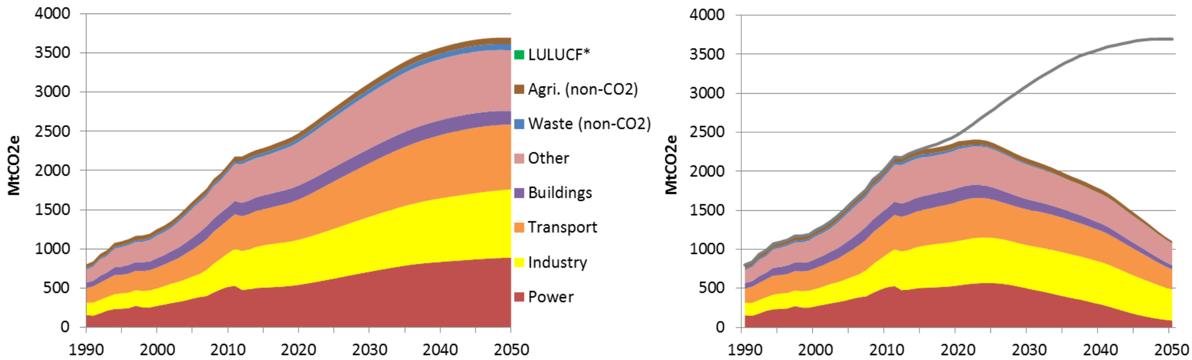
Source: JRC POLES model

[79] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.7 Persian Gulf region[80]

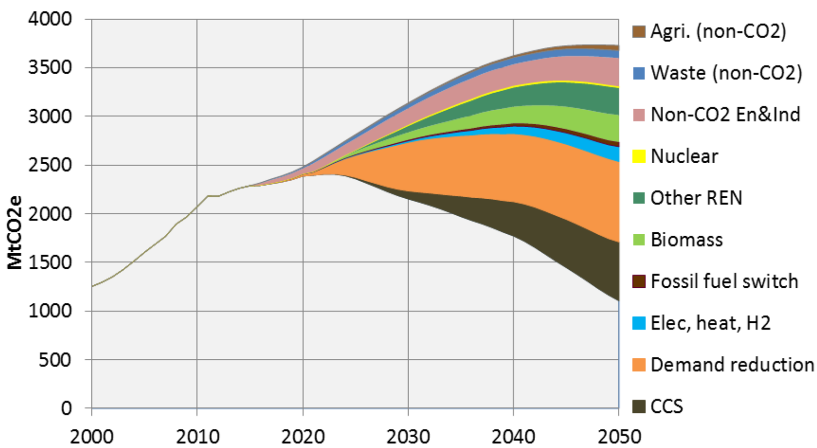
In the Global Mitigation scenario, the emissions from Iran, Saudi Arabia, UEA, Qatar, Oman, and Bahrein peak by 2025 and gradually decline. In the Baseline, Iran and Gulf countries are amongst the countries with high income, high emissions per capita and per unit of GDP. These countries are currently confronted with the fastest increase in energy consumption requiring large-scale investments in new capacities especially to satisfy peak demands and demand for water resources. The evolution from the Baseline to the Global Mitigation scenario seems realistic as, in the context of the national strategy to diversify their economy to support their long-term growth, the Gulf countries have set renewable energy development goals, and considering how to learn from the experiences of energy efficiency policies from other regions (like fuel efficiency standards, or energy-using equipment standards or labels). Improving the energy efficiency in many sectors could enable to valorise further the fossil fuel endowment of the region, and to direct investment to sustain long-term growth. One of the key mitigation options emerging in the Global Mitigation scenario are fossil-fuel switching and reducing CH_4 emissions from fossil fuel production (IEA 2014a, IRENA 2014c).

Figure 142. Gulf sectoral GHG emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 143. Gulf emission reduction options (excl. LULUCF)



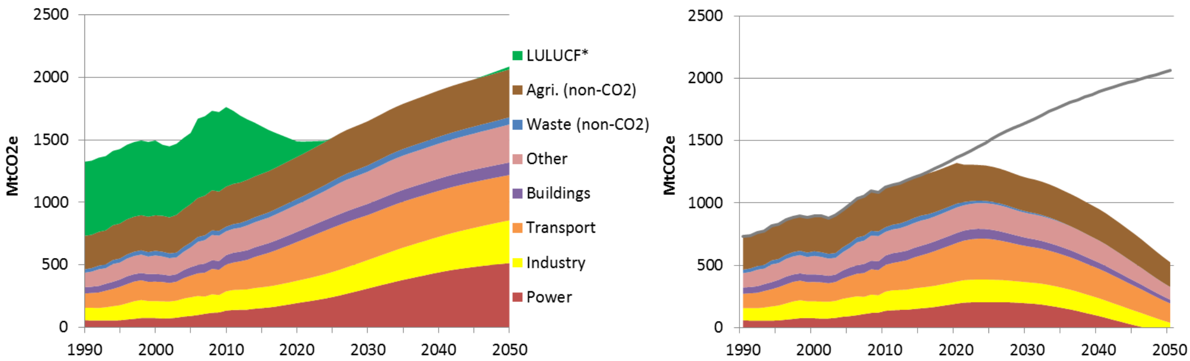
Source: JRC POLES model

[80] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.8 South America (excl. Brazil)[81]

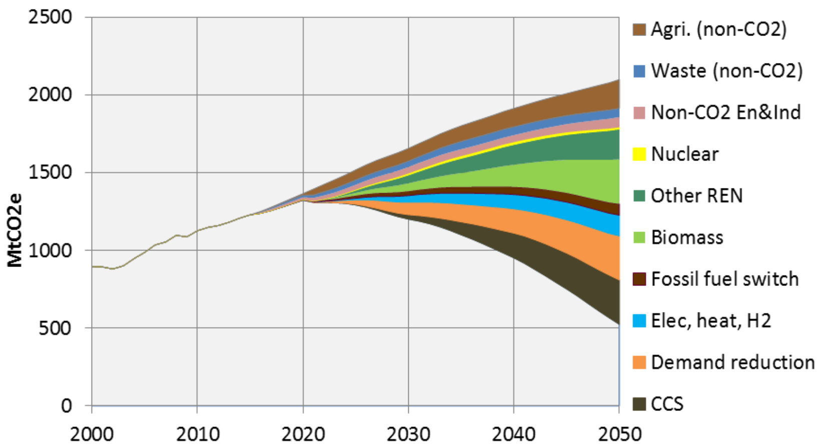
In the Global Mitigation scenario, Central and South American countries depart from a fast-growing emission pathway and instead achieve gradual emission reductions from 2020 onwards, in a context of dynamic economic growth. A significant share of emissions in this region was historically related to the land-use sector. In the Baseline, emissions increase largely in the power sector, as the region is growingly exploiting its fossil fuel energy sources or importing them to satisfy higher energy consumption. This modelling seems realistic as a number of countries in the region have already set a framework for their transition to a low-emission future. Costa Rica is aiming for carbon neutrality, and Peru, Colombia, Chile, Uruguay, Dominican Republic are implementing sector specific policy measures cutting across a variety of sectors (agriculture, forestry, sustainable housing and transport, waste, energy). Ecuador, Argentina, Panama are also working on some individual actions. Overall, the modelling suggests that there is scope for realising further mitigation opportunities distributed across all sectors of the economy, whilst aiming for a low level of emissions per capita in the long run. (CLIMACAP 2013, World Bank 2014a).

Figure 144. South America (excl. Brazil) emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 145. South America (excl. Brazil) emission reduction options (excl. LULUCF)



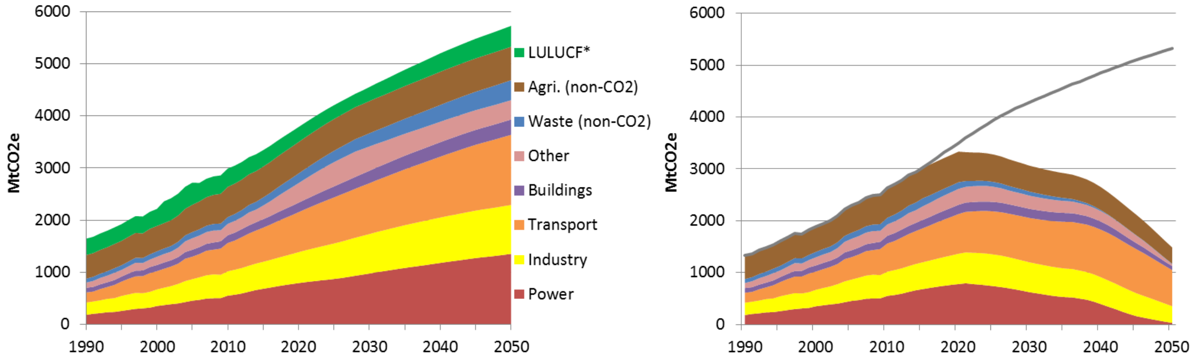
Source: JRC POLES model

[81] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.9 South Asia & South East Asia (excl. China, India, Indonesia) [82]

