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Economic Assessment of Post-2012 Global Climate Policies

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Table of contents

List of Tables

List of Figures

Executive Summary

This report summarizes the JRC/IPTS modelling activities for the Communication "Towards a comprehensive climate change agreement in Copenhagen", published on 28/1/2009.

Policy background

The European Union agreed to limit the average global temperature increase to less than 2°C compared to pre-industrial levels. Several European Commission Communications have dealt with the required global climate policies to attain such temperature target before. Firstly, the March 2005 Communication 'Winning the Battle Against Global Climate Change' highlighted the need for a broad international participation in the efforts in tackling climate change.

The European Council of March 2005 acknowledged this and also requested the European Commission to further deepen its analysis. As a result, the European Commission adopted the January 2007 Communication on 'Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond', where global climate policy scenarios for 2030 and beyond were explored.

Following that Communication, in March 2007 the European Council endorsed a firm independent EU commitment to reduce greenhouse gases by at least 20 % by 2020 compared to 1990; this target will be extended to 30 % under a comprehensive international agreement that broadens global participation and if other developed countries commit themselves to comparable emission reductions. At the same time, the Council adopted an 'Energy Policy for Europe' supporting amongst others a 20% renewable energy target by 2020, improvements in energy efficiency and other low carbon sources which will help in achieving the required emission reductions.

The 2007 Bali Action Plan started a process in order to reach an international agreement on climate for the post-2012 period at the UN Conference to take place in Copenhagen in December 2009. In order to set out specific proposals for the climate agreement, in January 2009 the European Commission has adopted the third of the Communications, titled 'Towards a comprehensive climate change agreement in Copenhagen'.

Objectives and approach

The objective of this report is to describe in detail the quantitative modelling work underlying the scenarios analysis of the 2009 Communication. The POLES world energy sector model and the multi-sector general equilibrium GEM-E3 model were used to assess the technological and economic effects of various scenarios that can meet the 2°C target.

The two models are complementary as they focus on different relevant aspects. While POLES provides a rich analysis of the technologies of the energy sector at a global scale, computing the direct cost of reducing emissions in the energy sector, the GEM-E3 model has a multi-sector perspective that permits to assess the economic consequences in the whole economy, therefore assessing the direct and indirect effects of the mitigation policies foreseen in the Communication.

One of the main purposes of the Communication has been to study the consequences of alternative targets by countries. This is certainly a key issue in the forthcoming negotiations for the post-2012 period because the distribution of mitigation costs across countries makes necessary to consider not only efficiency but also equity issues. In particular, four different criteria have been taken into account to prescribe alternative burden-sharing methodologies. Firstly, GDP per capita has been chosen as an indicator of wealth, and therefore ability to pay for mitigation actions. Secondly, the greenhouse gas (GHG) intensity of the economy, defined as the GHG emission per GDP, is an indicator of the potential to reduce emissions. Third, the observed GHG emission trend is considered an indicator of 'early action': the steeper the reduction has been since 1990, the less ambitious can the future reduction target be, therefore rewarding early mitigation effort (for Kyoto Annex I countries). Population growth is the fourth of the indicators that allow relatively less demanding emission reduction targets to countries that have experienced higher population growth in the recent past.

Finally, a scenario that combines the four criteria, the 'central scenario', also consistent with the 2°C target, has been analysed using POLES and GEM-E3 models, as well.

Another key aspect for assessing global climate policies is the way the international carbon markets operate. Several cases have been analysed: perfect global trading of permits (full trading across all countries and sectors), imperfect trade (international trading gradually develops in time including more countries and sectors) and absence of global trading (a situation where countries reach the reduction targets only through domestic policies and measures). In the central scenario the imperfect case has been taken into account.

Results of the scenario exercise

Baseline

Global GHG emissions in the baseline scenario in 2020 are 71% higher above 1990 levels. Emissions increase much faster in developing countries than in developed countries. It is estimated that the resulting increase of temperature by 2050 is around 2°C above the pre-industrial level. Moreover, the economic growth projections take into account the effect of the 2008/2009 financial crisis, following recent IMF economic forecasts.

POLES

Under the central scenario, all countries reduce their emission substantially below the baseline scenario in order to meet the EU two degrees temperature target. Developed countries reduce emissions by 30% in the 1990-2020 period, while developing countries only increase their emissions by 20% for the same period. Those reductions are achieved through an accelerated decommissioning of carbon-intensive technologies and their replacement by low-carbon, climate-friendly ones. Price signals via a carbon price play a large role to attain such technological transformation, together with energy efficiency and savings policies.

Concerning the contribution of the various technologies to reduce emissions, energy savings measures allow for substantial reductions compared to the baseline scenario in most sectors of the economy, notably in industry, transport, residential and services. Approximately such measures represent half of the global reduction in the 2020-2030 period, being close to 2/3 in the developing countries in 2020. In particular, a large potential for energy efficiency improvements in the power generation sector seems to be available at competitive costs.

Fossil fuel switches towards less carbon intensive fossil fuels and cleaner technologies, together with renewable energies, nuclear and carbon sequestration are the other technologies absorbing the bulk of the reduction emissions worldwide. For instance, while in the year 2020 the carbon capture and sequestration is virtually absent in the baseline scenario, under the central scenario 18% of fossil fuel power generation employs this technology. As a consequence, from a sectoral perspective, the power generation sector captures half of the overall reduction in the 2020-2030 period, the contribution of the industrial sector comes second, while the role of the transport and residential sectors is less prominent.

The POLES model estimates that the annual global abatement costs, mainly in the energy and industrial sectors, are about €150 billion in 2020, being the cumulative global cost €666 billion over the 2013-2020 period. Approximately 55% of those costs arise in developed countries. Those figures do not include the financial flows generated by international carbon emission trading. In terms of aggregated costs, the study reports that, for the central mitigation scenario, most countries would face costs amounting between 0.4 and 1.2% of their respective GDPs.

GEM-E3

The overall effect of the central scenario on world GDP in 2020 is estimated to be a decrease of 0.9%, compared to the baseline. While some developed countries, such as the EU27 and the Commonwealth of Independent States (CIS), have higher GDP reductions than the world, other economies such as China, India and Brazil have lower GDP losses.

The GEM-E3 model has assessed the effects in developed countries of the allocation of targets according to the single criterion, instead of the combination of the four criteria (central scenario). Given that the single criterion lead often to disproportional costs or gains in single countries (e.g. for the case of the GDP per capita high income countries undergo very large GDP losses), it seems unlikely that the allocation of targets will be based on single criteria. The criteria used in the central scenario lead to smaller GDP changes in all developed countries, in the range of -0.6% to -2%, with the exception of the CIS, which undergoes a 3% GDP loss.

Carbon markets

The central scenario assumes an imperfect global carbon market for the sectors included in the EU's Emission Trading System (ETS). The marginal abatement costs do not equalise across the sectors on a global scale, but instead these carbon prices vary across the various regions in the world because of differences in transaction costs. These costs are assumed to diminish over time, and the carbon prices tend to converge.

The last chapter of the study compares the costs of climate policy in the central case (with an imperfect global carbon market) to the cases with a perfect global carbon market and without a global carbon market. With a perfect carbon market, the GDP changes are lower, being around -0.5% for the world economy, whereas with no global carbon market it becomes -1%. Regarding the marginal abatement costs, according to the POLES model, in the central scenario the carbon price in 2020 is 43 €/tCO_2, increasing to 72 €/tCO_2 without global trade and falling to 22 €/tCO_2 if there is perfect trade on global level. Therefore, these results underline the role of international trading in attaining a cost-efficient international agreement beyond 2012.

1 Introduction

The European Union agreed to limit the average global temperature increase to less than 2°C compared to pre-industrial levels. In March 2005 the Communication 'Winning the Battle Against Global Climate Change' (European Commission, 2005) highlighted the need for a broad international participation in the efforts in tackling climate change.

The European Council of March 2005 requested the European Commission to further deepen its analysis. As a consequence, in January 2007 the European Commission adopted the Communication on 'Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond' (European Commission, 2007a), where global climate policy scenarios for 2030 and beyond were explored. Russ et al. (2007) documents the scenario analysis and modelling work of JRC/IPTS for the 2007 Communication.

After the Communication, in March 2007 the European Council endorsed a firm independent EU commitment to reduce greenhouse gases by at least 20 % by 2020 compared to 1990; this target will be extended to 30 % under a comprehensive international agreement that broadens global participation and if other developed countries commit themselves to comparable emission reductions. At the same time, the Council adopted an 'Energy Policy for Europe' supporting amongst others a 20% renewable energy target by 2020, improvements in energy efficiency and other low carbon sources, which will help in achieving the required emission reductions.

The 2007 Bali Action Plan started a process in order to reach an international agreement on climate for the post-2012 period at the UN Conference[4] to take place in Copenhagen in December 2009. In order to shape a comprehensive EU position ahead of the Conference, the European Commission has adopted the Communication titled 'Towards a comprehensive climate change agreement in Copenhagen'[5], published on 28/1/2009.

This report, which builds further on Russ et al. (2007)[6], documents the JRC/IPTS modelling activities underlying that Communication. The POLES world energy sector model and the multi-sector computable general equilibrium GEM-E3 model have been used to assess the technological and economic effects of scenarios that can meet the EU 2°C target.

The two global models are complementary. POLES provides a rich analysis of the technologies of the energy sector, computing the direct cost of mitigating greenhouse gas (GHG) emissions in the energy system and industrial emissions including other gases than CO_2. GEM-E3 has a multi-sector perspective that permits to assess the economic consequences in the whole economy, therefore assessing the direct and indirect effects of the mitigation policies foreseen in the Communication. The GEM-E3 model covers all economy-wide emissions except those from land-use change.

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[4] The 15th Conference of the Parties to the UNFCCC.

[5] European Commission (2009a), http://ec.europa.eu/environment/climat/future_action.htm

[6] See also European Commission (2007b).

Five global mitigation scenarios have been analysed, which can lead to the 2°C objective. Under all scenarios in order to achieve the temperature target by 2020 developed countries as a group reduce their emissions by 30% below 1990 levels and developing countries as a group limit emissions to 15% to 30% below the business as usual scenario. Four criteria were used to allocate the reduction emissions to the countries: 1) "GDP (gross domestic product) per capita", as an indicator for the ability to bear mitigation costs; 2) "GHG emission per GDP", being an indicator of the potential to reduce emissions; 3) "Early action", the GHG emission trend since 1990, as an indicator of the ambitiousness of future reduction targets; and 4) "Population growth", as directly proportional indicator of emission reduction. The GEM-E3 model has assessed the economic consequences of each of the four indicators separately applying them to the developed world regions. The fifth scenario consists of a combination of the four criteria, and its effects have been assessed both with the POLES and GEM-E3 models. In this report this is called the "central scenario".

The "central scenario" assumes an imperfect global carbon market for the sectors included in the EU's Emission Trading System (ETS). The marginal abatement costs do not equalise across the sectors on a global scale, but instead these carbon prices vary across the various regions in the world due to differences in transaction costs and market imperfections. These costs are assumed to diminish over time, and the carbon prices tend to converge. The POLES and GEM-E3 models have been used to compare the costs of climate policy in the central scenario with the two alternative cases: a perfect global carbon market and the absence of a global carbon market.

This document has six more chapters in addition to this introduction. Chapter 2 presents the methodology and, in particular, the features of the POLES and GEM-E3 models. Chapter 3 describes the baseline scenario. In chapter 4 the global mitigation scenarios are constructed. In chapter 5, POLES models the "central scenario". Subsequently, chapter 6 analyses the macro-economic effects of the global mitigation scenarios (the "central scenario" and the four scenarios following the individual criteria) using the GEM-E3 general equilibrium model. Finally, in chapter 7 the role of a global carbon market is addressed.

2 Methodology

The methodology of the present study is analogous to Russ et al. (2007). The report describes scenarios that have a 50% likelihood of limiting the increase in global temperatures to 2ºC above pre-industrial levels in line with the objectives of the European Council. The implications of these scenarios on the overall economy and the energy sectors in particular will be compared to the baseline. The JRC/IPTS modelling was done using the POLES and GEM-E3 models.

2.1 POLES

The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy price.

The model is developed in the framework of a hierarchical structure of interconnected modules at the international, regional and national level. It contains technologically-detailed modules for energy-intensive sectors, including power generation, iron and steel, the chemical sector, aluminium production, cement making, non-ferrous minerals and modal transportation sectors (including aviation).

In each sector, energy consumption is calculated both for substitutable fuels and for electricity, taking into account specific energy consumption. Each demand equation has an income or activity variable elasticity, price elasticity, technological trends and, when appropriate, saturation effects. Particular attention is paid to the treatment of price effects. The world is broken down into 47 regions[7], for which the model delivers detailed energy balances. There is a single world oil market (the "one great pool" concept), while three regional markets (America, Europe and Asia) are identified for gas, in order to take into account different cost, market and technical structures. Coal production and trade flows are modelled on a bilateral trade basis, thus allowing for the identification of a large number of geographical specificities and the nature of different export routes.

All energy prices are determined endogenously in POLES. Oil prices in the long term depend primarily on the relative scarcity of oil reserves (i.e. the ratio of reserve to production). In the short run, the oil price is mainly influenced by spare production capacities of large oil producing countries. It must be noted that the endogenous price forming mechanism cannot model the price volatility induced by short term market expectations and/or geopolitical instabilities.

The model is continuously being enhanced both in detail and by regional disaggregation. Recent modifications include the addition of detailed modules for energy-intensive sectors [see, e.g. Szabó et al., 2006], and the extension to cover non-CO_2 greenhouse gases [see Criqui, 2002 and Criqui et al., 2006].

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[7] See Annex.

2.2 GEM-E3

The world version of the General Equilibrium Model for Energy-Economy-Environment interactions (GEM-E3)[8] is an applied general equilibrium model, representing simultaneously 18 world regions, linked through endogenous bilateral trade. GEM-E3 covers the interactions between the economy, the energy system and the environment. The calibration of the model is based on empirical data. The output of GEM-E3 includes projections of input-output tables, employment, capital flows, government revenues, household consumption, energy use, and atmospheric emissions. The model allows the evaluation of the welfare and distributional effects of various environmental policy scenarios, including different burden sharing scenarios, environmental instruments[9] and revenue recycling scenarios.

The GEM-E3 model has the following general features. The model simultaneously computes the equilibrium prices of goods, services, labour, capital and tradable emission rights such that all markets clear under the Walras law. It integrates micro-economic behaviour into a macro-economic framework and allows assessing the medium to long-term implications of policies. The model version for this exercise is global, while the sectors, the structural features of energy/environment and the policy instruments (e.g. taxation) are disaggregated. Hence, it can analyze the economic and distributional effects of environmental and economic policies for sectors, agents and regions, while ensuring that the world economy remains in equilibrium.

The model is dynamic, driven by the accumulation of capital and equipment. Technological progress is explicitly represented in the production functions. The amount of capital is fixed within each period. The investment decisions of the firms in the current period affect the stock of capital in the next period. The allocation of investment across sectors and regions is based on their respective profitability. The model allows for various degrees of capital mobility (across sectors or regional borders). This means that firms can close down and start up in another sector (capital mobility across sectors), or start again in another world region (capital mobility across regions).

The economic agents (firms, consumers) optimize their objective and determine the supply or demand of capital, energy, environment, labour and other goods. The firms' production uses capital, labour, energy (i.e. electricity and fuels) and intermediate consumption of goods from other branches. For each region, a representative consumer allocates his total expected income between consumption of goods and services (both durables and non-durables), savings and leisure.

The demand of goods by the final consumers, the firms (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic goods and imported goods, using the Armington specification.

Government behaviour and policy are exogenous. The model distinguishes between 8 categories of revenues, including indirect taxes, environmental taxes, direct taxes, value added taxes, production subsidies, social security contributions, import duties, and foreign transfers.

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[8] For a full model description see Van Regemorter (2005).

[9] E.g. taxes, various forms of pollution permits or command-and-control policy.

The environmental module of GEM-E3 can be extended to concentrate on three air pollution problems: (i) climate change (ii) acidification and eutrophication through deposition of emissions, and (iii) ambient air quality linked to tropospheric ozone concentration.

The model evaluates the emissions of carbon dioxide (CO_2), other GHG (e.g. CH_4), and there is a possible extension for a number of other air pollutants (NO_x, SO_2, VOC, NH_3, and PM_{10}). There are three mechanisms of emission reduction: (i) substitution between fuels and between energetic and non-energetic inputs, (ii) emission reduction due to less production and consumption, and (iii) purchasing abatement equipment.

2.3 Other models

The modelling activities of JRC/IPTS for the Communication "Towards a comprehensive climate change agreement in Copenhagen" have been complemented by a number of other models[10]. These include:

- IMAGE: Estimating the direct emissions and the potential for mitigation from agriculture using the land use change model of the integrated assessment model of the Netherlands Environmental Assessment Agency (PBL, Planbureau voor de Leefomgeving).
- TM5: Estimating the effects of different GHG emission scenarios and their corresponding energy consumption on local air pollutants (JRC/IES).
- G4M and GLOBIOM[11]: Assessing the potential for mitigation from both reduced deforestation and increased afforestation, and estimating the indirect emissions from deforestation due to agriculture, including increasing demands for bio-energy (IIASA).
- GAINS Europe and GAINS Asia: Assessing the inter-linkages between GHG and local air pollution abatement policies and their respective costs if applied in parallel (IIASA).
- The JRC/IES provided a spreadsheet based tool to assess the impact of different accounting rules for the Land Use, Land Use Change and Forestry (LULUCF) sector for the current developed countries under the Kyoto Protocol based on historic data for the base year 1990 or the base period 1990-1999.

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[10] A detailed description of the models can be found in Annex 1 of the Staff Working Document (European Commission, 2009b).

[11] Gusti *et al.* (2008).

2.4 Improvements and differences compared to 2007 Study

This report builds further on Russ et al. (2007), which summarizes the JRC/IPTS model activities for the 2007 Communication "Limiting global climate change to 2ºC". Compared to Russ et al. (2007), the present analysis differs and is improved in the following ways:

- In the baseline of this report, the carbon price in the EU ETS starts at 20 €/tCO_2 in 2010 and increases linearly to 24 €/tCO_2 in 2030. This is similar to the approach that was used in the baseline scenario to assess the impact of the EU climate change and energy package[12]. Russ et al. (2007) assumed a baseline carbon price of 5 €/tCO_2.
- Despite the high oil price, total GHG emissions of energy and industry grow as fast in the present baseline as in the study of 2007 (Russ et al., 2007).
- The present baseline takes the consequences of the financial crisis into account as was known by October (IMF, 2008).
- This study analyses more scenarios with different targets for each single country based on indicators.
- The present GEM-E3 modelling includes a gradually developing carbon market for all developing countries.

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[12] See European Commission (2008) and Capros *et al.* (2008).

3 The Baseline Scenario

This Chapter describes the assumptions and conditions on which the baseline scenario has been built. POLES and GEM-E3 have calibrated their baseline scenario using these common assumptions and conditions.

Moreover, five global mitigation scenarios have been developed, which can lead to the 2°C objective. These scenarios will be described in more detail in Chapter 4.

3.1 Common assumptions

The baseline scenario takes into account the existence of the ETS market in the EU and the prospect of future climate policies in other countries, the consequences of the financial crisis in 2008/2009, and the evolution of the oil prices.

3.1.1 Baseline carbon price

In the baseline, the carbon price in the EU ETS starts at 20 €/tCO_2 in 2010 and increases linearly to 24 €/tCO_2 in 2030. This is similar to the approach that was used in the baseline scenario to assess the impact of the EU climate change and energy package (Capros *et al.*, 2008). However, the baseline for the EU used for the present assessment does neither include the implementation of the unilateral GHG reduction target (20% compared to 1990 by 2020) nor the renewables target (20% by 2020) as proposed in the EU energy and climate change package, which were still under discussion when this assessment was made (European Commission, 2008). Therefore the baseline used in the present analysis does not include the outcome of the approved policy changes under the adopted climate change and energy package.

In the other developed countries a 5 €/tCO_2 carbon price is included for the same sectors as those included in the EU's ETS. This aims to simulate the fact that also in developed countries that presently lack ambitious climate change policies, investment decisions are already influenced by the prospect of future mitigation policies.

3.1.2 GDP growth and the financial crisis

In the baseline between 2005 and 2020, average yearly growth is 2.4% for developed countries and 5.3% for developing countries, resulting in a yearly average global growth of 3.9%. The baseline takes into account the current financial crisis. The growth projections were adapted when the deterioration of growth prospects became obvious in autumn 2008. Growth rates were reduced for the main regions for the coming 2 years using the then most recent IMF economic forecasts (IMF, 2008). Afterwards, it is assumed that growth will return to higher levels.

3.1.3 Oil prices

Oil prices in the updated baseline scenario differ from the ones in the 2007 Impact Assessment (European Commission, 2007a). While in the 2007 assessment prices of 53.2 US$/bl in 2020 and 61.5 US$/bl in 2030 were assumed, in the present assessment prices are projected to reach 73 US$/bl in 2020 and 89 US$/bl in 2030 (in 2005 prices). The proposed oil price scenario entails also higher coal and gas prices than those presented in the 2007 Impact Assessment. For comparison, these oil prices are lower than the most recent ones projected by the IEA in its World Energy Outlook 2008, which estimates price levels of 110 US$/bl in 2020 and 122 US$/bl in 2030 (in 2007 prices)[13].

3.2 Total emissions in baseline for POLES

Despite the high oil price, world GHG emissions of energy and industry grow as fast in this baseline as in the baseline for the 2007 Communication (European Commission, 2007a; Russ et al., 2007). In 2020 they are 71% above 1990 levels. This is mainly due to slightly higher economic growth forecasts for developing countries which have a high share of coal in their energy mix and a slightly higher share of coal in the global total primary energy mix.

Global emissions, excluding LULUCF, increase by 63% over the period 1990-2020. They increased by 23% over the period 1990-2005 and are projected to increase by a further 33% over the period 2005-2020. The best estimate[14] of resulting global average temperature increase in the baseline in 2050 is projected to be already around 2°C above pre-industrial level and continues to increase afterwards.

Emissions increase faster in developing countries than in developed countries. In developed countries that are Annex I parties under the UNFCCC, GHG emissions, excluding LULUCF, decline by 2% in 2005 compared to 1990. Afterwards, baseline emissions increase again to reach 1990 levels by 2020. Emissions, excluding LULUCF, in developing countries increased significantly over the period 1990 to 2005 and are projected to increase at a slightly lower rate resulting in an increase of 166% over the period 1990 to 2020.[15].

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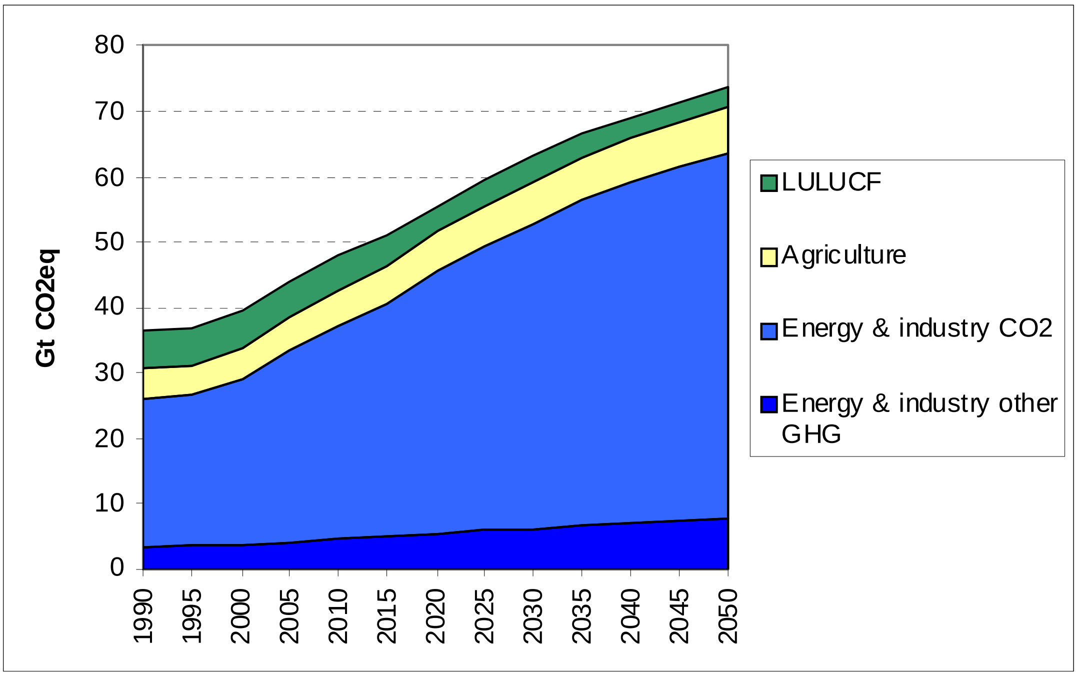
[13] IEA (2008).

[14] The best estimate temperature projection was done using the MAGICC model, version 5.3.

[15] Annex 6 in European Commission (2009b) gives further information how this baseline relates to baseline projections of other studies, e.g. those used by the IPCC assessment reports that are based on the scenarios described in the Special Report on Emissions Scenarios (SRES).

Figure 1: Baseline emissions, all sectors



Source: POLES (JRC, IPTS), G4M (IIASA), Image (PBL)[16]

3.2.1 Energy

Emissions from energy use increase faster than emissions from other sources. On a global level energy related CO_2 emissions are projected to increase by 71% over the period 1990-2020 (75% including international bunkers). For comparison, the IEA baseline for the World Energy Outlook 2008 projected an increase of these emissions between 1990 and 2020 of 74%.

Energy CO_2 emissions are projected to increase by 6% and by 68% in 2020 compared to 2005 in developed countries and developing countries, respectively. Energy GHG emissions from developing countries overtake those of developed countries before 2010. By 2020 they 43% above those of developed countries.

3.2.2 Agriculture and deforestation

Global emissions from agriculture[17] grow at a lower speed than those of energy and industry. They increase by 30% over the period 1990-2020. Agricultural emissions in developed countries decreased substantially over the period 1990 – 2005 and are projected to remain fairly stable over the period 2005 – 2020, while those in developing countries are reported to

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[16] For a description of G4M and IMAGE model see Kindermann et al. (2006, 2008), and Bouwman (2006), respectively.
The lower historic total emissions as compared to the figures given in the IPCC AR4 are due to the use of GWPs as defined in the IPCC SAR and different assumptions on emissions from deforestation.

[17] Emissions from agriculture are estimated by the IMAGE model.

have grown by 23% over the period 1990 - 2005 and are projected to continue to grow by 51% over the period 1990 - 2005.

Finally, annual emissions from gross deforestation decrease in the baseline by around 20% by 2020, from a level of around 4.3 Gigaton CO_2 per annum in 2005 to around 3.5 Gigaton CO_2. This means that by 2020, the size of emissions from deforestation are about twice as high as the proposed EU ETS cap in the same year[18]. Almost all these emissions stem from deforestation in developing countries.

3.3 The baseline for macro-economic assessment with GEM-E3

The GEM-E3 is a computable general equilibrium model that can assess the macroeconomic effects of the various scenarios. The GTAP 6 database has been used to calibrate the GEM-E3 model to its base year 2001. The baseline scenario to the year 2030 has been established by taking into account the GDP and CO_2 emissions of the POLES baseline scenario and also the agricultural non-CO_2 emissions which are not included in POLES. The resulting baseline is similar to the baseline based on the POLES + IMAGE models, even though the GEM-E3 baseline is slightly higher (Table 1).

Table 1: Baseline emissions in 2020, comparison POLES – GEM E3

Increase of emission levels compared to 1990 in 2020 in %		
2020	Developed countries vs 1990	Developing countries vs 1990
Baseline POLES + IMAGE (energy sector, industry and agriculture)	-2%	166%
Baseline GEM E3 model (energy sector, industry and agriculture)	2%	156%

Source: POLES, IMAGE, GEM-E3

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[18] Proposal for a Directive amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading system of the Community (2008/0013 (COD)).

4 Global Mitigation Scenarios

A global emission path compatible with the 2 degree target has been defined for both the POLES and GEM-E3 models, in the same way as in Russ et al. (2007).

4.1 Targets for developed countries

The IPCC defines 4 main drivers for GHG emissions, i.e. changes in energy and carbon intensity, population growth, and global per capita income growth. While these are often seen as drivers for emission growth, they can also be looked at as indicators for the ability to mitigate. The group of developed countries have a -30% target compared to 1990 in 2020, for which the targets of individual countries are allocated using a set of 4 indicators. The emissions of developing countries in 2020 are limited to 20% above 1990 levels.

The four indicators on which the targets of the individual country are based are GDP/capita, GHG/GDP, early action and population trends. The individual country targets for all developed countries of all options add up to reach the overall -30% emission reduction target in 2020 compared to 1990[19]. Table 2 lists the four single indicators and their respective reduction targets, as well as the central scenario based on the 4 single indicators[20].

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[19] The target for the group of developed countries as a whole is smaller than 30% as the table compares to 2005, and the emissions have decreased in the developed countries between 1990 and 2005.

[20] See Annex in European Commission (2009b) for more details on how the Central Scenario was constructed.

Table 2: Targets for developed countries resulting from the four allocation options

	GDP/cap		GHG/GDP		Early action		Population trends		Central Scenario
	GDP per capita in 1000€, 2005	2020 Target compared to 2005	GHG/GDP, 2005, in kg of CO2 per US$(2000)	2020 Target compared to 2005	GHG trend 1990 to 2005 in %	2020 Target compared to 2005	Population trend 1990 to 2005 in %	2020 Target compared to 2005	2020 Target compared to 2005
EU	22.5	-25.1%	0.43	-20.1%	-8%	-22.4%	4.0%	-38.1%	-24%
USA	33.8	-45.3%	0.53	-26.8%	16%	-41.5%	17.1%	-13.1%	-34%
Japan	28.7	-37.1%	0.24	-6.1%	7%	-36.1%	3.5%	-38.4%	-29%
Canada	28.3	-36.5%	0.67	-32.5%	25%	-46.8%	16.5%	-14.4%	-39%
Australia, New Zealand	26.9	-34.2%	0.77	-36.7%	27%	-47.9%	20.3%	-6.2%	-38%
Other OECD Europe	45.7	-64.5%	0.19	-2.1%	5%	-35.1%	9.1%	-30.5%	-30%
Commonwealth of Independent States	3.6	15.5%	4.66	-46.0%	-35%	6.0%	-4.6%	-42.7%	-12%
Developed countries		-27.3%		-27.3%		-27.3%		-27.3%	-27%

4.1.1 "GDP per capita" scenario

GDP/capita is selected as a first simple indicator that could be used to attribute a reduction target to a country. The higher the indicator, the more stringent the reduction target is set. The income level of a country determines to a large extent the ability to pay for mitigation action. Rich countries have a higher ability to invest in reductions than poor ones and can invest more in GHG reductions in other countries through offsetting mechanisms. There is no need to project GDP/capita over time and one can simply use recent available data, as this indicator measures the ability to act today on climate change.

One can measure GDP/capita in current prices or in purchasing power parity (PPP). As most clean environmental technologies and services required for large scale investments in a low carbon energy infrastructure are traded internationally at world market prices, the GDP/capita in current prices reflects more appropriately the availability of the financial resources.

4.1.2 "GHG emissions per GDP" scenario

The ratio GHG emissions per unit of GDP, is selected as a second simple indicator that could be used to attribute a reduction target to a country. The higher the indicator, the more ambitious the reduction target can be. The total emissions a country emits in order to produce its goods and services may indicate whether there is a potential to reduce emissions. Low carbon productivity can be attributed either to a carbon intensive energy mix or to a high degree of energy inefficiency. These conditions generally offer substantial mitigation potential at lower cost than those economies that have a low carbon energy mix or are highly energy efficient. GHG/GDP measures the ability to mitigate as of today, and there is no need for projections over time, as such recent data can be used for the allocation.

4.1.3 "Early action" scenario

The observed GHG emission trend is selected as a third simple indicator that could be used to attribute a reduction target to a country. The steeper the reduction was since 1990, the less ambitious the future reduction target is set. Since 1992, developed countries have the obligation under the UNFCCC to act on climate change. Over the period 1990 to 2005 total GHG emissions of the group of these countries has actually declined. But there have been huge differences in the country by country performance within this group with large reductions in some while others have increased their emissions substantially. By taking early action many emission reduction options have already been realised in the past. At the same time, taking early action into account provides a reward and an incentive for the future. The data used in this assessment are the historic GHG emissions trend over the period 1990-2005, excluding the LULUCF sector.

4.1.4 "Population growth" scenario

Population trend is, therefore, selected as a fourth simple indicator that could be used to attribute a reduction target to a country. The higher the indicator, the less stringent the reduction target can be. Countries with an increasing population will face more difficulties to reduce their emissions than countries with stable or declining populations, assuming per capita income, carbon and energy intensity are all stable. The data used in this assessment are the historic population trends over the period 1990-2005.

4.1.5 Central scenario

The central scenario[21] simultaneously takes into account all four single indicators: GDP/capita, GHG/GDP, GHG emission trends and Population trends. Each developed country has intermediate targets which lie between the extremes of the single-indicator targets. The individual country targets in the central scenario for all developed countries add up to -30% emission reduction target in 2020 compared to 1990. The central scenario will be analyzed in chapters 5 and 6 with POLES and GEM-E3, respectively.

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[21] See Annex 9 of part 2 in European Commission (2009b) for more details on how the central scenario is defined.

4.2 Action of developing countries

For the developing countries it was assumed that they would also introduce internal actions to ensure global emissions are on a pathway stay within the 2ºC objective, i.e. that emission growth would be limited to a level of around 20% above 1990 levels. In order to determine the level of action by developing countries in this scenario, similar indicators were used as for developed countries.

- GDP per capita, addressing the capacity to pay for emission reduction within a country
- GHG per GDP, addressing the opportunities to reduce GHG emissions
- Projected Population trends over the period 2005 – 2020, recognising different pressures on the projected emission evolution.

The higher a country's GDP per capita, the more national actions it would need to undertake to limit emissions growth compared to baseline. The higher a country's GHG emissions per GDP, the more it would need to undertake action to limit emission growth compared to baseline. And finally, the higher a county's projected population growth rate up to 2020, the less mitigation action it would need to undertake. It actually would be allowed to increase emissions compared to baseline. Summing up the three factors will result in the necessary emission limitations below the baseline.

Table 3 gives an overview of the implications of each indicator on the total amount of reduction needed compared to baseline in this internal action scenario for China, Brazil and India. Brazil being the richest of these three countries would need to limit emissions most according to its GDP/Capita. But for Brazil the reverse is true for GHG intensity of its economy, where it is one of the better performers. Finally, India has a high population growth rate while that of China is very low resulting in a different amount of allowed increase compared to baseline. In total, China is expected to reduce more than the other two compared to baseline.