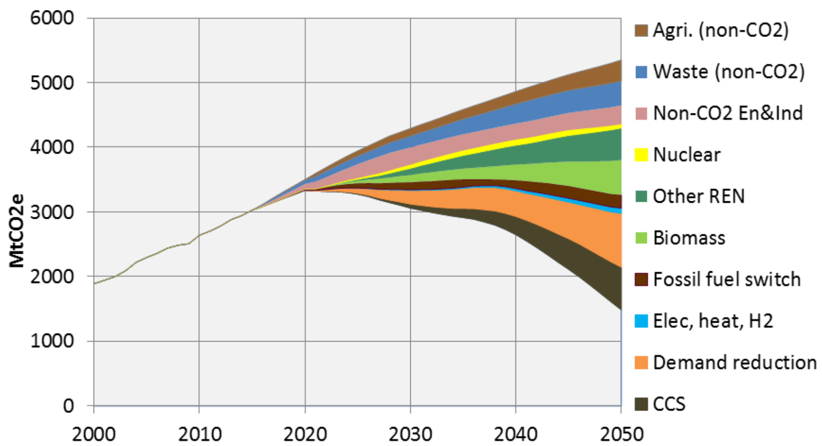
The South Asia and South East Asia regions aggregate countries with different socio-economic characteristics: GDP/cap levels and emission intensity vary significantly across Singapore, Malaysia, Philippines, Thailand, Vietnam, Pakistan, etc. Nonetheless, in the Baseline scenario projections, the region collectively experience fast growth in the coming decades. In the Baseline, this would be coupled with significant increase of emissions above 4,5 $GtCO_2e$ in 2030 and about 5,5 $GtCO_2e$ in 2050. Other studies indicate this region is particularly vulnerable to impacts of dangerous levels of climate change (World Bank 2014c). In the Global Mitigation scenario, emissions slowly decline from 2020 onwards and use low-emission technologies by 2050. The modelling indicates mitigation opportunities are distributed across sectors by 2030, with a significant role to play for energy efficiency improvements.

Figure 146. Asia (excl. China, India, Indonesia) emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 147. Asia (excl. China, India, Indonesia) emission reduction options (excl. LULUCF)



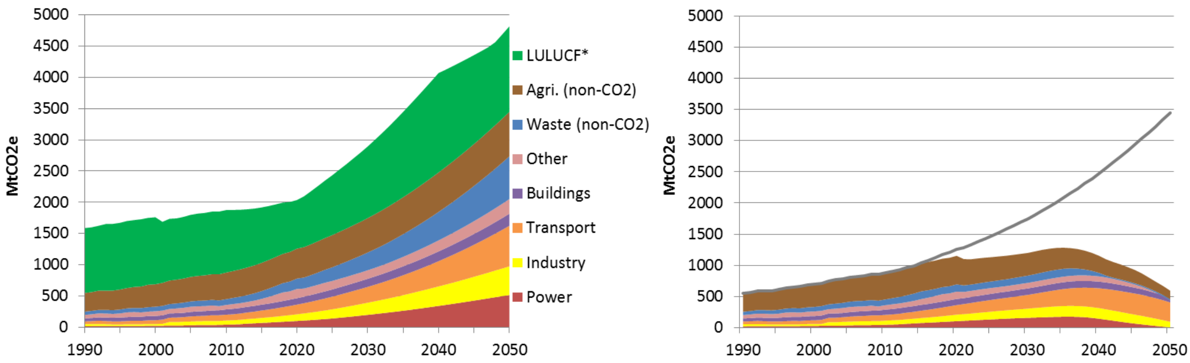
Source: JRC POLES model

82 This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.10 Sub-Saharan Africa[83]

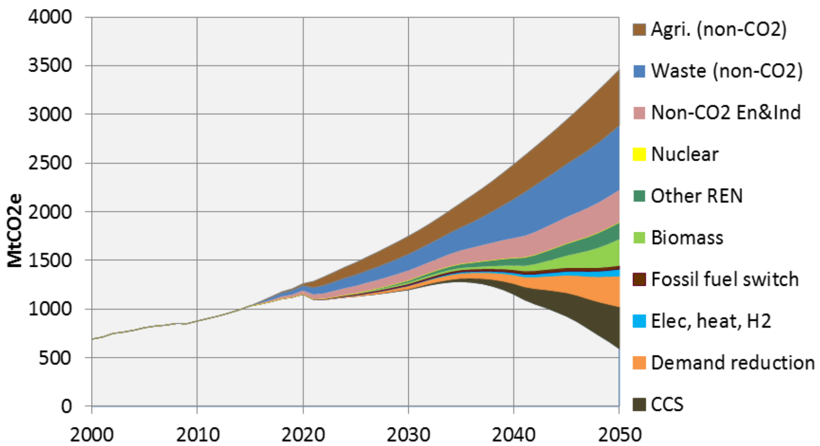
Emissions from the region are historically dominated by land-use emissions. However in the Baseline from 2020 onwards emissions from the other sectors accumulate to a large scale. Other studies (e.g. IEA 2014c) highlight the region is most vulnerable to climate damages and it needs to develop infrastructures for cities, access to energy, and transport. In our modelling the region experiences the fastest population growth up to 2050. In the Global Mitigation scenario, emissions peak in a late period (after 2035), and large-scale emission reductions are realised by developing new renewable energy capacities and sustainable agriculture production. Both options translate in improved emission intensity of the economies and productivity gains. These results seem realistic as some countries in the region have outlined national strategies turning the need to control emissions into an opportunity for development (e.g. Ethiopia and Kenya). Fossil fuel energy producers could continue exporting energy even in the Global Mitigation scenario. The policy and macro-economic context will play a key role to realise the investments in renewable energy identified as cost-effective in the Global Mitigation scenario (see also IEA 2014c).

Figure 148. Sub-Saharan Africa (excl. South Africa) emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 149. Sub-Saharan Africa (excl. South Africa) emission reduction options (excl. LULUCF)



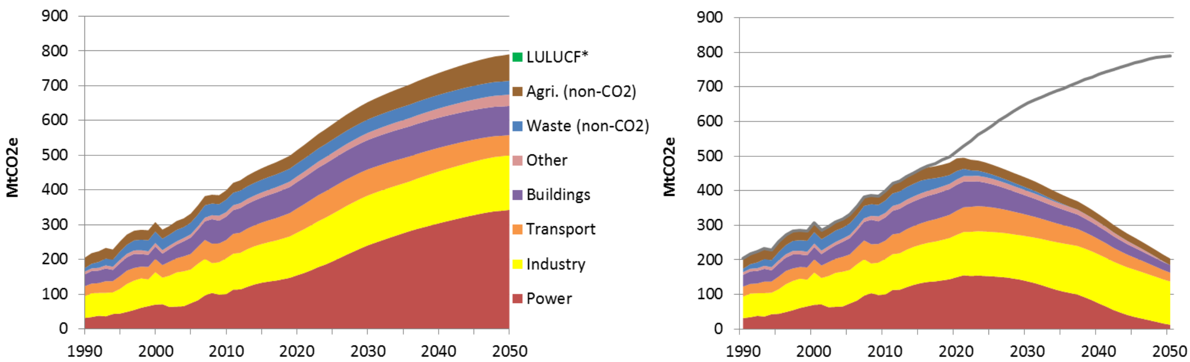
Source: JRC POLES model

[83] This section gives the possible evolution of the energy system and GHG emissions of the region under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

6.11 Turkey[84]

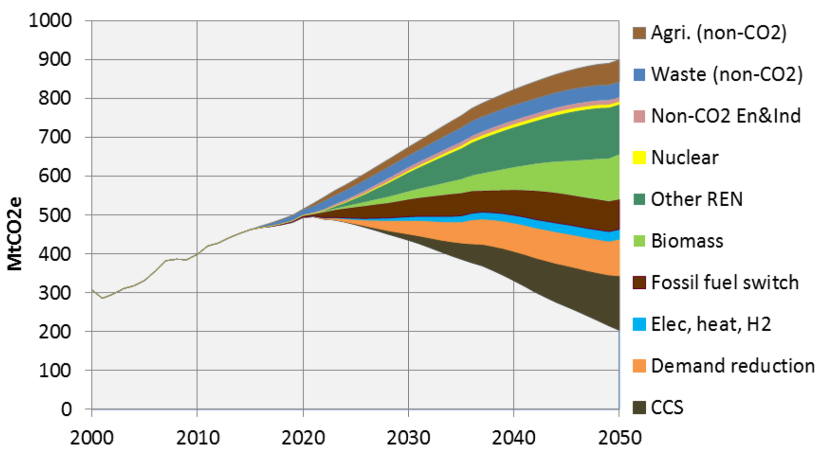
In the Baseline, emissions after 2025 increase significantly and the levels of per capita and emission intensity of the economy rise above levels consistent with IPCC findings to stay below 2°C. This large increase is particularly related to the power sector that will remain emission-intensive in the absence of new policies. Moreover, in this scenario, energy imports would also have to increase, burdening the economy. In the Global Mitigation scenario, a fast growth in renewable energy and in energy efficiency allows for a fast growth in the Turkish economy and the related growing energy demand, without rising emissions levels. These projections seem realistic as Turkey is working on deploying renewable energy and energy efficiency solutions. This shifting power generation and energy use improves the energy security of Turkey (World Bank 2014a).

Figure 150. Turkey emissions, Baseline (left) vs. Global Mitigation scenario (right, excl. LULUCF)



Source: JRC POLES model

Figure 151. Turkey emission reduction options (excl. LULUCF)



Source: JRC POLES model

[84] This section gives the possible evolution of the energy system and GHG emissions of the country under a specific set of constraints and within a particular modelling framework. As such it should not be regarded as policy prescriptive but rather as informative.