Table 3: Emission reductions for developing countries resulting from the allocation options (in % compared to baseline)

	Share according to GDP/cap	Share according to GHG/GDP	Share according to Population ’05-‘20	Total Reduction
Brazil	-13.2%	0.0%	3.9%	-9%
China	-4.2%	-13.0%	1.0%	-16%
India	-0.5%	-12.2%	4.9%	-8%

4.3 A gradually developing global carbon market

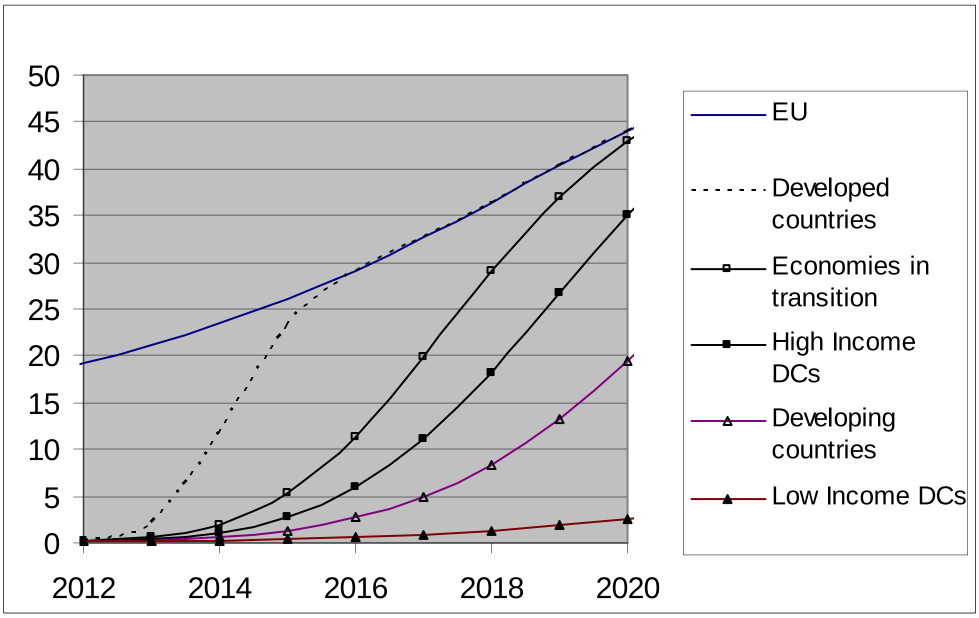
In the discussions on emission reduction scenarios, the standard reduction cases tend to operate with a normative optimisation approach, assuming perfect foresight and perfect emission trading. As a consequence there is only one carbon price across all world regions and sectors, which leads to minimum cost for compliance with a certain emission reduction target. While this approach can help in understanding the theoretically ideal pathway to reach a given target, it is questionable to what extent it represents existing behaviour in the real world.

Unlike many earlier scenarios, the scenarios developed in this study no longer assume ideal pathways with perfect trading in all sectors across all time periods and world regions. Instead, it aims at being more realistic while at the same time maintaining the idea of economic efficiency by a gradually developing global carbon market across sectors and countries, resulting in different abatement and thus different carbon costs.

Developed countries take on a collective emission reduction target in the range of 30% compared to 1990, and they set up a trading system such as the EU ETS or similar policy measures that establish a carbon price for the energy intensive industrial sectors, including the power sector. A carbon market exists for the sectors included in the EU ETS but it is not perfect and thus it does not equalise Marginal Abatement Costs for the involved sectors on a global scale. Instead of this, the effective carbon prices are assumed to vary between the various regions in the world because of differences in transaction costs (see figure below), and they converge over time. Carbon prices are similar across markets in developed countries by 2015. Economies in transition follow suit but carbon prices would be equal as of 2020.

Energy intensive sectors in developing countries are exposed to a low carbon price in 2012, simulating the limited penetration or visibility of a carbon price for all individual firms through policy instruments such as the CDM. However, differences in the carbon prices become smaller over time as a result of a strengthened regulatory framework in close relationship with the state of development of the economy. Between 2025 and 2030, these differences in carbon prices become relatively smaller for all groups of countries apart from low income countries. Figure 2 and Table 4 illustrate the developing carbon market for POLES and GEM-E3 respectively. This gradually developing carbon market will increase the overall economic costs of achieving the 2ºC objective compared to a scenario that assumes perfect trading, but is considered a more realistic representation of the carbon market.

Figure 2: **Carbon price developments in the global carbon market in POLES**[22]



Source: JRC/IPTS, POLES

Transport, agricultural, residential and services sectors do not participate in the global carbon market. Developed countries reduce emissions in these sectors through energy efficiency improvements, and sector-specific policies. In developing countries, only energy efficiency policies in these sectors are implemented.

Table 4: Carbon market penetration in developing countries in 2020 for GEM-E3 (in %)

Brazil	76%	China	55%
Southern Africa	73%	India	33%
Rest of Eastern Asia	72%	Rest of Asia	30%
Rest of Latin America	67%	Middle Africa	30%

Source: JRC/IPTS, GEM-E3

The degree of development of the global carbon market in 2020 is an important factor to assess the costs of GHG mitigation. Therefore in Chapter 7 the GEM-E3 model is run to compare the costs for mitigation policies with a developing carbon market under two extremes, i.e. no global carbon market at all and a perfect global carbon market that equalises on a global scale the marginal abatement costs in the sectors involved.

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[22] Breakdown of regions in the reduction scenario: Europe: EU - 27 + Switzerland and Norway; Developed Countries: US, Japan, Australia, New Zealand; Economies in transition: Russia + Ukraine + Rest of Central Europe; High Income Developing Countries: Gulf states, Mediterranean Middle East, South Korea, Mexico; Other Developing: China, Brazil, RIS, South East Asia, North Africa, South America, Turkey, Central America, Former Soviet Union States in Asia; Low Income Developing Countries: India, Egypt, Sub Sahara Africa, South Asia.

5 The Impact on the Energy Sector (POLES)

In this chapter, POLES model analyses the type of actions/technologies necessary in the energy and transport sector to ensure that GHG emissions are limited to be in line with the objectives proposed by the EU with respect to the baseline assumptions and conditions. In this chapter POLES only analyzes the "central scenario" with intermediate targets combining the four "driver" indicators. In chapter 6, the GEM-E3 model not only assesses the economic effects of the central scenarios but also of each of the single-indicator scenario described in chapter 4. The results analysed in chapter 5 and chapter 6 are under the condition of a gradually developing carbon market. Chapter 7 compares these results with the cases without carbon market and with a perfect carbon market.

5.1 General results of the central scenario

GHG emissions in developed countries decrease by 22% in 2020 compared to 1990 in this scenario. The EU27 takes its part from this burden as its domestic GHG emissions decrease by 22%. The remaining 10% is achieved through offsetting mechanisms that generate credits for reductions in developing countries. GHG emissions of developing countries continue to grow up to 2020 and reach a peak between 2020 and 2025, however in 2020, emissions from energy and industry in developing countries are 19% below baseline projections (Figure 3:)[23].

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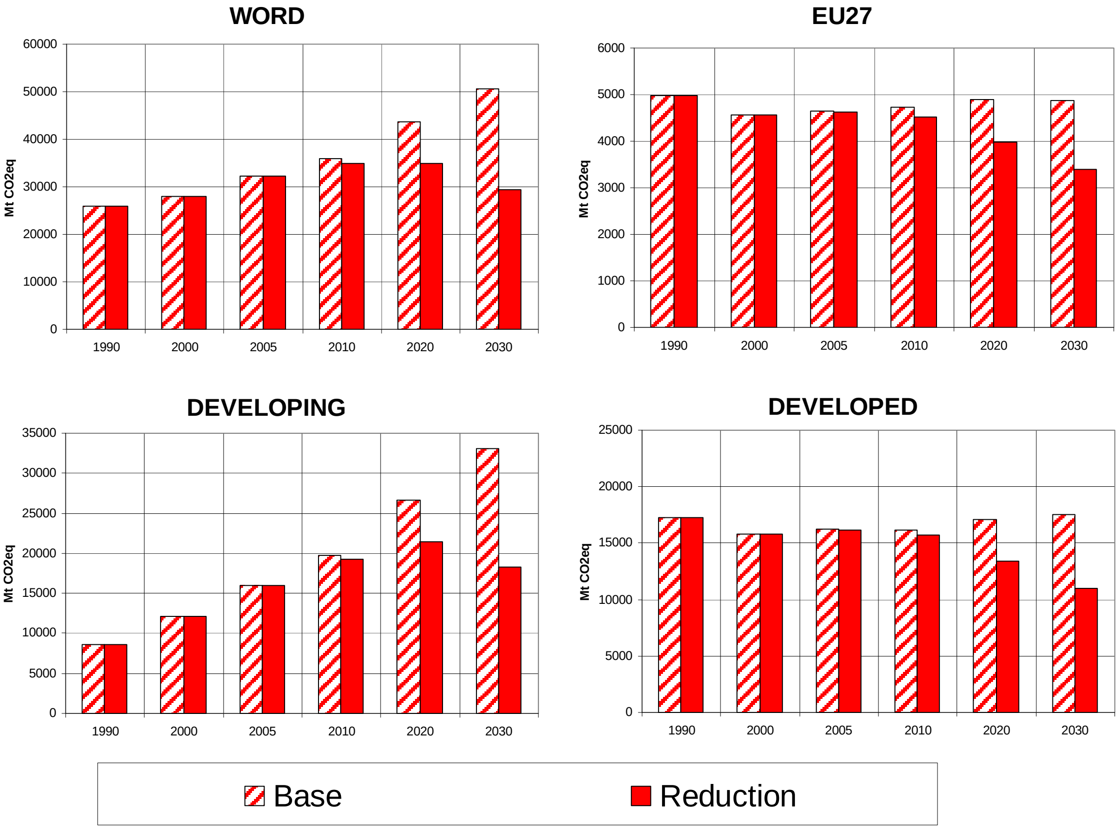
[23] See Annex in European Commission (2009b) for more details on impacts of the central scenario on selected MEM participants.

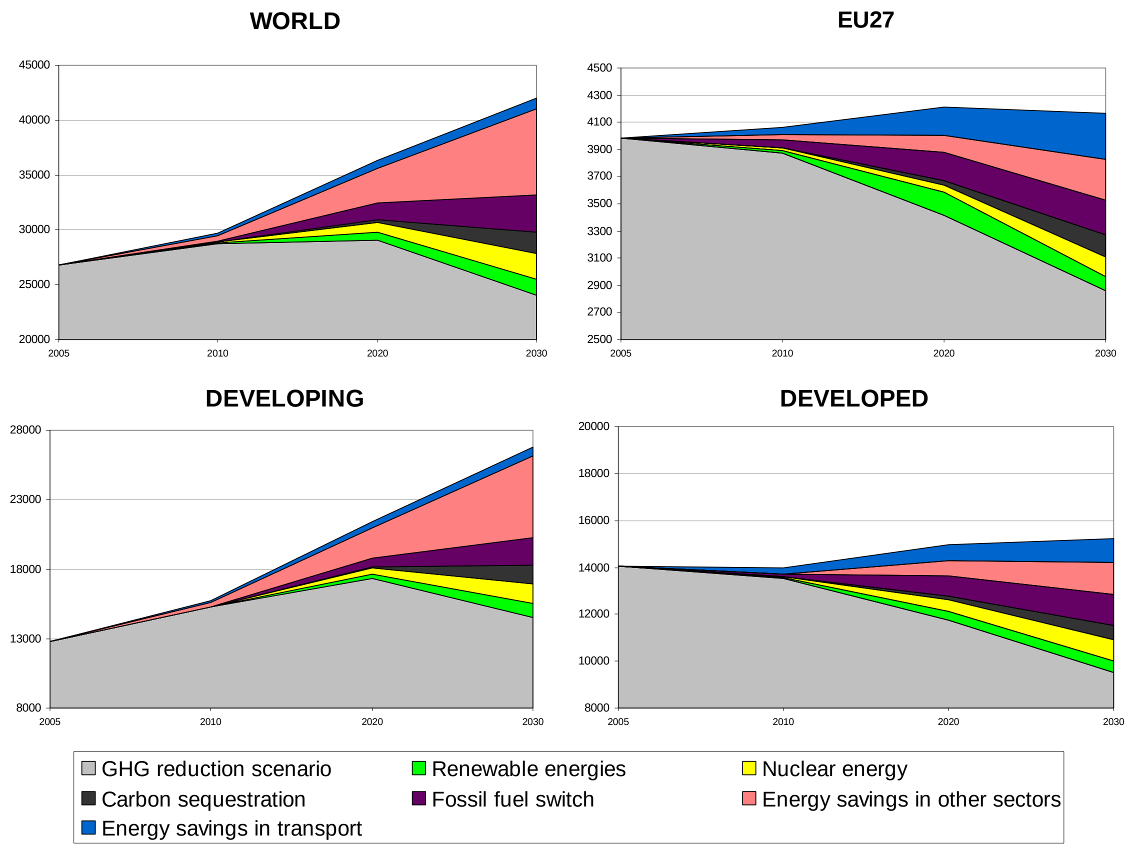
Figure 3: Country GHG emissions in POLES baseline & central scenarios



Source: JRC/IPTS, POLES

Figure 4 identifies six main categories for the period 2005-2030 for various geographical regions, which are the most important to achieve the emission reductions. These are the energy efficiency improvements in the various economic sectors, energy transport sector in the transport sector, carbon capture and sequestration technologies (CCS), switch to renewables, increase in nuclear, and substitution amongst the various fossil fuels. These changes are examined in detail in this section together with an in depth analysis of the investment need these changes require in the power generation sector.

Figure 4: **Contribution of different technologies to reduce CO_2 emissions**



Source: JRC/IPTS, POLES

5.2 Energy efficiency, a crucial ingredient of the central scenario

Until 2020, energy efficiency measures represent the bulk of the reduction potential. Both in technical and economical terms it is the single most important opportunity in the coming decade.

A large variety of low-cost measures can be used in an early phase, most of which are already available and have negative or low costs even though the upfront investments might be considerable. All sectors have potential to improve energy efficiency (both supply and demand sectors)[24]. The POLES model simulates the implementation of energy efficiency

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[24] Energy efficiency improvements that are not introduced through increases in the carbon price, related to the different energy transforming equipments and/or to the final energy use in the industrial, residential and services sectors, are modelled through autonomous energy efficiency indicators (AEEIs). For road transport the impact of measures, including standards, on the efficiency improvements of the whole transport fleet is modelled in the transport module of the POLES model, based by the assessment on their impact on fuel efficiencies of the newly introduced vehicles in the future. Estimates are made for the upfront costs of these energy efficiency improvements. These are based on studies by JRC for EU energy efficiency measures, a study by

policies through a gradual improvement of the global energy intensity. Moreover, the gradual introduction of a carbon price at higher levels than the one assumed in the baseline stimulates further carbon price-induced energy efficiency improvements.

Figure 5 shows the crucial importance of such induced energy efficiency improvements for the overall emission reductions, delivering up to 50% of total global effort compared to baseline in 2020 in the industrial sectors and in transport. In 2030 it still accounts for almost half the global effort. For developing countries this share is even higher with about 2/3rd of the total action coming from energy efficiency.

The energy efficiency improvements are partly driven through the smaller energy price differentiation across developed and developing countries and all economies become more or less equally exposed to the same energy price changes and volatility. As such, developing countries have stronger incentives for the early adoption of innovative energy saving technological solutions[25].

In power generation, a large potential for cost efficient improvements for various types of power plants exists, covering the full spectre from combined cycle gas turbines to supercritical coal plants. This potential is very large in both developed and developing countries, but particularly interesting in developing countries such as China and India. Among developed countries, the US have ample room for efficiency improvements. Moreover, in developing countries, the coupling of energy improvements with air pollution abatement technologies could also generate significant health benefits[26]. Important efficiency gains can be reaped by improving the overall architecture of the power generation system and of the transmission and distribution grid, with effective integration of intermittent power sources like renewables or distributed generation like CHP. Smart grids, superconducting electric lines, power storage devices ranging from pumping hydro to new generation batteries are the crucial technologies to realise these efficiency gains.

Further, the industrial sector is the second most important source for energy efficiency improvements. They are potentially very large in emerging economies, especially in those where economic growth is accompanied by a fast development of energy intensive industries (typically the case of China and other East Asian economies). Faster economic growth also fosters rapid capital equipment turnover, opening possibilities for adopting best available technologies (BAT) from the international technology market. Their benefits are reinforced by the fact that very often BAT deliver not only the most energy efficient performance but also considerable co-benefits in terms of reducing air and water pollutants.

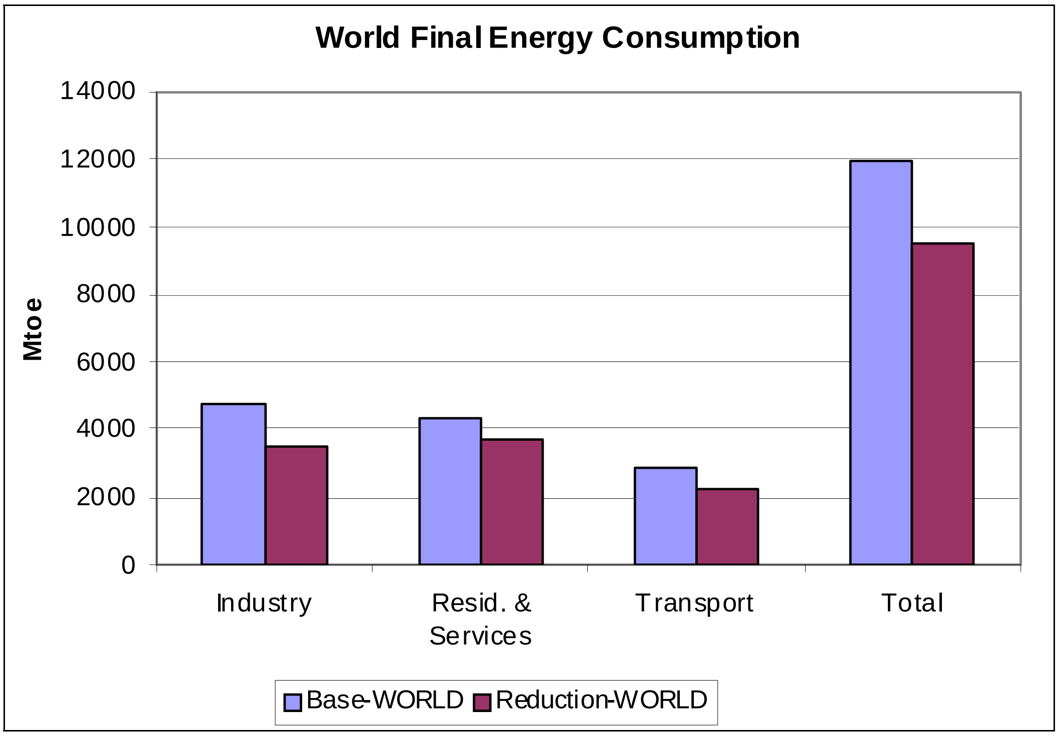
Resources for the Future on demand side energy efficiency policies, work for the 2007 US Energy Independence and Security Act and other energy efficiency related programs (e.g. Energy Star).

[25] Examples include the shift to secondary iron, steel and non-ferrous metal production or substituting materials that are the most energy intensive in the production processes (e.g. reducing clinker content in cement, application of inert carbon anodes in aluminium production, or simply applying higher recycling rates in paper and glass making, shifting to more sustainable building materials and insulation).

[26] See section 6.9 in European Commission (2009b).

Comparing the Baseline and the Central scenarios in terms of final energy consumption, the latter suggests a balanced effort between sectors, bearing in mind the different technological possibilities. At global level, the Central scenario results in 20.4% less global final energy consumption compared to the Baseline scenario by 2030.

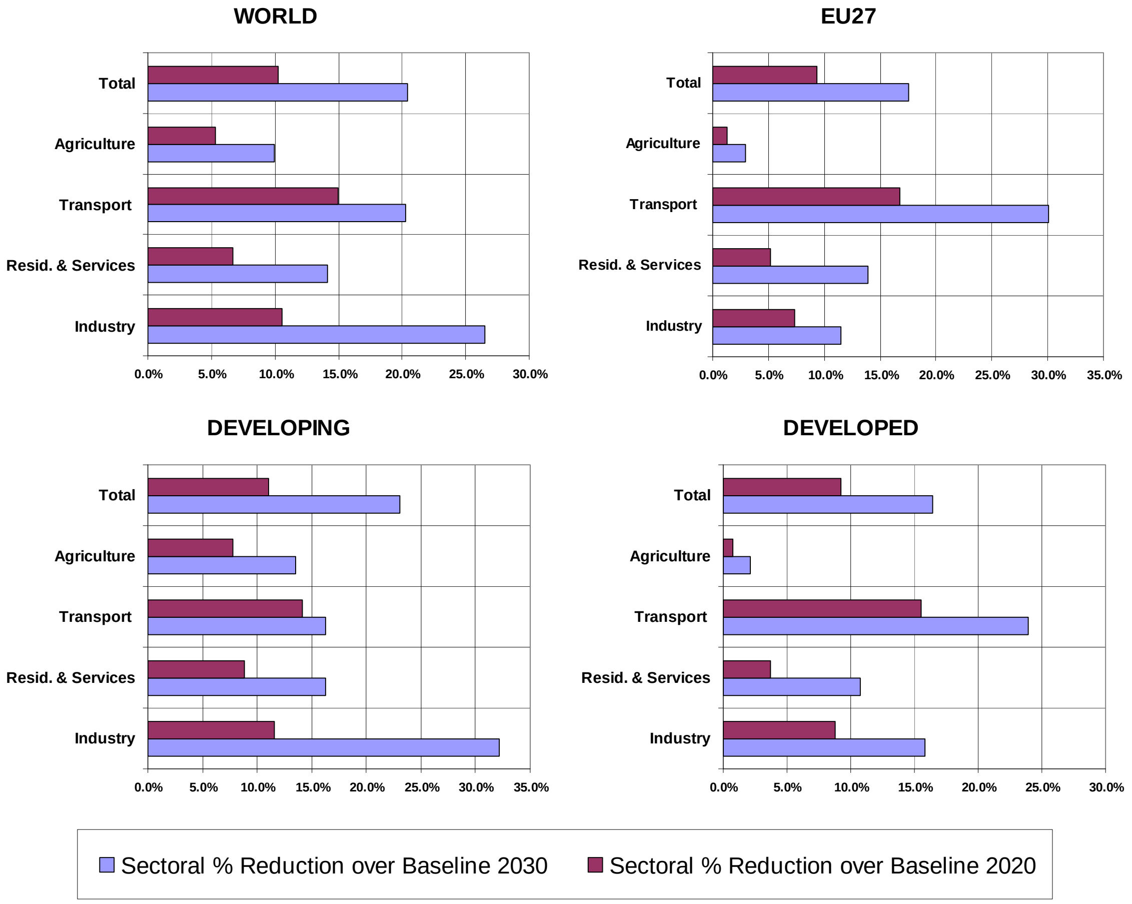
Figure 5: World Final Energy Consumption for Baseline and Reduction Scenarios



Source: JRC/IPTS, POLES

This large potential for efficiency gains in final energy demand can be either driven by policy interventions (e.g. setting standards, targeted loan programmes, higher energy prices), which lead to technology improvements. The potential for improvements in the residential and transport sector are proportionally more important in the EU-27 and in other developed countries (at least in the short term), as larger shares of energy consumption in these two sectors are typical for wealthy economies. Within the residential and tertiary sector, several emerging electric and heating appliances can play a significant role. Compact light bulbs offers already a large saving potential (-80%) at virtually zero cost. LEDs, a technology that is rapidly becoming available, are likely to offer even larger savings. Intelligent management of stand-by electronic appliances also offers substantial savings potential. More efficient electric motors and compressors can further improve the performances of washing machines and refrigerators. Heat consumption can also be lowered with appropriate building standards and the generalised introduction of low temperature solar thermal appliances producing domestic hot water and other uses. These technologies will be particularly crucial in those emerging countries with a relatively low energy intensity growth path (India, Brazil, etc) but where income growth is expected to push up domestic energy consumption. Out of the final consumption sectors, the transportation sector provides the best opportunities, via (a) improvement in power trains engine efficiency, (b) lowering the weight of engines and cars, (c) shifting to less carbon-intensive fuels (i.e. biofuels), and (d) shifting from private to public transport or from road to rail.

Figure 6: Sectoral Final Energy Savings compared to Baseline



Source: JRC/IPTS, POLES

Tertiary sectors are expected to deliver less, especially in developing countries: this will be due to counterbalancing income effects as per capita incomes are expected to rise but also due to changing social patterns and population dynamics. The figures for the residential and services sector are 14.2% and 13.9%, for the world and EU-27, respectively.

The transport sector, even if technologically rigid, can achieve substantial reductions of final energy demand between the two scenarios thanks to energy efficiency improvements, a modal shift towards more performing electric transportation schemes, and an increased use of public transport. In 2030, energy savings from the transport sector are expected to amount in the Central scenario to around 20% and 30% compared to the baseline for the world and the EU-27, respectively.

5.3 Renewable energy

Renewable energies are not only carbon free, but they also improve the security of supply within energy balances. Most of them are particularly relevant for power production (hydropower, on- and off-shore wind power, solar PV, high temperature solar, geothermal, different types of biomass-fed power plants, and in perspective geothermal, tidal and wave power). They present often zero or very low GHG emissions. They are available at a wide range of development levels, from commercially mature to those that are only at the conceptual stage. Particularly innovative are some technologies to improve the performance of photovoltaic cells, but also biotechnologies for biofuels or hydrogen production. These still need important R&D efforts. Other technologies, close to commercial stage, attempt to compete with the conventional technologies, but might need support schemes or a smoothly functioning carbon market with a significant carbon price.

The baseline scenario foresees that electricity output from renewables would grow worldwide by 148% by 2020 and by 246.8% by 2030 with respect to 1990. Renewables would increase by 185.4% by 2020 and by 322.4% by 2030 in the central scenario for the same period, showing that climate policies enhance renewables. The potential growth of each technology, however, depends on the remaining potential. Hydropower, for instance, offers limited expansion capacity in many developed regions, and by 2030 the hydropower output differences between the two scenarios are small, around 5% with respect to the reference year (that is, an 85.3% increase in the central scenario versus an 80.3% increase in the Baseline). By 2030 'new' renewables (mainly wind and to a lesser extent solar) are expected to multiply by 24 compared to 1990 levels in the Baseline and multiply by 34 in the Central scenario. These changes look impressive but in fact they represent in the baseline scenario a yearly growth rate of 8.8% until 2020 and of 8.3% until 2030, and in the Central scenario slightly higher yearly growth rates (10.0% until 2020 and 9.2% until 2030). The real acceleration takes place in the period 2005-2020, when production increase more than sevenfold in the baseline and more than tenfold in the Central scenario.

For the EU renewables growth in power generation would be 272,2% in 2020 and 331.1% in 2030 with respect to 1990 in the central scenario (against 221% and 310.4% in the baseline for the same period). The growth in "new" renewables, excluding hydropower, would be much faster, with rates close to 13.4%/yr to 2020 and 10.6%/yr to 2030 in the central scenario.

Total growth in renewables allows to reach a share of 17% over total primary energy by 2020 and 18,3% by 2030. They represent respectively 17% in 2020 of total final energy consumption[27].

Renewables have also an important market niche in non-electric applications. In domestic and industrial sectors, low temperature solar thermal devices and biomass-fuelled boilers can be used. In the transport sector, bio-ethanol, bio-diesel or other forms of sustainable biofuels are also already extensively used in several countries, and in some of them have gained a significant market share. Their worldwide potential is significant[28].

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[27] This figure does not include the contribution of heat-pumps in Residential and Services surface heating, geothermal, tidal and wave energy. Heat production for local CHP plants based on biomass is not considered in the model. If these sources would be incorporated in the calculation, the renewables share would increase towards the 20% target. See also the results of the Green-X model used for the staff working document accompanying the Renewable Road Map Communication on the estimations of the excluded sources (COM 2006/1719).

[28] See European Commission (2009b) for an assessment of the potential impact of biomass and biofuels on deforestation and agricultural production.

5.4 Nuclear power

Another carbon free energy source is nuclear power. In the baseline, worldwide nuclear power sees a 40.6% capacity increase and a 40.1% output increase over the period 2005-2020. This is higher than in the 2007 Impact Assessment[29] due to higher overall fossil fuel prices. In the Central scenario more nuclear power capacity is added, with an 80.9% increase of installed capacity and an 80.5% increase in output by 2020 compared to 2005. Over half of total additional capacity would be installed in developing countries. In the EU, capacity is roughly maintained in 2020 at 2005 levels in both scenarios in line with current phase-out plans in Member States.

5.5 Fuel switch

Fuel not only entails a change to less carbon-intensive fuels but may also lead to additional gains in efficiency as the switch implies a substantial change in technology (e.g. replacing oil-fired boilers with advanced high-efficient gas turbines). However, this is not always the case, since some standard combustion plants can accommodate a range of fuels from highly carbon intensive coal to virtually zero-carbon biomass. At a global scale, the power generation sector is the one that would show most of the fuel switch in the projected period due to its relatively high technological flexibility.

Interestingly, the upward trend in the demand for electricity is much higher compared to the projected increase in overall final energy demand, i.e. the share of electricity will increase. Electricity will continue to be the most valued and demanded final energy carrier, and even in the Central scenario total global electricity demand grows by 160% by 2030 with respect to the 1990 level. However, the technological portfolio is expected to radically change: carbon-free primary electricity is supposed to account for around 55-56% of total electricity produced by 2030 (both worldwide and in EU-27) in the Central scenario, whereas in the baseline this share is expected to reach a mere 33.6% worldwide and 47,7% in the EU.

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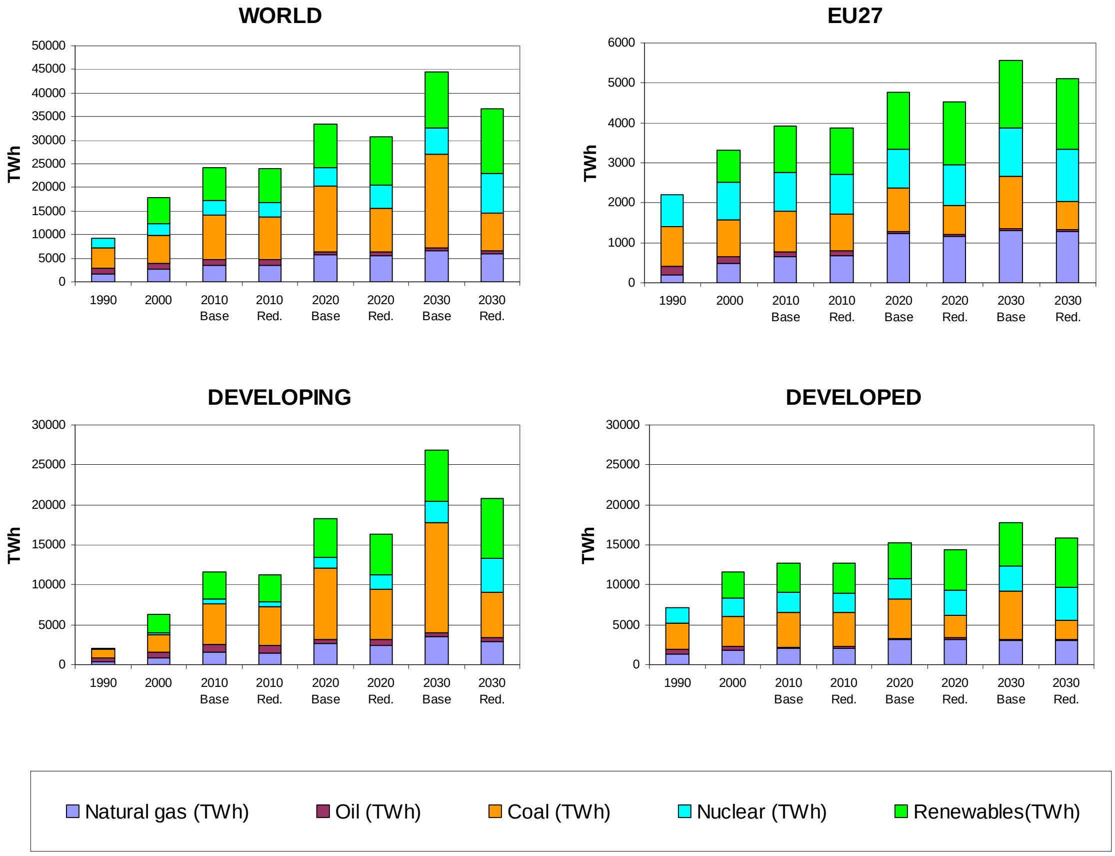
[29] Impact assessment accompanying the Communication "Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond".

Figure 7: Power Generation by fuel type



Source: JRC/IPTS, POLES

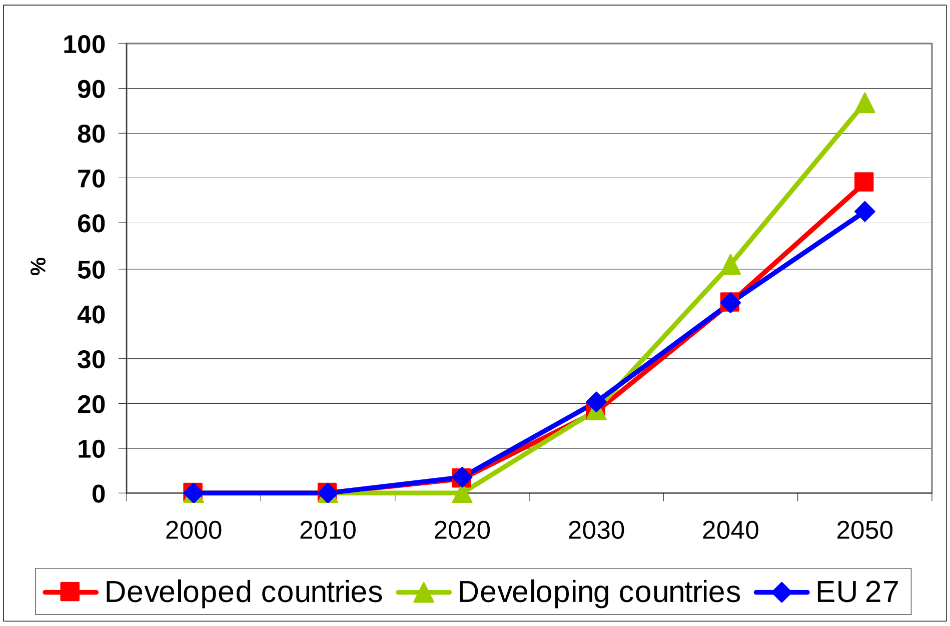
It should be noted that since 1990 the share of carbon free electricity produced globally has dropped significantly. This is due to the massive growth in fossil fuel power generation capacity (particularly coal-fired), and to the slowdown or outright halt of nuclear programmes worldwide over the last two decades. The Central scenario will take the world back in terms of share of carbon free electricity almost exactly to the share as it stood in 1990, but on the scale, which is 3.5 times bigger than in 1990.