7 Areas for further research

Based on the modelling work with the POLES and GEM-E3 models prepared in relation to this report, further research could be relevant:

1. To improve further the country representation in the above-mentioned models by disaggregating regions with large emissions into specific countries with different energy mixes, economic structures, established or planned policies;

2. To develop the analysis of the co-benefits of mitigation actions, in terms of air pollution reduction, food security, socio-economic development, and the benefits from new investments for access to energy, energy security or productivity, competitiveness and jobs;

3. To further develop the analysis of the benefits for specific sectors and the diversification of the economies along low-emission development pathways, including taking into account that countries are actively working on the liberalisation of trade in environmental goods and services in order to increase the dissemination and uptake of climate-friendly technologies;

4. To represent further options of international cooperation on climate action. Countries are developing national and international carbon pricing schemes and putting in place domestic and international institutions to finance mitigation efforts. The new Paris agreement will set out legally binding mitigation commitments for all countries and a dynamic process, informed by science, that reviews every five years the international cooperation on climate action in order to stay over time on track to achieve the below 2° objective. All countries will be implementing their new mitigation commitments and their low-emission development strategies. The modelling framework and scenarios will have to evolve to represent and inform these policy developments.

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Annex 1. Socio-economic Assumptions

Macro-economic and socio-economic assumptions for the scenarios have been derived from the following sources:

<u>EU</u>

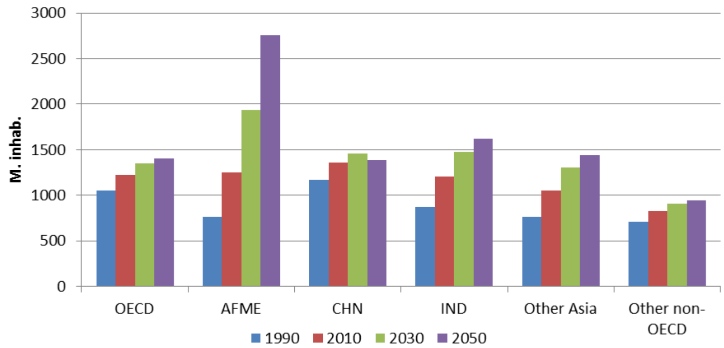
- Population and GDP are from the EU Trends to 2050 scenario (EC, 2013a), using historical data from Eurostat.

<u>Non-EU</u>

- Population: UN (2013) Population Division, medium fertility scenario
- GDP:
    - Historical GDP up to 2012: World Bank (2014b)
    - by 2019: growth from IMF International Economic Outlook (IMF, 2014)
    - from 2030: growth derived from OECD Economic Outlook (OECD, 2013) and Dellink, R. et al. (2014)
    - between 2020-2030: interpolation of growth rates

The following figures illustrate the evolution by 2050 of the main socio-economic drivers.

Figure 152. World population, 1990-2050



The GDP assumptions are fairly consistent to what is used in other international energy outlooks, such as the International Energy Outlook (EIA, 2013) or the World Energy Outlook (IEA, 2014).

Figure 153. GDP 1990-2050: yearly growth (left), volume (right)

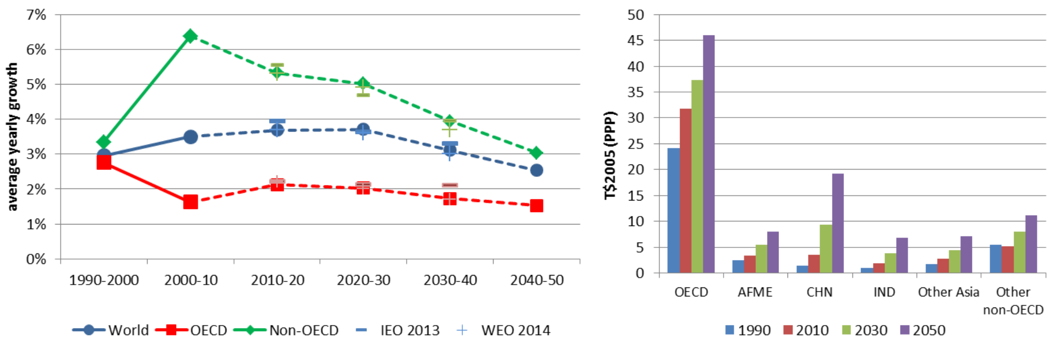
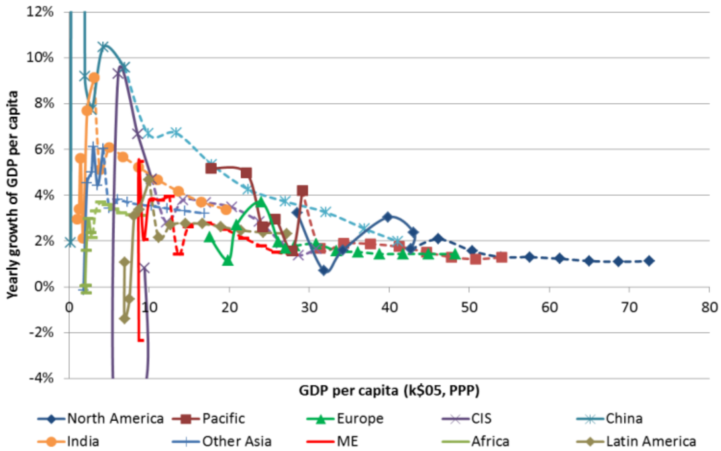


Figure 154. GDP per Capita growth vs. GDP per Capita, 1980-2050



Note: GDP is expressed in $2005 PPP, points are given every 5 years, plain lines: 1980-2010, dashed lines: 2010-2050

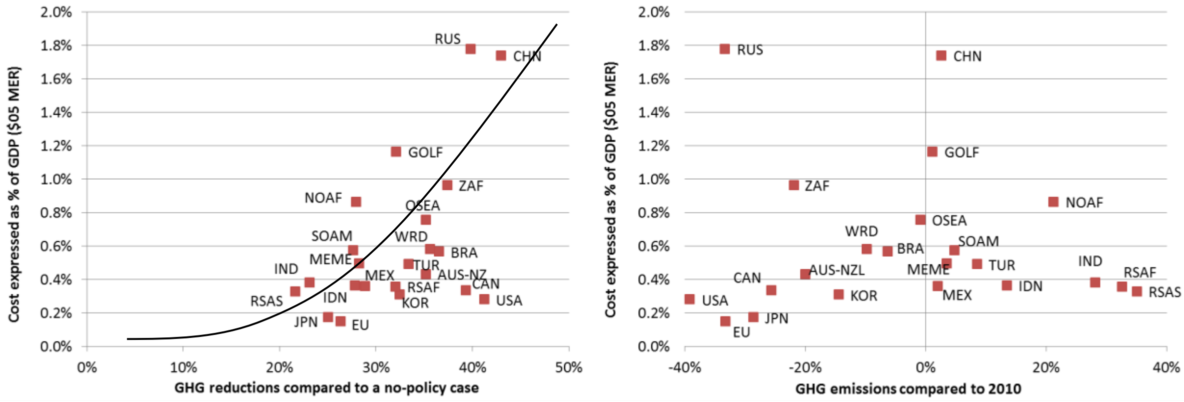
Annex 2. Abatement costs

Annex 2.1 Regional abatement costs

Figure 155 gives the countries' abatements cost in 2030 versus the GHG reductions (left: compared to emissions in a no-policy case[85], right: compared to 2010 emissions). The total costs and emissions include three sectors: energy, industry and agriculture, covering most GHG emissions (excl. LULUCF). The cost is calculated as the area under the marginal abatement cost curve aggregated over all sectors, without consideration of macro-economic feedback.

Costs in 2030 remain limited, with a World average reaching 0.58% of total GDP. Coal-intensive countries like China and South-Africa, as well as oil and gas producers like Russia (which is also coal-intensive), the Gulf region and North Africa (NOAF) face higher costs.

Figure 155. 2030 GHG abatement costs in the Global Mitigation scenario



Note : POLES abatement cost is calculated as the area under the marginal abatement cost curve (MACC) aggregated over energy, industry and agriculture.
Source: JRC POLES model

Brazil, Russia, South-Africa, EU, USA, Japan, Canada, South Korea and Australia-New Zealand show emissions reductions compared to 2010. All other regions see their 2030 emissions at the same or higher level than in 2010.

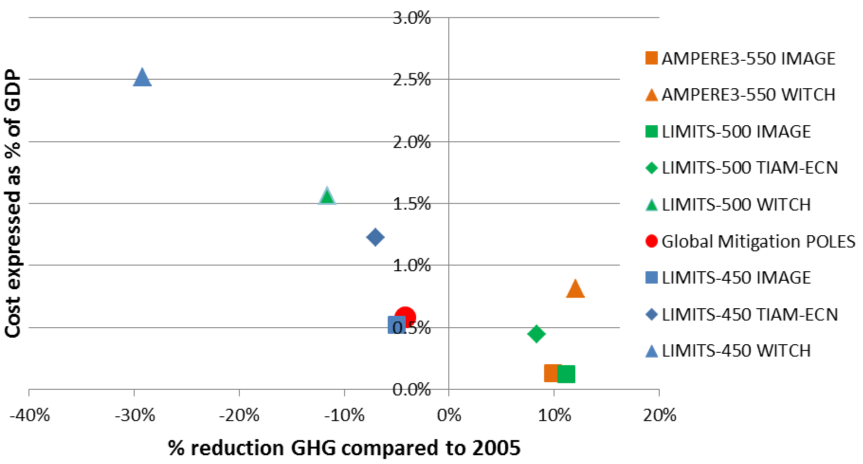
[85] This "no policy" case is a scenario without any new policy implemented from 2014 on, which translates mostly in the absence of a carbon price. It thus differs from the Baseline which already includes the necessary carbon value to respect 2020 pledges for some countries and regions (see section 3.2 above).