5.6 Carbon capture and storage

From the point of view of new technologies, a significant contribution to emission reductions is expected from carbon capture and storage (CCS): in fact a very fast deployment of this technology would be necessary from the very low current levels to those projected for 2030 in the Central scenario. This technology is already being used especially in the context of enhanced oil recovery and natural gas production but the marginal costs for retrofit applications is still significantly higher than prevailing carbon prices. Furthermore, the environmental impact of large scale deployment of this technology in the power sector over long periods is largely unknown. The environmentally sound and safe deployment of this technology requires a sound legal framework like the one that has been adopted by the European Union.

Unsurprisingly, at global level, in the Baseline, the penetration of CCS with respect to fossil-fuelled power plants by 2030 is virtually zero, whereas the Central scenario results in a significant share (18%) of fossil fuel power generation with CCS (Figure 8). This underlines how crucial this technology will be in the future to achieve a sustainable carbon emission path at global level, and that large scale demonstration has to take off without delay. The greatest potential for expansion of this technology is anticipated to take place in the US and in China, while it would be relatively smaller in the EU. Most new fossil fuel power plants built after 2020 would be with CCS.

Figure 8: **Share of power sector emissions captured through Carbon Capture and Storage**

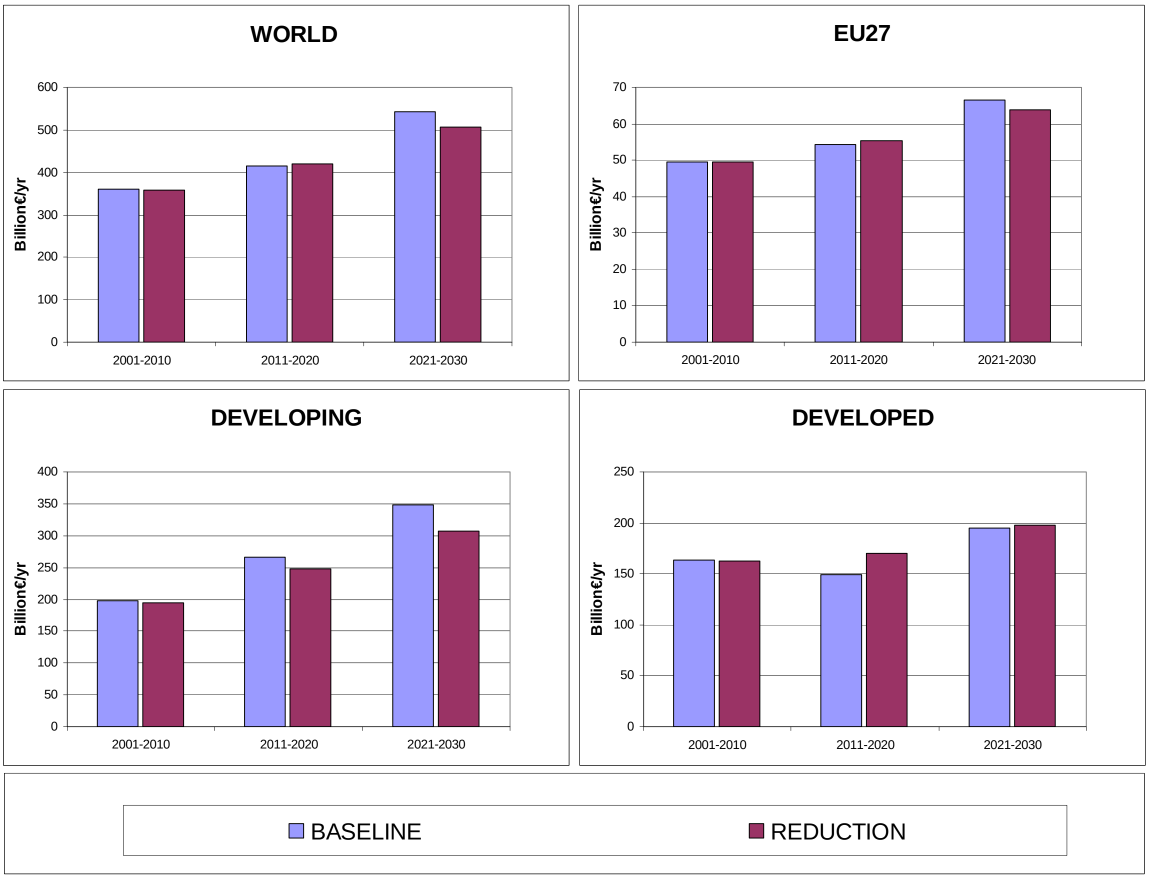


Source: JRC/IPTS, POLES

5.7 Investment needs in the power sector

The Central scenario implies an accelerated decommissioning of carbon-intensive technologies and its replacement by low-carbon, climate-friendly ones. The latter typically exhibit higher investment costs, therefore higher investment flows are required. However, while the costs of single investments are higher, a carbon constrained world also entails more efficient end-use of energy and therefore a lower total final energy demand requiring less power plants overall. This affects all final energy carriers, but most especially the power generation sector, which is the one expected to contribute a significant share to the overall decarbonisation of the energy sector. The annual investment in newly installed capacities for the power sector (26 power generation technologies are considered) is shown in Figure 9 for both scenarios until 2030. For CCS installations, this investment cost includes the costs to capture CO_2 but not to transport and store it. As such total investments including CCS might be higher in 2030 due to a large penetration of CCS by then.

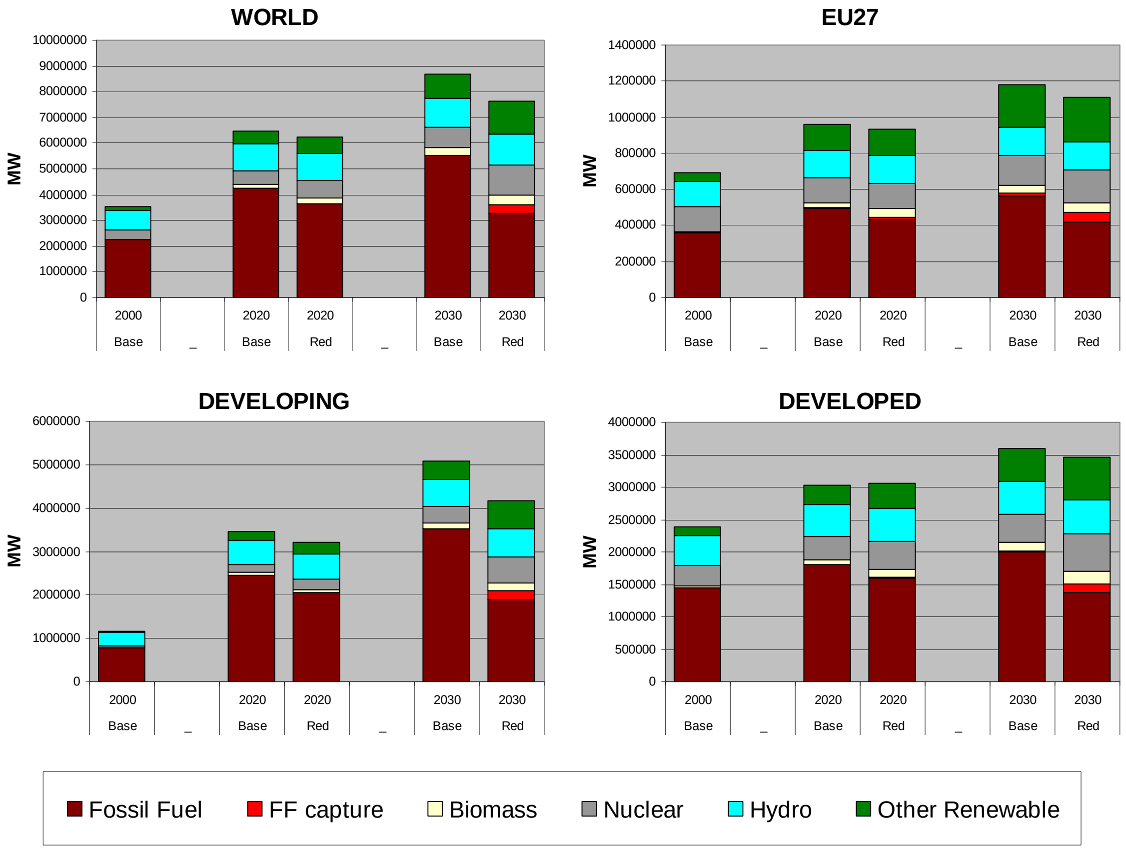
Figure 9: Annual Power Generation Investments



Source: JRC/IPTS, POLES

The results indicate that the differences in costs within the power generation sector are not very high because efficiency gains are projected to offset higher specific capital investment costs.

Figure 10: Changes in the mix of power generation

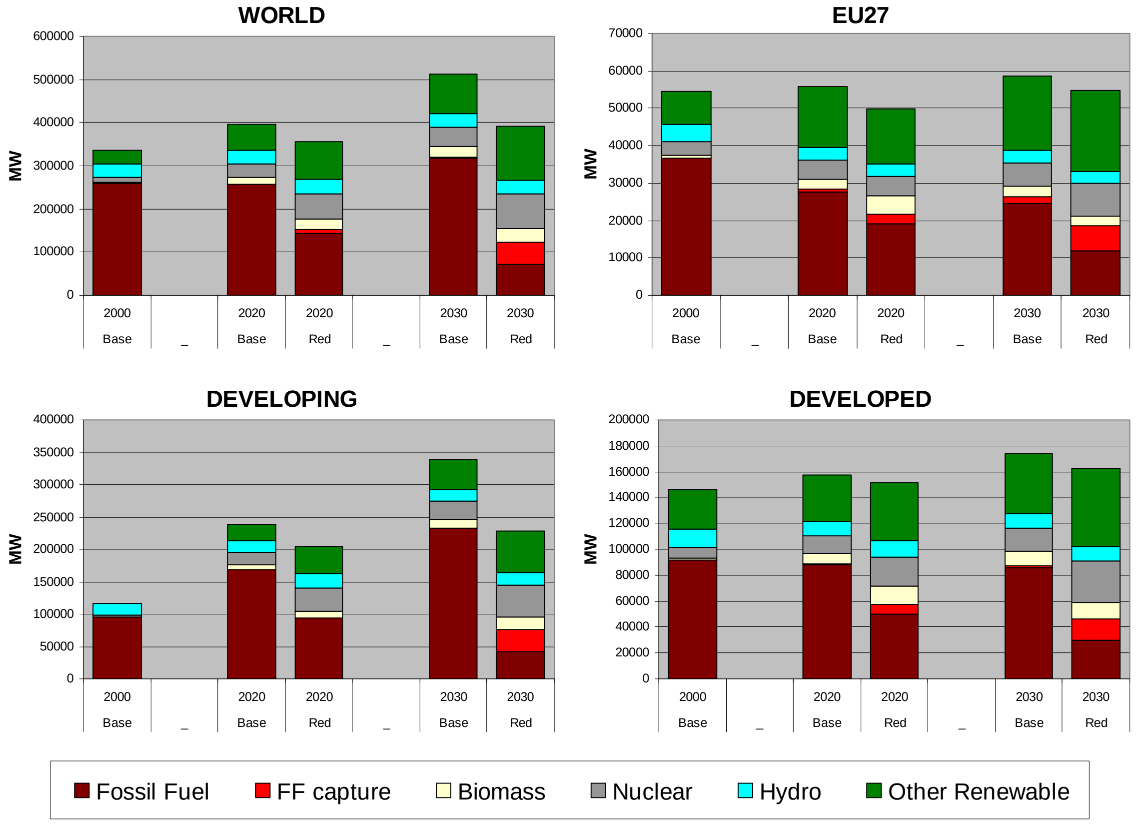


Source: JRC/IPTS, POLES

The main changes in generation capacity (Figure 10) between the Central scenario and the baseline would concern the thermal-electric power from fossil fuels: worldwide it would decrease by around 41% in the Central scenario by 2030, but the impact until 2020 would be much smaller. This trend is particularly obvious in China, India and the US. But the losses of fossil fuelled generation capacity would be to a large extent substituted by increases in renewables and nuclear capacity. Additional capacity in developed countries would be provided mainly by new renewables and hydro. Nuclear would also grow in all regions.

Considering the new capacity additions the changes are significant (Figure 11). Conventional fossil based technologies represents less than a fifth of the new capacity additions by 2030, a ratio which stands between 66 and 85 % at present. While electricity generation would require the installation of much less capacities indicated by these figures, they are made in technologies (nuclear and renewables) characterised with higher unit investment costs. While the total investment cost does not reduce, the dependency on imported fossil fuels reduces substantially.

Figure 11: Additional, new capacity in Power generation compared to 2000



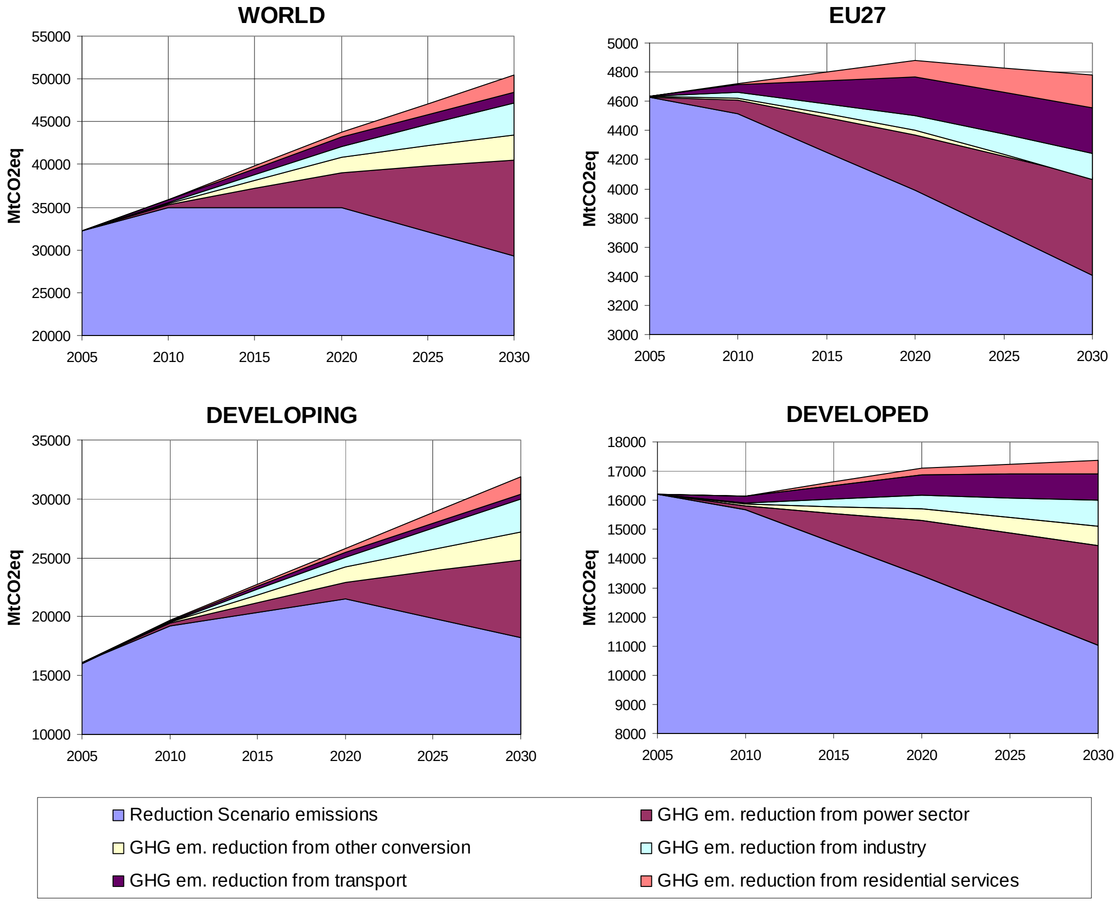
Source: JRC/IPTS, POLES

5.8 Sectoral contributions to the central scenario

The structure of energy-based and industrial GHG emissions provides an insight on the different opportunities of emission cuts by sectors (Figure 12). More than half of the potential emission cuts are to be found within the power generation sector. This reflects the great potential of this sector to shift to less carbon intensive technology portfolio combined with the possible reductions on the demand side. On the second place comes the industrial sector, where significant opportunities can be found as well. This emission reduction potential is particularly important in developing countries, so that the power generation and industrial sectors in these economies appear to be the key sectors for GHG abatement actions in the future international agreement.

Sectors like residential and transport exhibit lower rates of technological change as private persons might lack sufficient cash to purchase energy efficient goods at optimal levels due to sometimes high upfront investments (e.g. energy efficient household equipments or better thermal insulation of houses).

Figure 12: GHG reductions per sector, World Regions



Source: JRC/IPTS, POLES

5.9 Costs associated with the actions in the energy system and the industrial sectors

The real incremental mitigation costs that are experienced within an economy induced through carbon prices and the upfront investments necessary to achieve energy efficiency measures are estimated by the POLES model and can be found in Table 5. They do not include the financial flows generated by the trade in emission reduction credits, even though developed countries only reduce by around -22% by 2020 compared to 1990 so around 8% further reductions would have to be achieved through acquisition of credits through the use of offsetting mechanisms.

The annual global reduction costs in the year 2020 amount to € 152 billion by 2020[30]. Over the whole period 2013-2020 cumulative global costs are equal to € 666 billion. Costs in developed countries are equal to € 81 billion in 2020 or € 374 billion cumulated over the period 2013-2020. Costs in developing countries are equal to € 71 billion in 2020 or € 292 billion over the period 2013-2020.

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[30] The abatement cost rise to € 175 billion if costs in agriculture and avoided deforestation are considered.

Table 5: Costs in developed and developing countries and trade in emissions rights

	Cost of reductions in CO_2 from energy and Non CO_2 emissions from industry	
	Costs in the year 2020	Total costs over the period 2013 – 2020
	Total costs in Billion € (2005 prices)	Total costs in Billion € (2005 prices)
	(a)	(c)
World	152	666
Developed countries	81	374
Developing countries	71	292
EU	23	126
USA	34	157
Japan	7	30
Russia	7	22
China	30	109
Brazil	3	14
India	5	24

Source: JRC/IPTS, POLES

6 Economic Implications (GEM-E3)

As mentioned in Chapter 2, the POLES model analysis was complemented by the assessment of the reduction scenario with the multi-sectoral computable general equilibrium model GEM-E3. The two models are complementary: while POLES is a partial equilibrium model focussed on the global energy system, GEM-E3 is better suited to analyze the interactions between all the sectors in the economy and between regions through the international trade flows. The partial equilibrium energy model calculates the direct cost of the carbon reduction policy in the energy sector. In a general equilibrium framework, the direct impact of the climate policy on the energy sector is taken into account but also the indirect impact and cost on all other sectors and agents of the economy. GDP can be used as a measure of the overall macroeconomic adjustment to meet the emission target.

6.1 Assumptions

Comparability of efforts of developed countries is one major issue in the current negotiations. Therefore, the economic impacts of the various options for sharing the effort between developed countries were assessed with the help of the GEM-E3 model. All GEM-E3 emission reduction scenarios respect the following assumptions:

- Developed countries take on a combined reduction commitment of 30% below 1990 levels by 2020.
- Developed countries set up a cap and trade system for the sectors which are at present in the EU ETS, equalising the carbon price in these sectors among developed countries.
- Developing countries undertake nationally appropriate actions themselves in sectors belonging to the ETS, as well as belonging to the non-ETS.
- Developed countries also have access to the global carbon market including carbon credits from developing countries. It is assumed that the use of the offsetting mechanisms is limited to the sectors which are typically part of the EU ETS.

However, this global carbon market is not perfect but has significant transaction costs in transactions with developing countries. This means that the developing countries offer fewer reduction credits to the global carbon market than they would do without transaction costs. As a consequence, carbon prices in each of the developing countries remain below those in developed countries.

Developing countries introduce policies over time allowing them to overcome these transaction costs and participate gradually in the global carbon market. The richer a developing country is the more advanced its policies/mechanisms are, and the lower the transaction costs. Hence, its carbon price gets closer to the one in the ETS markets of developed countries.

6.2 Four single-indicator scenarios

On the basis of recent UNFCCC emission data for the year 2005, developed countries need to reduce their emissions as group by about 27% between 2005 and 2020 in order to meet the

EU's proposed 30% reduction target compared to 1990. In the following analysis the necessary effort is shared among developed countries according to the four single-indicator scenarios indentified in Chapter 4. Table 6 gives an overview of these options for the main developed countries.

Table 6: Key indicators of the four options for allocating the mitigation efforts among developed countries

	GDP per capita in 1000€, 2005[a]	**GHG/GDP, 2005, in kg of CO_2 per US$(2000)[b]**	**GHG trend 1990 to 2005 %[c]**	**Population trend 1990 to 2005 %[d]**
EU27	22.5	0.43	-8	+4.0
Australia	28.1	0.80	+27	+20.4
Canada	28.3	0.67	+25	+16.5
Iceland	43.7	0.21	+11	+16.1
Japan	28.7	0.24	+7	+3.5
New Zealand	21.2	0.56	+25	+20.1
Norway	52.8	0.20	+9	+9.4
Russia	4.3	4.41	-29	-3.1
Switzerland	41.3	0.17	+2	+8.6
Ukraine	1.5	6.56	-55	-9.0
USA	33.8	0.53	+16	+17.1
a Adapted from World Bank and Eurostat				
b Data from IEA2007				
c Data database UNFCCC website				
d UN population data				

The allocation option that leads to the least economic impact for the group of developed countries is the one that uses GHG intensity of the economy, but this is also the one that has the relatively most negative impact on the Commonwealth of Independent States reflecting the very high mitigation potential but relative low GDP (Table 7).

If one looks at the impact on welfare[31], US, Canada and Australia & New Zealand all would favour population trend as the preferred option to allocate targets, whereas the EU, Japan and Other OECD Europe would prefer the option based on the GHG intensity of the economy. Welfare in the Commonwealth of Independent States could even increase if targets were set only in accordance with the option using early action or GDP/capita. Europe would be faced with the highest economic impacts with the option using population trends as the sole indicator. USA, Japan and Other OECD Europe would incur highest welfare losses when using GDP/capita.

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[31] Note that in the GEM-E3 model the consumers optimise their welfare (which is a function of Private consumption and leisure), whereas firms maximize their profits. GDP as such is not optimised; it results from the interaction between firms, consumers, the public sector, and the external sector.

Relative impacts on GDP are very similar to the relative impact on overall welfare. Note that GDP decreases in the Commonwealth of Independent States, even when early action or GDP/capita is used as the indicator to establish the targets while economic welfare increases. The reason is that the Commonwealth of Independent States becomes a net seller in the carbon market, and uses the revenue rather for extra consumption than for investments that would increase GDP growth. For employment and private consumption similar relative differences can be noted.

Some of the single-indicator scenarios have large differences in emission targets across developed countries resulting in very large differences in the economic impact. Most notably, the indicators for GHG intensity in the economy or population trends lead to very ambitious targets for the Commonwealth of Independent States, and their respective impacts become unacceptably high. Similarly, GDP per capita leads to very high impacts for Other OECD Europe. The same is true to a lesser extent for Canada using the early action indicator.

Table 7: Results for 4 indicators and the related targets for developed countries

Change in 2020 compared to baseline				
Impact on economic welfare if targets are based on:				
	GDP/Cap	GHG/GDP	Early action	Population trends
EU27	-1.6%	-1.1%	-1.3%	-2.6%
USA	-1.2%	-0.5%	-1.0%	-0.3%
Japan	-1.0%	-0.1%	-0.9%	-0.9%
Canada	-2.2%	-1.6%	-3.1%	-0.8%
Australia & New Zealand	-1.8%	-1.7%	-2.6%	-0.7%
Other OECD Europe	-5.7%	-0.5%	-1.9%	-1.5%
Commonwealth of Independent States	1.2%	-8.5%	0.8%	-7.7%
Average Developed countries	-1.3%	-0.9%	-1.1%	-1.4%
Impact on GDP if targets are based on:				
	GDP/Cap	GHG/GDP	Early action	Population trends
EU27	-1.5%	-1.0%	-1.3%	-2.1%
USA	-1.2%	-0.5%	-1.0%	-0.5%
Japan	-1.0%	-0.2%	-0.9%	-0.9%
Canada	-2.0%	-1.5%	-2.7%	-0.9%
Australia & New Zealand	-2.0%	-1.8%	-2.8%	-1.0%
Other OECD Europe	-4.8%	-0.3%	-1.3%	-1.0%
Commonwealth of Independent States	-2.6%	-7.3%	-2.5%	-6.6%
Average Developed countries	-1.4%	-0.8%	-1.2%	-1.2%
Impact on employment if targets are based on:				
	GDP/Cap	GHG/GDP	Early action	Population trends
EU27	-0.4%	-0.4%	-0.4%	-0.7%
USA	-0.5%	-0.3%	-0.4%	-0.2%
Japan	-0.4%	-0.1%	-0.4%	-0.4%
Canada	-0.7%	-0.6%	-0.9%	-0.4%
Australia & New Zealand	-0.7%	-0.8%	-1.1%	-0.4%
Other OECD Europe	-1.8%	0.1%	-0.2%	-0.2%
Commonwealth of Independent States	-1.6%	-2.2%	-1.5%	-1.9%
Average Developed countries	-0.7%	-0.7%	-0.7%	-0.8%
Impact on private consumption if targets are based on:				
	GDP/Cap	GHG/GDP	Early action	Population trends
EU27	-2.1%	-1.4%	-1.8%	-3.3%
USA	-1.9%	-0.8%	-1.6%	-0.6%
Japan	-1.6%	-0.3%	-1.5%	-1.5%
Canada	-3.4%	-2.5%	-4.7%	-1.3%
Australia & New Zealand	-3.0%	-2.8%	-4.3%	-1.3%
Other OECD Europe	-8.3%	-0.6%	-2.5%	-2.1%
Commonwealth of Independent States	-0.2%	-12.5%	-0.7%	-11.2%
Average Developed countries	-2.1%	-1.2%	-1.8%	-1.8%

Source: JRC/IPTS, GEM-E3

6.3 Central scenario

Chapter 4 shows the mitigation targets for the central scenario. Table 8 reports on the economic impacts of the central scenario for each region.

For every country, impacts are between the extremes of impacts of the policy scenarios based on single indicators (see Table 7). Overall impacts for the group of developed countries are very close to the outcome when GHG intensity would have been used as an indicator.

Table 8: Economic Impacts resulting from the central scenario in 2020

Change compared to baseline	Target vs 2005	Economic Welfare	GDP	Employment	Private consumption
EU27	-24%	-1.4%	-1.2%	-0.4%	-1.8%
USA	-34%	-0.7%	-0.8%	-0.4%	-1.2%
Japan	-29%	-0.6%	-0.6%	-0.3%	-1.0%
Canada	-39%	-2.2%	-2.0%	-0.7%	-3.4%
Australia & New Zealand	-38%	-1.9%	-2.0%	-0.8%	-3.2%
Other OECD Europe	-30%	-1.5%	-1.0%	-0.1%	-2.0%
Commonwealth of Independent States	-12%	-1.4%	-3.0%	-1.5%	-3.4%
Average Developed Countries	-27%	-1.0%	-1.0%	-0.6%	-1.5%

Source: JRC/IPTS, GEM-E3

Impacts on welfare are highest for Canada and Australia & New Zealand who have also the highest targets compared to 2005. The Commonwealth of Independent States has also a relatively high impact, particularly for GDP, even with relatively low targets compared to the rest of the group. The Commonwealth of Independent States still has a relatively low GDP, so even low absolute costs have relatively higher impacts than in the richer countries. Importantly, in the countries where the economic impact looks relatively high compared to baseline in 2020, growth rates are also higher and thus impacts appear less significant when compared in terms of overall GDP growth over the period 2001- 2020 (Table 9).

The US and Japan face the lowest economic impacts (Table 8). For Japan this is partly due to the fact that it has a very low GHG intensity per GDP. So even if marginal costs are relatively high per ton of CO_2 reduced, total costs are small compared to GDP. The US has a similar GHG/GDP intensity as EU-27 in 2020. However, the domestic production and exports of energy intensive products is higher in the EU-27 than in the US.

Table 9: Impact on growth over the period 2001-2020

Growth in GDP over period 2001-2020		
	In Baseline	**In Target case**
EU27	38.9%	37.2%
USA	51.8%	50.6%
Japan	37.5%	36.6%
Canada	55.1%	52.0%
Australia & New Zealand	61.8%	58.5%
Other OECD Europe	38.1%	36.7%
Commonwealth of Independent States	99.7%	93.7%

Source: JRC/IPTS, GEM-E3

Concerning Canada, Australia & New Zealand, these countries face higher impacts because their GHG emissions/GDP and energy consumption/GDP shares are rather high compared to the rest of developed countries. Furthermore, domestic production and exports of energy intensive industrial products are higher in Canada, Australia & New Zealand leading to higher macro-economic costs.

7 The Role of the Global Carbon Market

The carbon market has a crucial role to play in order to implement the climate policies in a cost-efficient way. It is not only a market for a number of energy-intensive industries in the developed world, but it also links the climate policies in the developed and developing world. The offsetting mechanisms are limited to the sectors which are typically part of the EU ETS. In chapters 5 and 6, it was assumed that the global carbon market is imperfect as there are significant transaction costs in the transactions with developing countries. As a consequence the developing countries are unable to sell the full potential of their carbon credits given the carbon price.

This chapter analyses the sensitivity of the economic effects in the central case with respect to the degree of development of the global carbon market. Three cases are distinguished:

Case 1: Imperfect global carbon market

This is the standard approach as is used in chapters 5 and 6. GHG emissions in developed countries decrease by 20% compared to 1990 by 2020. The remaining 10% of their -30% target needs to be achieved through offsetting mechanisms in the global carbon market.

Case 2: No global carbon market

The developed countries reach the -30% target completely domestically.

Case 3: Perfect global carbon market

There is a global carbon market encompassing all sectors in both developed and developing world. This ensures that there is a single equalised carbon price (in all sectors and all countries), assuming there are no transaction costs[32].

7.1 Carbon market in POLES

The "Central scenario" with a gradually developing carbon market (see chapter 5) was analysed in order to assess the trade flows of the emissions credits. Economy-wide mid-term targets (QELROs) were allocated to developed countries, creating a demand for emission reduction credits from developing countries.

Table 10 shows the targets (2nd column), domestically realised emissions reductions (3rd column) and the carbon credit purchases (4th column) in the developed countries, as well as the domestically realised emission reductions (5th column) and carbon credit sales (6th column) in the developing countries for the central scenario with a gradually developing carbon market.

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[32] Note that in the baseline already a carbon price is included in the EU and other developed countries. It is assumed that this carbon price is not lowered, even if in a optimal global perfect carbon market prices would go below these carbon prices assumed already in baseline.

Table 10: **Reductions in developed and developing countries and trade in emissions rights**

	2020 target vs 1990 emissions	Achieved domestic reduction in 2020 vs 1990 emissions	Amount bought (+) or sold (-) in 2020 via the carbon market as a % of 1990 emissions	Reduction in 2020 vs baseline emissions	Amount sold via carbon market as % of baseline emissions
Developed countries	-31%	-22%	9%		
EU	-30%	-20%	10%		
USA	-24%	-9%	15%		
Japan	-24%	-6%	18%		
Russia	-38%	-46%	-8%		
Developing countries				-19%	-6%
China				-20%	-6%
Brazil				-20%	-6%
India				-13%	-4%

Source: JRC/IPTS, POLES

In the central scenario, developed countries would decrease their domestic emissions by 22% compared to 1990 and thus need to acquire an amount of emission credits which is equal to 9% of their 1990 emissions. Developing countries reduce their emissions compared to baseline by 19%, of which 6% can be sold through the carbon market[33]. This means that still 13% of reductions in developing countries would need to come from domestic measures. Around two third of this 13% can be achieved through measures at low carbon value or even negative costs ('win-win') in the short to mid term.

Carbon prices for the ETS-type of sectors in developed countries range from 72 €/tCO_2 in case of the need to achieve the 30% internally (no global carbon market) to 22 €/tCO_2 in the case of a perfect global carbon market, with 44.5 €/tCO_2 as a price level in case of the imperfect carbon market.

Table 11 gives an overview of direct mitigation costs of climate policy of the major economic regions and key countries for the three cases of carbon market. It is important to see that these total mitigation costs are different from the financial transfers due to trade flows in emission rights.

Columns (a) to (c) in Table 11 give the projected internal reduction cost experienced in 2020 while columns (d) to (f) give the cumulative costs over the period 2013 to 2020. Costs on a global scale are lowest for the option of the perfect carbon market. But also in the imperfect

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[33] 6% of 2020 baseline emissions of developing countries is equal to 8% of 1990 emissions in developed countries.

carbon market scenario, costs are substantially lower compared to the case where developed countries achieve all of the -30% domestically.

Table 11: Costs of the various carbon markets, POLES

	Total costs 2020 (Billion €, 2005 prices)			Total costs period 2013-2020 (Billion €, 2005 prices)		
	No global carbon market	Imperfect global carbon market	Perfect global carbon market	No global carbon market	Imperfect global carbon market	Perfect global carbon market
	(a)	(b)	(c)	(d)	(e)	(f)
World	213	152	113	996	666	500
Developed countries	166	81	39	755	374	179
Developing countries	48	71	75	241	292	321
EU	47	23	12	249	126	66
USA	68	34	16	318	157	72
Japan	15	7	3	60	30	13
Russia	17	7	3	51	22	12
China	18	30	30	86	109	121
Brazil	2	3	3	11	14	15
India	5	5	8	23	24	34

Source: JRC/IPTS, POLES

Table 11 clearly confirms that a gradually developing carbon market reduces global reduction costs substantially. But in order to estimate overall costs per region, both mitigation costs of reducing emissions from energy and non CO_2 in industry (see table above) and potential costs and revenues related to trade flows in the carbon market need to be taken into account.

Table 12 gives an overview of the costs incurred by different key countries. The first column represents the domestic reduction costs, while the second takes into account any additional costs from acquiring emissions credits on the carbon market or revenues from selling emission credits on the carbon market.

The transfers on the carbon market are € 51 billion in total, including trade between developed countries. Trade between developed and developing represents € 38 billion. Developed countries benefit substantially from this trade with developing countries. Even though the acquisition of the credits costs them € 38 billion, their mitigation costs diminishes by € 85 billion, from € 166 billion in case of no global trade to 81 € billion in case of global trade (see Table 11). This represents a net gain of € 47 billion.

Table 12: Costs in developed and developing countries and trade in emissions rights

	Average annual cost of reductions in CO_2 from energy and Non CO_2 emissions from industry in 2020 (Total costs in Billion € (2005 prices)	
	Not taking into account revenues or expenditure for carbon trade in 2020	Taking into account revenues or expenditure for carbon trade in 2020
World	152	152
Developed countries	81	119
Developing countries	71	33
EU	23	37
USA	34	57
Japan	7	13
Russia	7	-3
China	30	12
Brazil	3	2
India	5	4

Source: JRC/IPTS, POLES

In the scenario with no global market at all, it was assumed that developed countries reach their -30% target and developing countries would also undertake appropriate own actions that would see global emissions in line with a 2°C scenario[34]. The cost of this appropriate action is equal to € 48 billion in developing countries (Table 11). The gradual introduction of a carbon market in developing countries is assumed to pay only for offsetting for those credits that are generated for emissions beyond the appropriate action. The price paid is assumed to be equal to the highest experienced marginal abatement cost within the developing country's region that is selling credits, which is still below the carbon price in developed countries.