Annex 2.1 Policy costs compared to AMPERE and LIMITS projects

We compare below the policy costs of the Global Mitigation scenario with findings of other projects focusing on Global Mitigation strategies: the AMPERE project[86] and the LIMITS project[87], both funded by the 7th Framework Programme for European Research and Technological Development (FP7[88]).

Figure 156 shows the abatement cost at World level of various scenarios corresponding to different long term GHG concentrations: 550 ppm (thereafter called "550"), 500 ppm ("500"), 450 ppm ("450").
It shows that for the Global Mitigation scenario the abatement cost[89] amount to 0.58% of GDP with emissions 4% below the 2005 level. This Global Mitigation scenario 2030 mitigation scenario is:
- Consistent with the 500 ppm scenarios (green dots) with abatement costs between 0.1% and 1.6% of GDP, and emission levels ranging from -12% to 11% compared to the 2005 level;
- Less constraining than the 450 ppm scenarios (blue dots), where abatement costs range from 0.5% to 2.5% of GDP with emissions levels between -5% and -29% compared to 2005.

Figure 156. 2030 World abatement cost: comparison with AMPERE and LIMITS projects

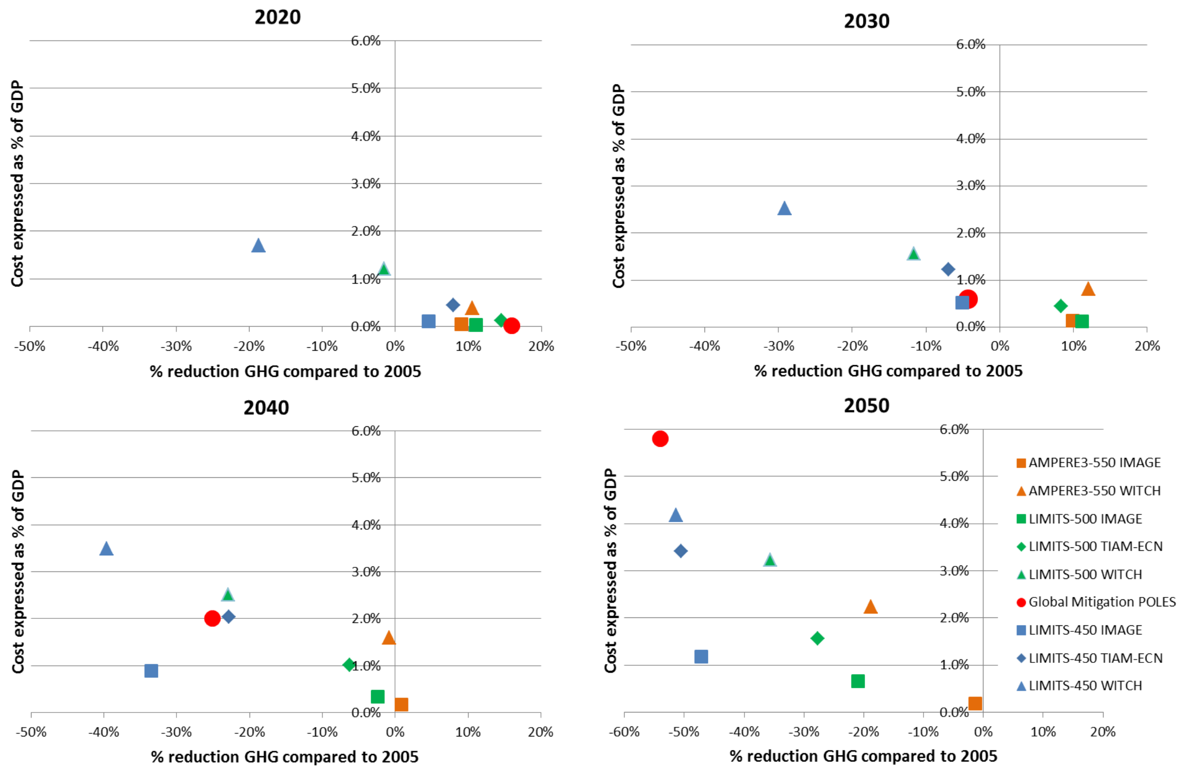


Note 1: Comparison with the European FP7 projects AMPERE and LIMITS
Note 2: "550"", "500" and "450" refer to the long term GHG concentration expressed in ppm
Note 3: The models IMAGE and GECO POLES give the area under the marginal abatement cost curve (MACC).The models TIAM-ECN and WITCH give the additional system cost
Source: AR5 database (2015), JRC POLES model

Figure 157 shows the evolution over time of the abatement cost (expressed as % of the GDP). In 2020 the Global Mitigation scenario is actually less ambitious than all other scenarios used for the comparison, including the 550 ppm scenarios. By 2030 it lies within the 500 ppm range. By 2040 it moves, in terms of mitigation ambition, towards the 450 ppm scenarios. In 2050 it more ambitious than the 450 ppm scenarios, in order to compensate for lower GHG reductions at the beginning of the period, while staying consistent with the 2010-2050 CO_2 budget recommended by the IPCC (see Figure 14). This higher ambition in 2050 explains the more expensive cost observed at the end of the period for this scenario as compared to the findings of AMPERE or LIMITS.

[86] http://ampere-project.eu/web/
[87] http://www.feem-project.net/limits/index.html
[88] http://cordis.europa.eu/fp7/home_en.html
[89] The area under the marginal abatement cost curve calculated by the POLES model.

Figure 157. Abatement cost 2020-2050: comparison with AMPERE and LIMTIS projects

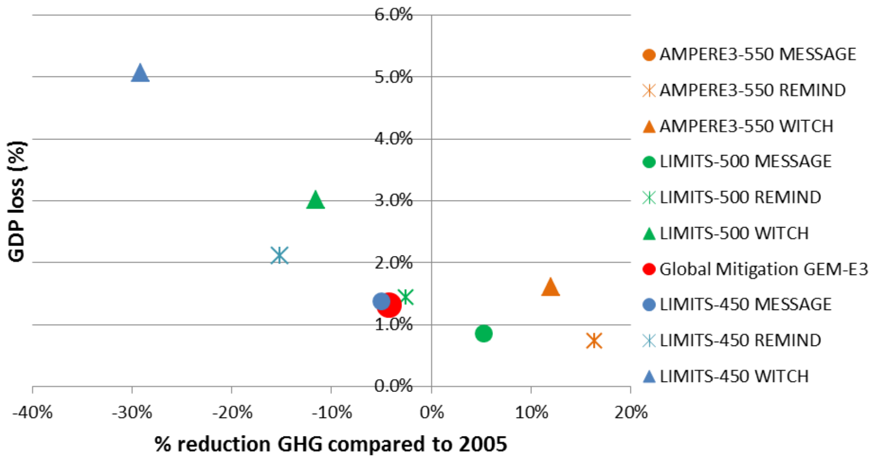


Note 1: Comparison with the European FP7 projects AMPERE and LIMITS
Note 2: "550"", "500" and "450" refer to the long term GHG concentration expressed in ppm
Source: AR5 database (2015), JRC POLES model

The comparison of GDP loss in 2030 (Figure 158) leads to similar findings as before: the Global Mitigation scenario with emissions 4% lower than in 2005 leads to a GDP loss of 1.3% by 2030, which is:

- In the range of the 500 ppm scenarios with GDP losses between 0.9% and 3%, and emission levels ranging from -12% to 5% compared to the 2005 level;
- Less constraining than the 450 ppm scenarios that show GDP losses from 1.4% to 5% for emissions being 5% to 29% lower than the 2005 level.

Figure 158. 2030 World GDP loss: comparison with AMPERE and LIMITS projects



Note 1: Comparison with the European FP7 projects AMPERE and LIMITS
Note 2: "550"", "500" and "450" refer to the long term GHG concentration expressed in ppm
Note 3: It shows the GDP loss compared to the baseline as described in the previous sections.
Source: AR5 database (2015), JRC GEM-E3 model

Annex 3. Definitions

Energy conversion

The calculation of primary energy equivalent uses the conversion methodology (physical energy content) and factors of the IEA. It translates into using:
- Nuclear: using a thermal efficiency of 33%;
- Geothermal: using a thermal efficiency of 10%;
- Wind, solar, hydro: primary energy is equal to the electricity or heat produced.