These offsetting mechanisms lead to further emission reductions in developing countries, consequently increasing the costs in developing countries from € 48 billion to € 71 billion. But for this cost increase of € 23 billion, developing countries receive revenues worth € 38 billion. In this way, emissions trading create a significant rent of € 15 billion over and above the emission reduction costs. This rent can be used to pay also partly for the costs of the appropriate own action which is estimated to amount to € 48 billion. Subtracting the rent only around € 33 billion will have to be paid for by developing countries themselves or through other additional support mechanisms.

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[34] Assuming that action on REDD and agriculture is also undertaken as described in European Commission (2009b), leading to a deviation from baseline in total between 15 and 30%.

This is a very important positive consequence of a well designed gradual carbon market. Future offsetting mechanisms should ensure that it only compensates for those reductions that are not 'low or negative' cost. In addition, it needs to go well beyond mere crediting of offsets compared to baseline, ensuring that the mechanism recycles rents from the trade in order to compensate for those emission reductions that do not generate credits.

7.2 Carbon market in GEM-E3

The GEM E3 model has been also run to assesses the macro-economic costs of climate policy according to the different degrees of development of the global carbon market. The target used for developed countries and developing countries correspond to those of the "central case".

Table 13 shows clearly for the three cases the role of a carbon market for welfare and GDP. As expected, global welfare losses are lower for the case of perfect market than the no-global trade case. This result applies also on a country-by-country basis: welfare is always higher with a perfect global carbon market than in the no global carbon market case. The gradually developing carbon market has an intermediate outcome.

For the GDP, however, the outcome is mixed. In general, the world GDP is better off with a perfect global carbon market, but this result does not apply on a country-by-country basis. Indeed, with a perfect global carbon market the GDP of the developed countries is the highest, whereas the developing countries have a higher GDP with no global carbon market. The main reason for this is related to the capital formation process. Due to the transfer of credits, consumers in developing countries receive a higher income which they decide to spend more-than-proportionally on consumption and leisure, and less-than-proportionally on capital investments. This maximizes welfare, but does not promote GDP growth. As a consequence, one expects that in these countries GDP would drop more than welfare. The opposite interpretation can be made for developed countries, where, in relative terms, welfare drops more than GDP. In this case, a consumption and leisure reduction is required to carry out substantial investments in energy-intensive sectors and to finance the purchase of emission permits in international markets: therefore consumption (and welfare) drops more than investment (and GDP), and this effect is more pronounced the more perfect international carbon markets are.

Table 13: Welfare and GDP effects of the various carbon markets, GEM E3

	Welfare compared to baseline			GDP compared to baseline		
2020	Perfect market	Imperfect market	No global market	Perfect market	Imperfect market	No global market
EU27	-0.7%	-1.4%	-1.4%	-0.4%	-1.2%	-1.5%
USA	-0.5%	-0.7%	-0.7%	-0.4%	-0.8%	-1.0%
Japan	-0.3%	-0.6%	-0.6%	-0.3%	-0.6%	-0.7%
CIS	-1.3%	-1.4%	-1.7%	-2.7%	-3.0%	-2.1%
China	0.5%	0.3%	-0.2%	-1.4%	-0.8%	-0.5%
Brazil	0.0%	-0.1%	-0.2%	-0.5%	-0.4%	-0.2%
India	0.1%	-0.2%	-0.4%	-1.4%	-0.5%	-0.5%
World	-0.3%	-0.7%	-0.8%	-0.5%	-0.9%	-1.0%

	GHG Emissions compared to baseline			GHG Emissions compared to 1990		
2020	Perfect market	Imperfect market	No market	Perfect market	Imperfect market	No market
EU27	-6.3%	-20.9%	-25.3%	-8.5%	-22.8%	-27.1%
USA	-20.9%	-31.6%	-37.7%	-1.0%	-14.3%	-22.0%
Japan	-14.8%	-23.9%	-31.0%	-7.4%	-17.3%	-25.0%
CIS	-24.9%	-26.1%	-20.4%	-46.7%	-47.5%	-43.5%
China	-32.9%	-20.8%	-16.2%	70.3%	100.9%	112.6%
Brazil	-18.8%	-12.3%	-9.3%	80.7%	95.2%	102.0%
India	-23.5%	-10.7%	-7.8%	143.1%	183.6%	192.9%
World	-21.4%	-21.4%	-21.4%	18.3%	18.3%	18.3%

Source: JRC/IPTS, GEM-E3

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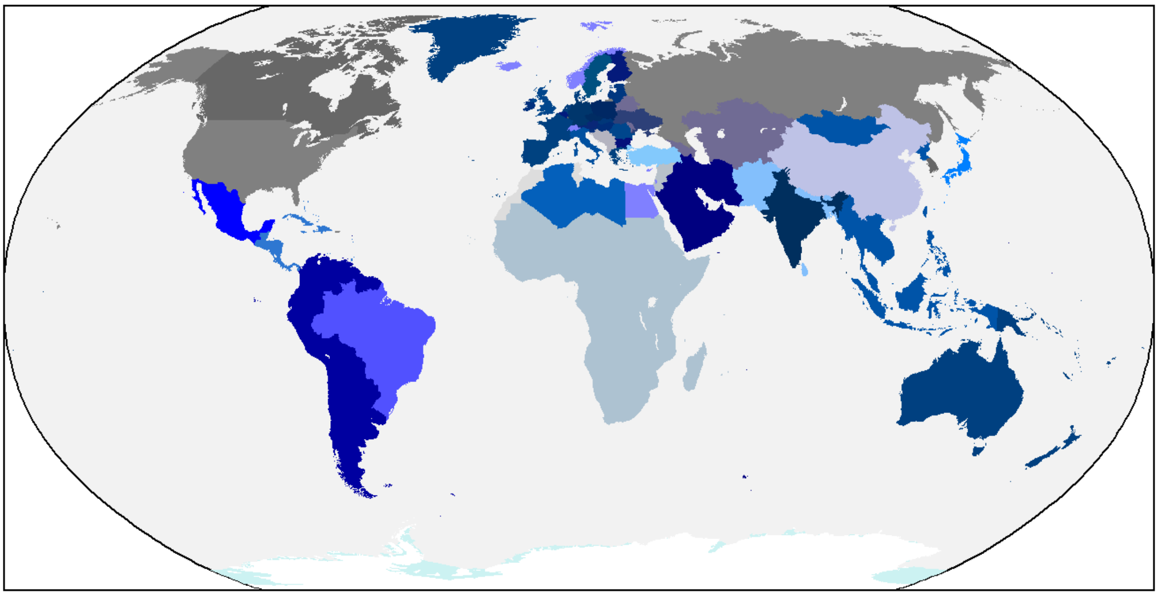
Annexes

POLES regions

	47 countries / regions	
NOAM		North America
	USA	United States
	CAN	Canada
CSAM		Central and South America
	MEX	Mexico
	RCAM	Rest of Central America
	BRA	Brazil
	RSAM	Rest of South America
WEUR		Western Europe
	RFA	Germany
	FRA	France
	ITA	Italy
	GBR	Great Britain
	ESP	Spain
	GRC	Greece
	PRT	Portugal
	AUT	Austria
	BLX	Belgium+ Luxembourg
	DNK	Denmark
	FIN	Finland
	IRL	Ireland
	NDL	the Netherlands
	SWE	Sweden
	TUR	Turkey
	ROWE	Other Western Europe
CEUR		Central Europe
	POL	Poland
	HUN,	Hungary
	RCZ	Czech Republic
	RSL	Slovak Republic
	ROM	Romania
	BGR	Bulgaria
	SMC	Slovenia, Malta, Cyprus

	BLT	Baltic Region
	RCEU	Rest of Central Europe
FSUN		Former Soviet Union
	RUS	Russia
	UKR	Ukraine
	RIS	Rest of former Soviet Union
MEMA		North Africa - Middle East
	NOAP	Algeria, Libya
	NOAN	Morocco, Tunisia
	EGY	Egypt
	MEME	Near East
	GULF	Middle East
SSAF	SSAF	South of Sahara Africa
SOAS		South Asia
	NDE	India
	RSAS	Rest of South Asia
SEAS		South East Asia
	COR	Korea
	RSEA	Rest of South East Asia
COAS		Continental Asia
	CHN	China
JANZ		Japan – Australasia
	JPN	Japan
	RJAN	Australasia

Figure 13: POLES regions



Baseline Scenario - European Union EU27

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	10297.0	11282.8	14018.3	16442.7	18694.7	21198.8
Population (Mcap)	490.8	495.6	498.8	496.5	489.9	479.9
GDP per capita (€/cap)	20978.7	22764.9	28102.6	33114.7	38162.6	44176.2
Gross inland consumption per capita (toe/cap)	3707.6	3850.3	4252.2	4624.0	5057.0	5517.3
Gross inland consumption/GDP (toe/€)	176.7	169.1	151.3	139.6	132.5	124.9
CO_2/Gross inland consumption (tCO_2/toe)	2319.2	2263.9	2118.1	1938.9	1809.1	1645.2
Gross inland consumption						
Natural gas (Mtoe)	443.0	431.6	582.0	616.7	655.8	662.7
Oil (Mtoe)	669.1	669.6	692.8	670.7	641.2	604.5
Coal (Mtoe)	323.2	364.1	324.1	343.6	395.7	435.8
Nuclear (Mtoe)	259.7	255.7	254.4	313.9	353.0	432.2
Other (Mtoe)	124.7	187.3	267.8	351.1	431.5	512.4
Total	1819.8	1908.3	2121.1	2296.0	2477.3	2647.6
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	126.9	140.0	238.3	256.3	282.5	288.7
Oil (Mtoe)	33.8	26.8	15.1	10.5	10.2	9.2
Coal (Mtoe)	238.6	262.8	245.4	270.9	321.8	357.8
Nuclear (Mtoe)	259.7	255.7	254.4	313.9	353.0	432.2
Others (Biomass) (Mtoe)	28.5	28.5	58.7	75.1	84.8	93.7
Total	687.5	713.7	812.0	926.7	1052.3	1181.6
Net generation capacities						
Natural gas (GW)	154.3	180.0	263.7	317.9	341.4	344.2
Oil (GW)	58.4	51.7	38.1	26.9	19.2	14.0
Coal (GW)	184.7	190.1	195.3	231.9	261.8	291.0
Nuclear (GW)	137.6	134.4	136.9	169.2	189.0	228.7
Hydro (GW)	131.7	133.1	135.4	137.1	138.1	138.9
Renewables (GW)	196.1	224.6	305.1	402.6	502.6	630.7
Total	862.8	913.9	1074.5	1285.6	1452.1	1647.5
Net electricity generation						
Natural gas (TWh)	646.2	662.6	1225.4	1317.4	1400.2	1337.6
Oil (TWh)	144.0	109.3	62.8	44.5	43.3	39.8
Coal (TWh)	966.3	1010.7	1073.9	1304.7	1604.8	1842.9
Nuclear (TWh)	996.8	981.3	976.2	1204.6	1354.8	1658.7
Hydro (TWh)	302.0	450.8	460.2	464.3	465.7	466.6
Renewables (TWh)	499.3	693.5	966.2	1235.4	1490.5	1794.9
Total	3554.6	3908.2	4764.7	5570.9	6359.3	7140.5
Final Energy Demand						
Demand of fuel by sectors						
Industry	449.3	456.7	513.2	554.4	609.0	657.6
Commercial and households	456.5	426.2	472.1	505.1	531.4	556.9
Transport	387.1	403.4	447.4	458.7	460.1	458.1
Agriculture	29.6	30.8	35.3	39.9	43.8	47.8
Total final energy demand						
Electricity (Mtoe)	237.1	268.0	338.1	406.1	474.5	546.5
Heat (Mtoe)	48.7	39.9	44.2	49.3	54.0	56.7
Natural gas (Mtoe)	292.3	275.2	317.1	330.5	340.5	340.1
Oil (Mtoe)	619.3	599.0	632.2	615.8	588.2	554.6
Coal (Mtoe)	68.5	73.1	56.7	50.7	49.0	49.7
Biomass (Mtoe)	56.3	61.1	77.9	101.9	132.3	165.5
Other (Mtoe)	0.2	0.8	1.9	3.8	5.7	7.3
Total	1322.4	1317.1	1468.0	1558.0	1644.2	1720.4
Emissions						
CO_2 Total (Mt CO_2)	4220.5	4320.2	4492.8	4451.8	4481.6	4355.9
CO_2 Power Sector	1384.2	1464.8	1567.5	1622.7	1761.0	1775.0
CO_2 other conversion + process emissions	405.2	541.7	568.1	577.2	592.3	601.8
CO_2 industry	690.5	692.0	706.1	716.6	753.5	773.5
CO_2 transport	996.9	984.1	1009.6	904.0	757.7	601.6
CO_2 residential, services	743.7	637.6	641.5	631.3	617.1	604.0
GHG Total (Mt CO_2eq)	4636.0	4719.0	4892.3	4881.9	4948.3	4865.5
GHG Power Sector	1289.0	1391.6	1505.7	1560.4	1697.7	1710.6
GHG other conversion + process emissions	358.5	431.3	414.4	419.5	436.9	449.7
GHG industry	1061.6	1088.1	1139.7	1188.1	1264.5	1329.8
GHG transport	1017.9	1006.9	1033.9	926.7	777.9	619.0
GHG residential, services	909.0	801.1	798.6	787.2	771.3	756.4

Mitigation Scenario - European Union EU27

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	10297.0	11282.8	14018.3	16442.7	18694.7	21198.8
Population (Mcap)	490.8	495.6	498.8	496.5	489.9	479.9
GDP per capita (€/cap)	20978.7	22764.9	28102.6	33114.7	38162.6	44176.2
Gross inland consumption per capita (toe/cap)	3707.6	3764.9	3915.8	3909.8	3937.7	3986.9
Gross inland consumption/GDP (toe/€)	176.7	165.4	139.3	118.1	103.2	90.2
CO_2/Gross inland consumption (tCO_2/toe)	2319.2	2213.4	1889.1	1614.3	1218.8	756.0
Gross inland consumption						
Natural gas (Mtoe)	443.0	436.7	550.3	552.4	501.0	368.9
Oil (Mtoe)	669.1	649.9	584.9	492.1	377.4	253.3
Coal (Mtoe)	323.2	328.2	224.6	195.8	160.1	117.1
Nuclear (Mtoe)	259.7	259.3	262.4	344.7	433.5	573.6
Other (Mtoe)	124.7	191.9	331.2	356.3	457.0	600.3
Total	1819.8	1866.0	1953.3	1941.3	1928.9	1913.2
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	126.9	145.5	227.2	252.0	247.6	205.1
Oil (Mtoe)	33.8	28.7	15.7	10.0	6.8	4.1
Coal (Mtoe)	238.5	234.7	164.1	147.8	130.3	102.6
Nuclear (Mtoe)	259.7	259.3	262.4	344.7	433.5	573.6
Others (Biomass) (Mtoe)	28.5	30.1	94.6	81.9	91.8	125.3
Total	687.4	698.3	763.9	836.4	910.0	1010.7
Net generation capacities						
Natural gas (GW)	154.4	180.6	243.0	287.2	280.9	240.4
Oil (GW)	58.4	51.7	38.2	27.0	19.2	13.6
Coal (GW)	184.7	182.5	163.6	156.6	121.3	91.6
Nuclear (GW)	137.6	136.4	141.2	185.6	231.8	302.8
Hydro (GW)	131.7	133.2	135.8	137.6	138.8	139.5
Renewables (GW)	196.1	229.1	326.0	421.5	549.2	720.5
Total	862.9	913.5	1047.8	1215.5	1341.2	1508.4
Net electricity generation						
Natural gas (TWh)	646.2	688.2	1156.0	1288.6	1223.4	974.8
Oil (TWh)	144.0	117.2	64.6	41.9	28.9	17.5
Coal (TWh)	966.2	907.9	719.6	695.5	621.8	497.4
Nuclear (TWh)	996.8	995.1	1006.9	1323.0	1663.6	2201.3
Hydro (TWh)	302.0	451.4	461.1	466.1	468.3	468.8
Renewables (TWh)	499.3	707.2	1120.2	1297.6	1624.0	2108.9
Total	3554.5	3867.0	4528.4	5112.7	5630.0	6268.7
Final Energy Demand						
Demand of fuel by sectors						
Industry	449.3	445.8	475.4	490.8	490.4	477.1
Commercial and households	456.5	424.5	447.7	434.9	417.1	395.0
Transport	387.1	387.5	372.4	320.7	273.2	224.8
Agriculture	29.6	30.7	34.9	38.7	41.5	44.1
Total final energy demand						
Electricity (Mtoe)	237.1	265.0	321.0	371.6	420.7	479.0
Heat (Mtoe)	48.7	39.9	44.2	49.3	54.0	56.7
Natural gas (Mtoe)	292.3	274.0	297.9	274.2	229.0	145.4
Oil (Mtoe)	619.3	578.7	530.7	449.5	345.3	232.2
Coal (Mtoe)	68.5	67.8	44.6	35.0	20.3	8.3
Biomass (Mtoe)	56.3	62.2	90.6	103.1	149.5	214.3
Other (Mtoe)	0.2	0.7	1.3	2.4	3.4	5.1
Total	1322.4	1288.5	1330.4	1285.1	1222.2	1141.0
Emissions						
CO_2 Total (Mt CO_2)	4220.5	4130.2	3690.0	3133.9	2350.9	1446.3
CO_2 Power Sector	1384.1	1367.8	1186.2	953.8	632.1	303.9
CO_2 other conversion + process emissions	405.4	528.4	517.1	492.9	442.4	353.3
CO_2 industry	690.5	664.0	633.0	597.9	487.6	311.6
CO_2 transport	996.8	932.6	749.3	600.8	424.5	252.7
CO_2 residential, services	743.7	637.4	604.4	488.5	364.3	224.8
GHG Total (Mt CO_2eq)	4631.1	4512.6	3986.8	3405.1	2548.2	1563.0
GHG Power Sector	1293.8	1296.3	1128.0	900.8	584.8	262.9
GHG other conversion + process emissions	348.8	415.6	359.0	323.8	275.5	207.8
GHG industry	1061.6	1049.3	1042.7	1005.9	839.6	566.8
GHG transport	1017.9	954.6	768.5	615.6	434.6	258.5
GHG residential, services	909.0	796.8	688.6	559.0	413.7	267.0