Abbreviations and Acronyms

AFME: Africa and Middle-East
AR4: IPCC 4th Assessment Report
AR5: IPCC 5th Assessment Report
AUS-NZL: Australia – New Zealand
BTL: Biomass-To-Liquids
C Am: Central America
CAN: Canada
CHN: China
CIS: Commonwealth of Independent States, former Soviet Republics
CO_2e ($GtCO_2e$, $MtCO_2e$, $ktCO_2e$): CO_2 equivalent, expression of GHG emissions using the IPCC AR4 global warming potential
CTL: Coal-To-Liquids
CV: Carbon Value (expressed in \$05/tCO_2e)
DG ECFIN: Directorate-General for Economics and Financial Affairs.
EC: European Commission
JRC: European Commission Joint Research Centre
EFTA: European Free Trade Association, includes Iceland, Norway, Switzerland (Liechtenstein is not included in the modelling analysis)
EIA: US Energy Information Administration
ETS: Emission Trading Scheme applied in the EU
EU: European Union, includes the 28 Members States
EU28: European Union, includes the 28 Members States
FYI: Former Yugoslavia
GDP: Gross Domestic Product
GEM-E3: General Equilibrium Model for Economy - Energy - Environment
GTL: Gas-To-Liquids
GHG: Greenhouse Gas emissions
GOLF: Persian Gulf countries
Gulf: Persian Gulf countries
GWP: Global Warming Potential (per greenhouse gas)
H2: Hydrogen
IA: Impact Assessment (from the European Commission)
IDN: Indonesia
IEA: International Energy Agency
IEO: International Energy Outlook, produced by the US Energy Information Administration
IIASA: International Institute for Applied Statistical Analysis
IMF: International Monetary Fund
IND: India

INDC: Intended Nationally Determined Contribution
IPCC: Intergovernmental Panel on Climate Change
JPN: Japan
KOR: Republic of Korea
Latin America: includes Mexico, Central America, Carribean islands, South America
LULUCF: Land Use, Land Use Change and Forestry
MACC: Marginal Abatement Cost Curve
ME: Middle-East
Med ME, MEME: Mediterranean Middle-East
MER: Market Exchange Rate (applies to GDP)
MEX: Mexico
Non-OECD: Countries that are not part of the 2014 OECD members, to the exception of Chile (which is not included in the report "OECD"), and Papua New Guinea (which is aggregated with Australia and New Zealand and thus included in the report "OECD")
North America: Canada, USA
Nth Af, NOAF: North Africa
Oceania: Australia, New-Zealand, Oceania islands
OECD: 2014 OECD countries
OSEA: Other South-East Asia: Brunei, Burma, Cambodia, North Korea, Laos, Malaysia, Mongolia, Philippines, Singapore, Taiwan, Thailand, Timor-Leste, Vietnam.
Pacific: Japan, Korea, Rep., Australia-New Zealand – Papua New Guinea
POLES: Prospective Outlook on Long-term Energy Systems, World simulation model
ppm: Parts per million
ppmv: Parts per million by volume
PPP: Purchasing Power Parity (applies to GDP)
RSAF: Rest Sub-saharan Africa: all Sub-saharan Africa countries except South Africa
RSAS: Rest South Asia: Afghanistan, Bangladesh, Bhutan, Maldives, Pakistan, Sri Lanka
RUS: Russian Federation
SAR: IPCC Second Assessment Report
SE Asia: South-East Asia
SOAM: South America except Brazil
Sth Am : South America
Sth Asia: South Asia
toe (ktoe, Mtoe, Gtoe): Ton of oil equivalent
TUR: Turkey
UNEP: United Nations Environment Programme
UNFCCC: United Nations Framework Convention on Climate Change
USA: United States of America
WB: World Bank
WEO: World Energy Outlook, produced by the International Energy Agency
WRD: World
ZAF: South Africa

Annex 4. Countries pre-2020 mitigation pledges and recent policy developments

G20 countries	GHG emission reduction in pre-2020 pledges	Recent policy framework developments	Share global GHG. 2012	World Bank income group
Argentina	Policy and measures	National Climate Change Strategy 2011. Initial stage of work under the UNDP LECB programme	0,8%	
Australia	5%-25% below 2000 by 2020	2014 Emissions Reduction Fund repealing the carbon pricing mechanism and extending the Carbon farming initiative. Renewable energy target scheme (to deliver 20% RES in electricity by 2020) being reformed. Power plant standard to close down around 2000 MW of inefficient capacity.	1,1%	High Income
Brazil	36.1 % - 38.9 % below BAU in 2020	2008 National Climate Plan. Low-carbon agriculture plan (ABC plan). 2 Actions plan for deforestation prevention and control (Amazon, Cerrado regions). Clear progress made to reduce emissions by 36 to 39% by 2020, esp. avoided deforestation 650 mtCO_2e/yr. Full implementation of the Forest code would further cut emissions. 10 year plan for energy expansion aiming to triple the use of new energy by 2020 (would result in 16% RES in electricity mix excl. large hydro).	6,0%	Upper Middle Income
Canada	17% below 2005 by 2020	Best available estimates indicate new measures needed, as only 1/2 of pledge secured with existing measures. Standard for new coal-fired power plants to enter into force mid-2015 (existing plants exempted). Fuel efficiency standards harmonised to US levels up to 2025.	1,5%	High Income
China	CO_2 emission intensity/GDP unit reduced by -40–45% by 2020 vs. 2005; 15% share of non-fossil fuel in primary energy consumption by 2020; forest coverage +40 million hectares and forest stock volume +1.3 billion cubic meters by 2020 vs. 2005	12th 5YP incl. the pledge targets, and 12th 5YP for renewable energy development. 2013 Climate Change Action Programme for Industries, with CO_2 reduction targets per unit of industrial value-added, and GHG reduction targets for 8 industrial sectors 2014-2020 National action plan on climate change and 2014-2020 energy development strategy action plan incl. policy measures announced for coal (10 GW inefficient plant closed and 350 GW improved, achieving average coal consumption of 310 g/kWh and coal electricity share down to 62% from today's 69%). Air pollution control action plan (with measures for transport). Clear progress to 2020 pledge: in 2013 carbon intensity was down by 28.5% from the 2005 level	25,0%	Upper Middle Income
India	Reduce CO_2 emissions (except agriculture) per unit of GDP by 20–25% by 2020 compared to 2005	9 in 22 States have a State Action Plans on Climate Change. National Action plan on climate change with a target: 15% RES in electricity by 2020 (implemented with RES certificates). National mission for enhanced efficiency (incl. the Perform Achieve and Trade PAT scheme to reach 5% energy consumption reduction below BAU for industry in 2015). National Solar mission in place; new plans to increase the ambition to: 100 GW capacity by 2022. Greening India mission for forestry.	6,0%	Lower Middle Income
Indonesia	26 % below its BAU emissions in 2020 (up to 40% with international help)	On-going work on monitoring and reporting elements of the National Plan on Greenhouse Gas Emission Reduction. NAMA seeking support in the registry (transport). Moratorium on new concessions for harvesting forest and peatlands; REDD+ agency established. National energy policy (with a new more ambitious goal: 23% RES share in total primary energy supply by 2025).	2,4%	Lower Middle Income
Japan	25% below 1990 by 2020 amended at COP19 to GHG 3.8% below 2005	1.6 trillion JPY for developing countries. 2012 Carbon Tax. Japan Top runner programme (car efficiency standards). 2011 Act on purchase of renewable sourced electricity, RES targets 2022: Wind (38 GW), Solar (20 GW) Solar thermal capacity (14 GW), in review depending on nuclear energy use; new Basic Energy plan (2014) includes a 13.5% RES electricity target for 2020; 20% for 2030 with feed-in tariffs.	2,5%	High Income

Mexico	30% below its BAU emissions in 2020	10-20-40 Climate Strategy: commitment to reduce emissions 30% by 2020, 50% by 2050 vs 2000. On-going work at state levels to implement mitigation measures. Aim for increasing non-CO_2 electricity share of 35% in 2024. Special RES program 2014 with new targets: 26.5% RES in energy production by 2027.	1,3%	Upper Middle Income
Russian Federation	15-25% below 1990 by 2020	Sept 2013 decree making Climate Doctrine legally binding and Sept 2014 Action Plan ensuring to deliver 25% emission reduction below 1990 levels. Energy saving and energy efficiency program to improve energy intensity of GDP by 40% of 2007 levels by 2020; 2010 Energy strategy aim to reduce energy intensity of GDP by 44% vs. 2005. Decree aiming at reducing emissions from gas flaring. RES share (besides large hydropower) in the primary energy supply to 4.5% by 2020: unlikely to achieve by 2020, but move towards them would deliver significant GHG cuts.	3,5%	High Income
Saudi Arabia	None	Prepare energy efficiency legislation. Royal Decree of 2010 for Atomic and Renewable Energies. Carbon management roadmap implemented with CCS projects. KSA's upcoming national 5-Year Development Plan would further economic diversification	1,1%	High Income
South Africa	34 % to 42% below BAU by 2020	2013 Budget with environmental tax reforms proposals. Aim to raise renewable energy share above current 2%. Working to develop energy efficiency indicators.	0,9%	Upper Middle Income
Korea, Rep.	30 % below BAU by 2020	Preparing a new roadmap for national emissions reduction/energy plans. 5Yaction plan: 6% share RES in primary energy; Renewable portfolio standard. Implementing the 2015 nationwide emissions trading scheme (first Asian country).	1,3%	High Income
Turkey	None	Preparations on setting up and implementing an MRV system, regulatory and sectoral impact assessments of EU climate policy, and capacity building on LULUCF and f-gases are continuing. Its 2012 Energy Efficiency Strategy puts forward a goal to decrease energy intensity by at least 20% by the year 2023.	0,8%	Upper Middle Income
US	17% below 2005. Subject to pending legislation and to global action. In addition: the pathway set forth in pending legislation would entail a 30% emission reduction by 2025 and a 42% emission reduction by 2030, in line with the goal to reduce emissions by 83% by 2050.	June 2013 President's climate action plan, with ongoing and new actions. Emission limits for power plants, both new and existing in preparation (rule on new power plants Sept 2013, rule on existing power plants June 2014 that would require utilities to cut emissions by 30% by 2030 vs. 2005 levels). Consultation on US EPA rules facing requests for extending the emission reductions from coal-based plants to 2030-2035.	11%	High Income

Examples of other countries with pre-2020 pledges and policies

Countries	GHG emission reduction in pre-2020 pledges	Recent policy framework developments	Share global GHG. 2012	World Bank Income group
Algeria	GHG emission below BAU level	National climate plan is being finalized	0,4%	Upper Middle Income
Angola	Regional pledge Agriculture	National Communication preparation started June 2013 for 3 years. National Adaptation Action Plan prepared. Combat desertification.	0,1%	Upper Middle Income
Antigua and Barbuda	25% below 1990 levels by 2020			High Income
Armenia	REDD+ projects	2010 Road Map for implementation of the national Programme on Energy Saving and Renewable Energy. Progress with reforestation actions, limited implementation in other sectors		Lower Middle Income
Belarus	8% below 1990 by 2020	Resolution of the Council of Min. on climate protection June 2013. Measures planned up to 2010. 1/3rd reduction of GHG emissions since 1990 with GDP increase of 100%	0,1%	Upper Middle Income
Benin	CDM projects		0,1%	Lower Income
Bhutan	Efforts to remain GHG neutral			Lower Middle Income
Burkina Faso	Regional pledge Agriculture	EE measures appliances and buildings, agriculture.	0,1%	Lower Income
Burundi	Regional pledge Agriculture	About to adopt a policy strategy and plan of action for CC.		Lower Income
Cambodia	Sustainable forest management (REDD)	Plans to launch (1) Cambodia Climate Change Strategic Plan (Dec. 2013) and (2) National Policy, Strategy and Action Plan on Energy Efficiency. NAMA being considered. First steps on REDD+	0,3%	Lower Income
Cameroon	Regional pledge Agriculture	Engaged in the REDD process; concluded a FLEGT VPA Agreement with EU; some CDP projects	0,2%	Lower Middle Income
Cape Verde	Regional pledge Agriculture	national communication and NAMAs in preparation; 2011-16 government programme aims to create "green agenda" for renewable energies		Lower Middle Income
Central African Republic	CDM and REDD+ projects		1,0%	Lower Income
Chad	Sustainable forest management projects	REDD+	0,2%	Lower Income
Chile	20% below its BAU emissions in 2020	2012 National strategy for Renewable energy; National Forestry and Climate Change Strategy. NAMA seeking support. Launched an energy agenda. Implementation of a CO_2 Tax.	0,2%	High Income
Colombia	77% of total electric capacity installed from RES and 20 % of fuel consumption from biofuels by 2020	2011 Colombia Low Carbon Development Strategy. Sector Action Plan. Monitoring system to be operational by end of 2014.Columbian development strategy with sector measures (transport, mining) to reduce growing trend of GHG emissions	0,4%	Upper Middle Income
Congo	Single project activities (CDM)	Laws implementing the principles of Copenhagen and REDD+ goals underway. 13 out of 33 mitigation measurs in waste and forestry in implementation	0,1%	Lower Income
Costa Rica	Carbon neutrality by 2021	Confirm carbon neutral country by 2021, by 2016 100% RES from 90% now		Upper Middle Income
Côte d'Ivoire	Sustainable forest management	Increase RES: 5% in 2015, 15% 2020, 20% 2030; EE rise by 20%; carbon neutral reforestation	0,1%	Lower Middle Income

Dominica	Implement the Low Carbon Climate Resilient Development Strategy	Intention to have a 120 MW geothermal plant with cables to Guadeloupe and Martinique.		Upper Middle Income
Dominican Rep.	Emission reduced by 25% between 2010 and 2030	Mitigation targets set in the Climate National Economic Development Plan	0,1%	Upper Middle Income
Egypt	CDM projects	National Energy Policy promoting RES, aim for 20% RES share in total electricity by 2020, expected now to deliver 12% by 2022	0,6%	Lower Middle Income
Ethiopia	CDM project, Inter urban electric rail NAMA	Aim from becoming a middle income economy country by the year 2030 and By 2025 climate resilience with zero carbon emission.	0,4%	Lower Income
Gabon	REDD+, CDM projects	Draft National Climate Plan identifying policies for forest and agriculture, to be published in December. Sustainable dev. Law in discussion in parliament with some climate mainstreaming measures. national land use plan in progress, ambition to reduce emission by 50% per head	0,1%	Upper Middle Income
Gambia	Regional pledge Agriculture			Lower Income
Georgia	GHG strategy, CDM projects	Starting to work on LEDS (high level inter-ministerial committee). Realising investment in hydropower as in the State programme "Renewable Energy 2008". Hydro to reduce carbon emission by 20% by 2020, aim for carbon neutrality by 2050 with support.		Lower Middle Income
Ghana	CDM projects, Sustainable forest management		0,2%	Lower Middle Income
Guinea	Regional pledge Agriculture		0,2%	Lower Income
Iceland	30% below 1990	2010 climate action plan. EU ETS.		High Income
Israel	20% below its BAU emissions in 2020	2010 GHG National Plan suspended for 3 years in 2013.	0,2%	High Income
Jordan	CDM projects	National Climate Change Plan 2013-2020 adopted but not in implementation. Slow progress to set up MRV. Energy policies needs follow up	0,1%	Upper Middle Income
Kazakhstan	15% below 1992 by 2020	Transit to Green Economy action plan, adopted in August, 2013, National Emission Trading System pilot launched Jan 2013 on non-verified data. Work on reduction of carbon intensity by 50% in 2050 of 2008 levels, and by 25% by 2025 compared to 1990	0,7%	Upper Middle Income
FYROM	Sectoral NAMA			Upper Middle Income
Madagascar	GHG strategy, Sustainable forest management	RES potential. Adaptation plan in drafting. Reforestation campaign	0,2%	Lower Income
Malawi	National, regional pledge	Agriculture. Adaptation.		Lower Income
Malaysia	Not formal pledge, but declaration: Aims to cut emission by 40% by 2020 (already 30% now with forests)	Key policies: 1) Climate Change Policy 2009 2) Green Technology Policy 2009 3) Renewable Energy Act 2011 (RE targets: 6% by 2015, 11% by 2020 etc.) 4) Low Carbon Cities Framework 2011 5) Green Technology Foresight 2030. Legislation/initiatives in preparation: 1) Low Carbon Green Growth Act 2) Energy Efficiency Master Plan 3) Carbon Footprint Labelling Scheme REDD+ national strategy to be completed by the end of 2013, ongoing work on forest inventory with support	0,6%	Upper middle income
Maldives	Long-term transformational effort to achieve carbon neutrality as a country by 2020	Developing Low Carbon Development Strategy/carbon neutrality roadmaps with support		Upper Middle Income

Mali	Regional pledge Agriculture	National action plan under discussion. 2 NAMAs developed. Focus on forest, agriculture, national program for water, RES 10% by 2020	0,2%	Lower Income
Marshall Islands	40% below 2009 level by 2020	Bardados declaration on achieving sustainable energy for all		Upper Middle Income
Mauritania	Enhancing forest carbon sinks, CDM projects			Lower Middle Income
Mauritius	Regional pledge Agriculture	Maurice Ile Durable Policy, Strategy and Action Plan (June 2013); aim for RES in electricity production at 35% by 2025, energy consumption in non-residential buildings cut by 10% by 2020 and in public sector buildings energy by 10% by 2020, and energy consumption in the transport sector by 35% by 2025, compared to 2010		Upper Middle Income
Moldova	35 % below 1990 by 2020			Lower Middle Income
Monaco	30% below 1990 by 2020	Reduce GHG emissions by 30% by 2020 and 80% by 2050 (1990 is Baseline).		High Income
Mongolia	CDM and REDD+ projects		0,1%	Lower Middle Income
Montenegro	20% below 1990 by 2020			Upper Middle Income
Morocco	CDM projects	Work on inventories and energy efficiency measures. Aim to use 42% of renewable energy.	0,2%	Lower Middle Income
Mozambique	Regional pledge Agriculture	National Climate Change Adaptation and Mitigation Strategy adapted (2012) for 2013-2025. In the process of REDD+ preparedness and readiness. Committed to develop emission inventory.	0,8%	Lower Income
New Zealand	10% to 20% below 2000 incl land management	2012 NZ ETS amendments extending transitional measures, postponing the entry of agriculture in ETS	0,10%	High Income
Norway	30 to 40% below 1990 by 2020 (2/3 domestic)	Climate action plan. Access to EU ETS. Support RES, EE, SLCPs, and smart agriculture initiatives.	0,10%	High Income
Papua New Guinea	at least 50% below BAU by 2030	Nov 2013 to debate a climate compatible development policy. Need provincial strategies to take forward the 2011 proposal for a national climate bill		Lower Middle Income
Peru	Renewable energy represents at least 33% of total energy used and zero net deforestation by 2020	Work on a ´Climate Change Plan´ to provide the framework for the implementation of National Strategy on Climate Change, for adoption in 2013. Challenging to reduce deforestation. Work on waste emissions.	0,2%	Upper Middle Income
Rwanda	Regional pledge Agriculture	2011 Green growth and climate resilience strategy with actions for adaptation/mitigation. Climate mainstreamed in economic development and poverty reduction strategy.	3,6%	Lower Income
San Marino	Energy efficiency target	Reduce GHG emissions by 2020, by 20%.		Upper Middle Income
Senegal	Regional pledge Agriculture	Legislative framework announced in new environmental code. National CC committee established to guide climate related policies.	0,1%	Lower Middle Income
Senegal	Regional pledge Africa group on Agriculture	Legislative framework announced in new environmental code. National CC committee established to guide climate related policies. Developing NAMAs + MRV		Lower middle income
Sierra Leone	GHG strategy, Sustainable forest management	Working on a range of measures (REDD+, CC policy, GHG inventory, CC Secretariat) including a coherent policy framework. The focus is on adaption rather than on mitigation.		Lower Income

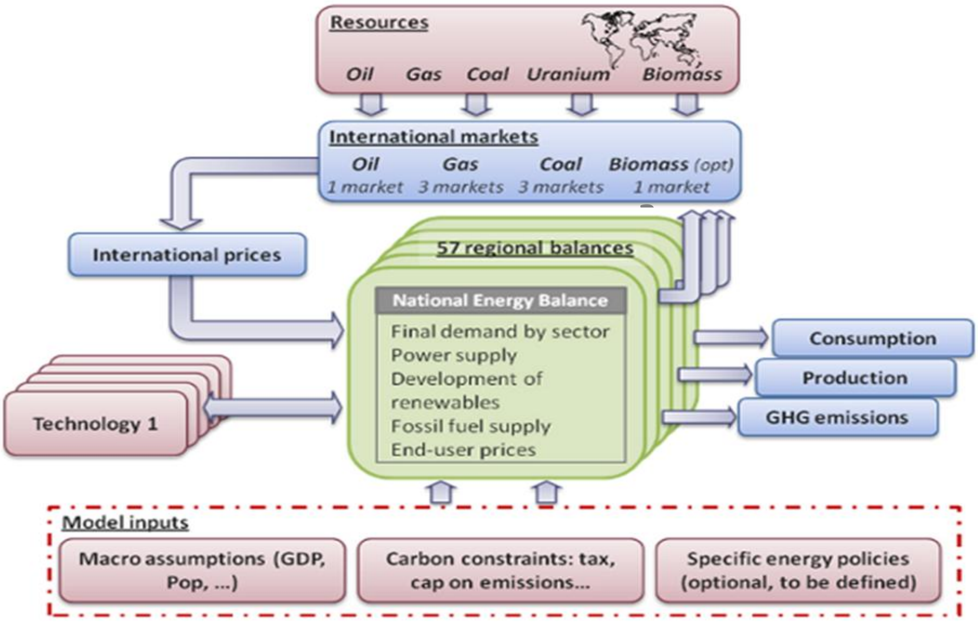
Singapore	16 % below BAU by 2020 contingent on a legally binding agreement	2012 Climate Change Strategy to reduce emissions by 7% to 11% below 2020 BAU. Increase energy efficiency by 11% by 2020 vs. BAU, green buildings by 2030	0,1%	High Income
Sudan	Regional pledge Agriculture	No overarching framework. Some projects implemented. activities in place to improve energy efficiency		Lower Middle Income
Swaziland	Regulation, R&D	National climate policy in place		Lower Middle Income
Switzerland	20 to 30% below 1990 by 2020	Climate action plan. Carbon tax framework.	0,1%	High Income
Tajikistan	GHG strategy/ inventory	National Action Plan (2003) on climate change mitigation; implementing law on RES program (98% of electricity is from hydropower, aim to develop other RES)		Lower Income
Togo	Enhancing forest carbon sinks, CDM projects	Preparing 3rd national communication on CC for 2015		Lower Income
Tunisia	CDM projects, Enhancing forest carbon sinks		0,1%	Upper Middle Income
Tuvalu	No pledge but Pacific island forum declaration	No pledge but Pacific island forum declaration for: Power Generation – 100% renewable energy between by 2020. Energy Efficiency – improvements of 30% of current annual demand of Funafuti.		Upper Middle Income
Uganda	Regional pledge Agriculture	Climate Change Policy Draft in process of approval before end 2013. Committed to reduce emissions. Interest to address forest and wetlands.	0,2%	Lower Income
Ukraine	20% below 1990 by 2020	On-going work on monitoring and reporting law. Work on methane emission mitigation projects.	0,8%	Lower Middle Income
Vanuatu	No pledge but Pacific Island Forum declaration	No pledge but Pacific Island Forum declaration: 100% of energy from renewables, 40% of power generation through renewables by 2015; 65% of power generation through renewables by 2020		Lower Middle Income
Zambia	Regional pledge Agriculture	Ongoing drafting of a Climate Change Policy. in process of finalizing a national policy / identify national potential (agriculture, industries, waste, energy etc.)	0,7%	Lower Middle Income

Annex 5. POLES description

POLES (Prospective Outlook on Long-term Energy Systems) is a global energy model covering the entire energy system, from primary supply (fossil fuels, renewables, ..) to transformation (power, biofuels, hydrogen) and final sectoral demand. International market and prices of energy fuels are simulated endogenously. Its high level of regional detail (57 countries / regions) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global frame such as access to energy resources, taxation policy, energy efficiency, and technological preferences. POLES operates on a yearly basis up to 2050 and is updated yearly with recent information (2012 data for most series).

We used for this exercise the EC JRC IPTS POLES 2014 version. Differences with other exercises done with the POLES model by EC JRC IPTS in other projects, or other entities using the same model (namely the University of Grenoble and Enerdata), can come from different i/ model equation upgrades, ii/ historical data sets, iii/ parameterisation, iv/ policies considered.

Figure 159. POLES model general scheme



Source: Enerdata

<u>Final demand</u>

The final demand evolves with activity drivers, energy prices and technological progress. The following sectors are represented:

- industry: chemistry (energy uses and non-energy uses are differentiated), non-metallic minerals, steel, other industry;
- buildings: residential, services (specific electricity uses are differentiated, different types of buildings are considered);
- transport (goods and passengers are differentiated): road (motorcycles, cars, light and heavy trucks – different engine types are considered), rail, inland water, international maritime, air domestic and international;
- agriculture.

<u>Power system</u>

The power system describes capacity planning of new plants and operation of existing plants for 40 technologies.

The planning considers the existing structure of the power mix (vintage per technology type), the expected evolution of the load demand, the production cost of new technologies, and resource potential for renewables.

The operation matches electricity demand considering the installed capacities, the variable production costs per technology type, the resource availability for renewables.

The electricity demand curve is built from the sectoral distribution over 2 typical days: one for summer and one for winter, each decomposed into twelve 2h blocks.
Electricity price by sector depend on the evolution of the power mix, of the load curve and of the energy taxes (by default kept constant).

Other sectors

The model also describes other energy transformations sectors: liquid biofuel (BTL), coal-to-liquid (CTL), gas-to-liquid (GTL), hydrogen (H_2).

Oil supply

Oil discoveries, reserves and production are simulated in 80 individual countries and for 6 types of fuel: conventional crude & NGLs (inland and shallow water), tar sands, extra heavy oil, oil shale (kerogen), deepwater and arctic oil.

The market is structured along the market power of the different countries:

- non-OPEC production produces depending on remaining reserves, oil price and production cost;
- OPEC production adjusts to the evolution of demand and non-OPEC production;
- Gulf production can develop a spare capacity to adjust for short term variations, it adjusts to the evolution of demand and non-Gulf production.

International oil price depend on the evolution of spare capacity in the Gulf (short term: 1 year), world R/P ratio (long-term) and the marginal production cost of non-conventional oil. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Gas supply

Gas discoveries, reserves and production are simulated in 80 individual countries or regions for 4 types of gas: conventional gas (inland and shallow water), shale gas, deepwater and arctic gas. They supply 15 regional markets, made up of the national gas demand of the 57 POLES countries and regions. 37 of the producers are considered as key producers with a capacity to export on international markets through trading routes. Gas transport is done through inland pipeline, offshore pipelines or LNG.
Gas price is simulated for 3 regional markets: Europe, America, Asia. It depends on the transport cost, the regional R/P ratio (long-term trend), the evolution of oil price and the development of LNG (integration of the different regional markets). Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Coal supply

Coal production is simulated in 74 individual countries or regions. Some countries (USA, Australia, China, India) have two or more production regions to better represent transportation costs which can represent a significant share of the coal delivery cost. They supply 15 regional markets, made up of the national coal demand of the 57 POLES countries and regions. 26 of the producers are considered as key producers with a capacity to export on international markets through trading routes.
Coal delivery price for each route depends on the transport cost (international and inland), the mining cost, and other operation costs. An average delivery price is calculated for each of the 15 consuming markets. The model also calculates an average international price for 3 "continental"

markets: Europe, Asia, America. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Biomass supply

The model differentiates 3 types of primary biomass: energy crops, short rotation crop (cellulosic) and wood (cellulosic). They are described for each of the 57 country through a potential and a production cost curve – in the case of SRC and wood this is derived from look-up tables provided by the specialist model GLOBIOM-G4M (Global Biosphere Management Model). Biomass can be traded, either in solid form or as liquid biofuel.

Wind, solar and other renewables

These renewables are associated to potentials per country, which can be more detailed (in the case of wind and solar, where supply curves are used) or less (hydro, geothermal, ocean where only a potential figure is used).

GHG emissions

CO_2 emissions from fossil fuel combustion are derived directly from the POLES energy balance that is influenced by mitigation policies (carbon value, support policies to technologies, energy efficiency targets). Other GHGs from energy and industry are simulated using activity drivers identified in the POLES model (e.g. sectoral value added, mobility per type of vehicles, fuel production) and abatement cost curves. GHG from agriculture and LULUCF are derived from GLOBIOM-G4M lookup tables.

Regional coverage

Table 43. POLES regional coverage (57 countries and regions, incl. 28 EU Member States)

Europe	CIS	North America	Latin America	Africa	Middle East	Asia
Detailed EU28	Russia	USA	Mexico	Egypt	Gulf	Japan
Switzerland	Ukraine	Canada	Rest Central America	Morocco & Tunisia	Mediterranean Middle East	Korea, Rep.
Norway	Other CIS					China
Iceland			Brazil	Algeria & Libya		Indonesia
Former Yugoslavia (excl. Croatia)			Rest South America	South Africa		India
Turkey				Rest Sub-Saharan Africa		Oceania (inc. Australia & New-Zealand)
						Rest South-East Asia
						Rest South-Asia

Source: JRC POLES model

Annex 6. GEM-E3 description

We choose the **GEM-E3 model**[90]**,** a Computable General Equilibrium (CGE) model to assess the direct and indirect impacts of mitigation efforts until the year 2030. The GEM-E3 model is a multi-sector, multi-region model that includes all the above-mentioned mechanisms and is specifically designed to analyse the interactions between the energy system, the economy and the environment. It is built on sound microeconomic foundations and integrates multiple data sources such as trade statistics, input-output data and information on emissions of greenhouse gasses. Furthermore, existing tax structures and unemployment mechanisms are incorporated. The version of the model used here is global (25 regions, see Table 44) and covers all industry sectors, disaggregated into 31 sectors, of which 10 electricity generating technology sectors (Table 45).

In a general equilibrium framework, results regarding impacts of imposed policies are presented comparatively with the Baseline projections of the economy, thus in terms of percentage differences from the Baseline scenario. The GEM-E3 **Baseline** is constructed on the basis of a variety of data sources. First, the future path of GDP is based on projections done by the OECD (see Dellink et al. 2014) for all regions in the world. Second, population projections are taken from the UN (2013). Third, the input-output tables and the data on bilateral trade flows are derived from the GTAP 8 database. Fourth, the emission levels of greenhouse gasses (totals and by sector) and the shares of electricity generation technologies are harmonised with the Baseline in the POLES model. For the EU, the Baseline is consistent with the 2013 reference of the PRIMES model[91]. Importantly, for the EU this Baseline already includes substantial policy measures. In particular, Europe complies with the "20-20-20 Package" and is in line with the "EU Energy, Transport and GHG emission trends to 2050; update 2013" (EC, 2013a). For the other regions, policy measures that are already put in place are included, in line with Table 3. Additional data sources include labour statistics from ILO and energy statistics from IEA.

[90] See http://www.gem-e3.net/ for more details.
[91] http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf

Table 44. Regions in the GEM-E3 model

Region	*Code*
European Union	EU28
USA	USA
Russia	RUS
Canada	CAN
Japan	JPN
Australia	AUS
China	CHN
India	IND
Indonesia	IDN
Brazil	BRA
Republic of Korea	KOR
Rest of Europe (Switzerland, Norway, Albania, Iceland, Bosnia, Serbia, Turkey…)	ANI
Mexico	MEX
Argentina	ARG
North Africa	NOA
New Zealand	NZL
Saudi Arabia	SAU
Iran	IRN
South Africa	ZAF
Rest of Middle East	MID
Sub-Sahara Africa	SSA
Rest of Central and South America (incl. Caribbean and North-Atlantic Islands)	CSA
Central Asia and Caucasus (incl. Belarus, Ukraine, Kazakhstan, Azerbaijan,…)	CAS
South-East Asia	SEA
Rest of Asia and Pacific	RAP

Source: GEM-E3 model

Table 45. Industry sectors in the GEM-E3 model

Nr.	Sector	Nr.	Sector
01	Agriculture	17	Transport (Air)
02	Coal	18	Transport (Land)
03	Crude Oil	19	Transport (Water)
04	Oil	20	Market Services
05	Gas	21	Non Market Services
06	Electricity supply	22	Coal fired
07	Ferrous metals	23	Oil fired
08	Non-ferrous metals	24	Gas fired
09	Chemical Products	25	Nuclear
10	Paper Products	26	Biomass
11	Non-metallic minerals	27	Hydro electric
12	Electric Goods	28	Wind
13	Transport equipment	29	PV
14	Other Equipment Goods	30	CCS coal
15	Consumer Goods Industries	31	CCS Gas
16	Construction		

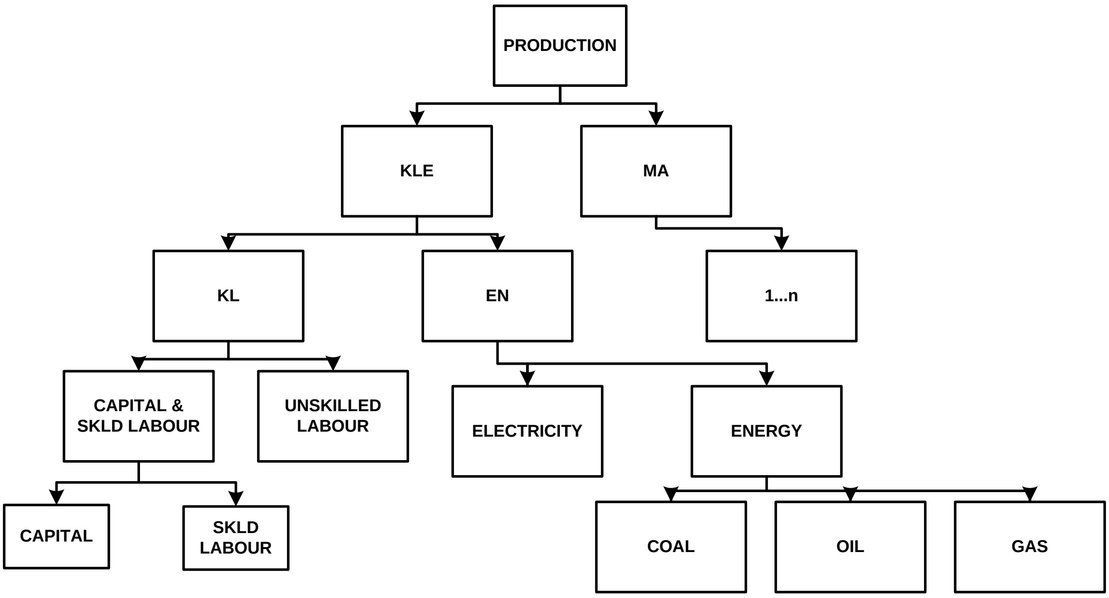
Source: GEM-E3 model

The GEM-E3 model is a recursive dynamic CGE model representing multiple regions, sectors and agents. The interactions between three types of agents are included: households, firms and governments.

In each region, a representative **household** chooses the consumption bundle that optimizes the level of welfare, embodied by a Stone-Geary utility specification (Linear Expenditure System or LES). In a first stage, the household decides between current and future consumption. In a second stage, consumption is allocated to different goods. The use of durables (heating systems, cars and electric appliances) is linked to the consumption of fuels and the corresponding fuel-specific CO_2 emissions. The optimal fuel mix is dependent on the relative prices of the fuels. Household behaviour is myopic in the sense that decisions are made based on prices observed in the current period.

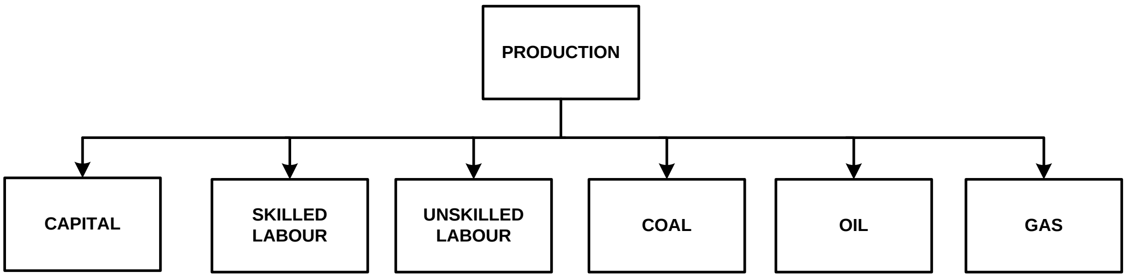
Firms decide on the optimal level of output. In addition, they decide on the optimal mix of inputs in the production process. The production technology combines skilled and unskilled labour (L), capital (K), intermediate materials (MA) and energy (EN) in a nested Constant Elasticity of Substitution (CES) structure. The intermediate material flows between different industry sectors capture the inter-industry links. The majority of the sectors follow the nested production structure presented in Figure 160. The production structure of the energy sectors is adjusted to reflect sector-specific processes.

Figure 160: Production structure of non-energy sectors



The modelling of 10 power generation technologies is done in a bottom up fashion. The relevant information was extracted from the TECHPOL database, the ENERDATA database and the PRIMES model database. The associated production structure is presented in Figure 161. Furthermore, emissions (excl. LULUCF) of all sectors have been included for the following greenhouse gasses: CO_2 from combustion, CO_2 from industrial processes, CH_4, N_2O, PFC, HFC and SF_6.

Figure 161: Production structure for power generation sectors



Firms base their **investment** demand on the difference between the current level of capital stock and the desired or optimal level given current capital prices. The investment decision of the current period affects the capital stock of the next period, hence the recursive dynamic set-up of the model. Investment demand is allocated to the different sectors in accordance with the investment matrix.

The total labour demand impacts the equilibrium wage. This wage rate is related to the level of **unemployment** via the wage curve mechanism. As a result, the number of jobs is endogenous in the model. Note that migration or commuting flows across regions are not considered.

The behaviour of **governments** is exogenous. The level of government spending is kept fixed to the Baseline level. The level and structure of pre-existing taxes is incorporated and reflects differences in tax policy between different regions.

Final demand (the sum of private, intermediate and public demand) is allocated between domestic and imported goods according to a nested Armington specification: on the first level, domestically produced goods can be imperfectly substituted by imported goods. On the second level, there is substitution between imports from different origin regions. Therefore, all bilateral **trade flows** are endogenous in the model. Note that all imports involve the demand for transport services.

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