Baseline Scenario - World*

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	49182.8	60161.6	86839.8	116369.0	149364.0	187318.0
Population (Mcap)	6514.8	6906.5	7667.1	8317.7	8823.5	9191.3
GDP per capita (€/cap)	7549.5	8710.8	11326.3	13990.5	16927.9	20379.9
Gross inland consumption per capita (toe/cap)	1729.0	1793.2	2021.0	2237.2	2455.9	2677.7
Gross inland consumption/GDP (toe/€)	229.0	205.9	178.4	159.9	145.1	131.4
CO_2/Gross inland consumption (tCO_2/toe)	2502.1	2533.3	2482.2	2381.8	2276.6	2133.0
Gross consumption						
Natural gas (Mtoe)	2370.4	2346.6	3140.8	3488.0	3836.5	4111.1
Oil (Mtoe)	4193.1	4158.4	4869.7	5245.1	5463.4	5477.9
Coal (Mtoe)	2915.9	3781.7	4741.8	6016.2	7187.9	8060.9
Nuclear (Mtoe)	719.7	792.5	1008.1	1472.1	2081.2	2971.1
Other (Mtoe)	1411.2	1710.9	2295.8	3143.6	4020.8	5040.8
Total	11610.2	12790.0	16056.1	19365.0	22589.7	25661.9
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	815.7	808.5	1146.0	1250.8	1369.6	1475.0
Oil (Mtoe)	287.6	282.1	160.2	146.8	160.5	177.1
Coal (Mtoe)	1903.9	2410.3	3112.3	4090.9	5095.3	5899.7
Nuclear (Mtoe)	719.7	792.5	1008.1	1472.1	2081.2	2971.1
Others (Biomass) (Mtoe)	72.7	108.7	274.9	482.2	666.1	870.2
Total	3799.6	4402.1	5701.4	7442.8	9372.7	11393.2
Net generation capacities						
Natural gas (GW)	933.1	1005.6	1390.7	1792.3	2091.7	2289.0
Oil (GW)	462.0	467.5	373.7	280.9	241.6	230.9
Coal (GW)	1324.4	1769.8	2492.9	3467.4	4348.3	5125.0
Nuclear (GW)	381.5	408.7	536.1	794.0	1119.9	1586.6
Hydro (GW)	805.4	885.0	1008.6	1088.6	1158.0	1213.5
Renewables (GW)	956.1	1135.4	1635.4	2269.6	3006.8	4009.3
Total	4862.5	5672.0	7437.4	9692.8	11966.3	14454.3
Net electricity generation						
Natural gas (TWh)	3579.9	3571.6	5736.5	6524.7	7002.3	7163.0
Oil (TWh)	1165.3	1173.9	683.9	630.6	693.8	777.7
Coal (TWh)	7087.0	9421.7	13829.7	19868.6	25571.5	30290.4
Nuclear (TWh)	2762.0	3041.5	3868.8	5649.9	7987.6	11402.8
Hydro (TWh)	2712.5	3138.5	3581.2	3869.2	4118.4	4318.8
Renewables (TWh)	3144.3	3922.8	5749.0	8023.0	10577.4	13941.2
Total	20451.0	24270.0	33449.1	44566.0	55951.0	67893.9
Final Energy Demand						
Demand of fuel by sectors						
Industry	2951.0	3247.4	4129.8	4746.5	5145.8	5284.4
Commercial and households	2717.6	2746.7	3362.6	3989.5	4575.3	5188.7
Transport	2321.2	2484.6	3117.8	3635.3	4133.9	4642.3
Agriculture	180.6	202.5	266.4	341.0	415.2	495.6
Total final energy demand						
Electricity (Mtoe)	1285.7	1537.5	2158.4	2935.4	3749.0	4628.2
Heat (Mtoe)	247.7	239.5	254.4	272.5	288.5	295.7
Natural gas (Mtoe)	1152.8	1146.3	1459.8	1630.3	1778.5	1889.3
Oil (Mtoe)	3622.1	3673.7	4472.9	4916.0	5174.4	5225.9
Coal (Mtoe)	815.7	998.6	1225.4	1341.7	1345.9	1268.5
Biomass (Mtoe)	1045.6	1081.2	1295.0	1586.7	1878.8	2216.8
Other (Mtoe)	0.9	4.4	10.8	29.7	55.2	86.6
Total	8170.4	8681.1	10876.6	12712.3	14270.2	15611.0
Emissions						
CO_2 Total (Mt CO_2)	29243.5	32613.7	40176.5	46632.3	52141.4	55697.4
CO_2 Power Sector	10246.4	12175.8	15274.6	19185.4	23278.2	26563.0
CO_2 other conversion + process emissions	3927.7	4628.8	5594.0	6456.8	7182.7	7719.8
CO_2 industry	5155.2	5836.6	7232.0	7928.7	8186.2	7951.6
CO_2 transport	6645.1	6917.3	8317.9	8754.4	8797.7	8482.7
CO_2 residential, services	3269.1	3055.2	3758.0	4307.0	4696.6	4980.3
GHG Total (Mt CO_2eq)	33305.3	37126.2	45480.8	52852.5	59178.6	63433.0
GHG Power Sector	8476.7	10211.7	13111.0	16763.1	20660.7	23801.4
GHG other conversion + process emissions	6097.4	6883.5	7813.7	8987.2	10009.1	10811.2
GHG industry	7005.9	8054.2	10006.6	11074.9	11589.3	11529.9
GHG transport	6721.3	6994.6	8403.3	8835.2	8869.9	8544.5
GHG residential, services	5004.0	4982.2	6146.2	7192.1	8049.6	8746.0

*Including international bunkers

Mitigation Scenario - World*

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	49182.8	60161.6	86839.8	116369.0	149364.0	187318.0
Population (Mcap)	6514.8	6906.5	7667.1	8317.7	8823.5	9191.3
GDP per capita (€/cap)	7549.5	8710.8	11326.3	13990.5	16927.9	20379.9
Gross inland consumption per capita (toe/cap)	1729.0	1750.9	1803.2	1768.9	1802.4	1832.0
Gross inland consumption/GDP (toe/€)	229.0	201.0	159.2	126.4	106.5	89.9
CO_2/Gross inland consumption (tCO_2/toe)	2502.1	2517.9	2255.3	1783.6	1238.6	664.9
Gross consumption						
Natural gas (Mtoe)	2370.4	2312.5	2970.3	2992.2	2718.8	1951.4
Oil (Mtoe)	4193.1	4012.8	4432.9	4483.9	4124.8	3287.5
Coal (Mtoe)	2915.9	3675.7	3341.0	2613.1	2166.5	1678.2
Nuclear (Mtoe)	719.7	801.3	1299.2	2193.3	3371.9	4796.5
Other (Mtoe)	1411.1	1695.2	2338.3	3154.5	4374.4	6056.5
Total	11610.1	12497.4	14381.6	15436.9	16756.3	17770.1
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	815.7	800.6	1143.3	1176.4	1095.3	848.2
Oil (Mtoe)	287.6	278.0	191.5	145.2	103.0	49.8
Coal (Mtoe)	1903.9	2323.9	2055.5	1694.9	1562.3	1352.4
Nuclear (Mtoe)	719.7	801.3	1299.2	2193.3	3371.9	4796.5
Others (Biomass) (Mtoe)	72.7	111.8	386.2	650.4	943.6	1409.4
Total	3799.6	4315.5	5075.6	5860.2	7076.2	8456.3
Net generation capacities						
Natural gas (GW)	933.1	1004.5	1269.5	1416.7	1450.4	1370.1
Oil (GW)	462.0	467.3	381.1	275.7	208.5	160.3
Coal (GW)	1324.4	1723.4	2010.9	1918.0	1607.9	1482.4
Nuclear (GW)	381.5	413.3	690.4	1185.0	1821.0	2573.0
Hydro (GW)	805.4	884.7	1020.4	1119.0	1190.4	1235.9
Renewables (GW)	956.1	1145.7	1851.0	2750.7	3749.5	5186.8
Total	4862.5	5638.9	7223.3	8665.1	10027.7	12008.5
Net electricity generation						
Natural gas (TWh)	3579.9	3528.0	5610.0	5941.8	5397.0	4080.4
Oil (TWh)	1165.3	1156.2	813.9	617.6	438.9	213.4
Coal (TWh)	7087.0	9099.4	9125.9	8027.0	7484.8	6639.7
Nuclear (TWh)	2762.0	3075.3	4986.0	8417.6	12941.0	18408.3
Hydro (TWh)	2712.4	3137.2	3622.8	3975.8	4232.3	4397.8
Renewables (TWh)	3144.2	3952.5	6613.8	9787.5	13359.0	18491.0
Total	20450.8	23948.6	30772.4	36767.3	43853.0	52230.6
Final Energy Demand						
Demand of fuel by sectors						
Industry	2950.7	3204.6	3693.9	3488.9	3361.7	3127.6
Commercial and households	2717.2	2704.8	3137.6	3424.5	3547.0	3488.5
Transport	2319.5	2374.1	2731.6	3019.1	3241.7	3407.8
Agriculture	180.6	199.8	252.2	307.2	361.7	413.0
Total final energy demand						
Electricity (Mtoe)	1285.5	1515.8	1967.4	2377.6	2894.3	3525.7
Heat (Mtoe)	247.7	239.5	254.4	272.5	288.5	295.7
Natural gas (Mtoe)	1152.6	1128.9	1338.0	1322.6	1159.2	758.0
Oil (Mtoe)	3620.3	3542.2	4004.3	4118.7	3845.2	3122.0
Coal (Mtoe)	815.7	987.8	1013.9	680.3	404.8	181.5
Biomass (Mtoe)	1045.5	1065.3	1230.7	1452.3	1883.1	2466.6
Other (Mtoe)	0.9	3.8	6.7	15.7	37.0	87.5
Total	8168.1	8483.3	9815.3	10239.7	10512.2	10436.9
Emissions						
CO_2 Total (Mt CO_2)	29243.5	31686.3	32880.7	28455.8	22303.1	14040.9
CO_2 Power Sector	10246.2	11802.4	11123.8	7985.9	4591.3	1211.6
CO_2 other conversion + process emissions	3934.0	4540.2	4839.3	4684.4	4316.9	3421.6
CO_2 industry	5154.8	5762.9	6195.9	4793.3	3618.9	2257.3
CO_2 transport	6639.9	6584.1	7228.5	7380.4	6793.3	5379.8
CO_2 residential, services	3268.6	2996.7	3493.2	3611.8	2982.7	1770.6
GHG Total (Mt CO_2eq)	33299.8	36152.2	36611.8	31501.5	24462.4	15631.1
GHG Power Sector	8481.4	9859.5	9981.8	6983.2	3728.5	579.5
GHG other conversion + process emissions	6093.8	6753.4	5043.1	4458.1	3832.7	2737.3
GHG industry	7004.9	7969.2	8690.5	7385.2	6043.3	4253.7
GHG transport	6716.2	6656.3	7299.0	7440.7	6840.0	5410.1
GHG residential, services	5003.5	4913.8	5597.4	5234.3	4017.9	2650.5

*Including international bunkers

Baseline Scenario - Developed countries

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	27232.5	30255.4	39037.5	47890.9	56775.2	65806.5
Population (Mcap)	1187.6	1205.6	1229.4	1239.3	1238.3	1229.7
GDP per capita (€/cap)	22930.5	25095.9	31753.3	38645.1	45847.5	53513.0
Gross inland consumption per capita (toe/cap)	0.0	0.0	0.0	0.0	0.0	0.0
Gross inland consumption/GDP (toe/€)	218.3	197.5	171.6	152.4	138.9	127.1
CO_2/Gross inland consumption (tCO_2/toe)	2462.4	2441.3	2333.3	2183.6	2037.1	1866.1
Gross inland consumption						
Natural gas (Mtoe)	1555.3	1411.1	1746.2	1757.6	1754.2	1677.0
Oil (Mtoe)	2197.4	1998.8	2131.6	2055.6	1920.0	1738.1
Coal (Mtoe)	1211.5	1435.3	1452.3	1657.5	1886.6	2047.6
Nuclear (Mtoe)	638.3	637.8	661.1	798.5	986.5	1263.6
Other (Mtoe)	341.9	491.9	709.4	1028.2	1336.5	1639.6
Total	5944.5	5975.0	6700.6	7297.4	7883.8	8365.8
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	497.2	455.1	627.7	611.6	605.5	568.5
Oil (Mtoe)	105.6	53.1	30.2	27.3	29.2	26.5
Coal (Mtoe)	885.7	1059.3	1101.7	1244.4	1421.6	1531.1
Nuclear (Mtoe)	638.3	637.8	661.1	798.5	986.5	1263.6
Others (Biomass) (Mtoe)	60.8	71.3	156.6	243.5	291.3	321.3
Total	2187.6	2276.5	2577.3	2925.2	3334.1	3711.0
Net generation capacities						
Natural gas (GW)	675.4	696.3	829.4	896.2	917.8	901.3
Oil (GW)	260.2	223.1	159.9	113.2	81.0	58.7
Coal (GW)	733.1	766.3	819.7	1001.7	1152.3	1274.4
Nuclear (GW)	336.9	328.7	351.5	430.0	529.0	671.5
Hydro (GW)	443.7	450.7	463.5	474.5	482.4	486.9
Renewables (GW)	546.5	611.2	818.5	1097.2	1372.3	1716.3
Total	2995.8	3076.3	3442.5	4012.8	4534.8	5109.1
Net electricity generation						
Natural gas (TWh)	2227.0	2002.0	3091.6	3037.4	2888.2	2504.9
Oil (TWh)	417.6	229.1	131.4	119.0	127.1	115.9
Coal (TWh)	3577.1	4359.4	4951.1	6061.5	7226.1	8034.1
Nuclear (TWh)	2449.9	2447.9	2537.3	3064.5	3786.0	4849.5
Hydro (TWh)	1432.8	1593.3	1642.8	1683.2	1710.5	1725.3
Renewables (TWh)	1787.6	2080.4	2831.0	3760.2	4579.7	5469.0
Total	11892.0	12712.1	15185.2	17725.8	20317.6	22698.7
Final Energy Demand						
Demand of fuel by sectors						
Industry	1407.9	1369.8	1532.2	1648.8	1771.9	1855.9
Commercial and households	1334.7	1254.2	1418.0	1531.5	1611.6	1682.8
Transport	1277.4	1286.3	1453.5	1510.7	1533.9	1541.6
Agriculture	73.9	77.0	91.4	107.4	123.7	140.4
Total final energy demand						
Electricity (Mtoe)	785.8	850.2	1041.5	1245.1	1458.1	1666.7
Heat (Mtoe)	199.0	183.5	188.5	194.4	199.1	200.1
Natural gas (Mtoe)	816.9	747.2	864.2	890.6	889.6	863.0
Oil (Mtoe)	1953.9	1849.0	1995.1	1959.7	1855.8	1704.7
Coal (Mtoe)	210.2	231.3	227.7	227.9	227.3	230.8
Biomass (Mtoe)	127.7	123.3	172.3	265.7	385.6	519.6
Other (Mtoe)	0.5	2.7	5.8	14.9	25.5	35.8
Total	4093.9	3987.2	4495.1	4798.3	5041.0	5220.6
Emissions						
CO_2 Total (Mt CO_2)	14637.5	14586.9	15634.5	15934.6	16060.3	15611.2
CO_2 Power Sector	4992.4	5393.1	5858.2	6286.4	6843.0	7033.0
CO_2 other conversion + process emissions	2032.3	1975.9	2062.7	2173.6	2249.7	2263.4
CO_2 industry	2070.8	2053.1	2176.7	2229.4	2301.3	2323.3
CO_2 transport	3599.8	3507.9	3776.0	3473.2	2936.4	2311.9
CO_2 residential, services	1942.2	1656.9	1760.9	1772.0	1729.9	1679.6
GHG Total (Mt CO_2eq)	16199.7	16147.5	17111.9	17482.9	17722.1	17379.3
GHG Power Sector	4333.8	4760.5	5359.5	5815.5	6359.5	6543.4
GHG other conversion + process emissions	2762.6	2618.8	2384.5	2414.7	2506.1	2534.3
GHG industry	3032.2	3076.1	3307.0	3491.7	3688.3	3823.0
GHG transport	3669.4	3577.6	3851.5	3543.1	2996.8	2361.3
GHG residential, services	2401.7	2114.5	2209.4	2217.9	2171.4	2117.3

Mitigation Scenario - Developed countries

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	27232.5	30255.4	39037.5	47890.9	56775.2	65806.5
Population (Mcap)	1187.6	1205.6	1229.4	1239.3	1238.3	1229.7
GDP per capita (€/cap)	22930.5	25095.9	31753.3	38645.1	45847.5	53513.0
Gross inland consumption per capita (toe/cap)	0.0	0.0	0.0	0.0	0.0	0.0
Gross inland consumption/GDP (toe/€)	218.3	193.7	156.4	128.5	108.8	92.8
CO_2/Gross inland consumption (tCO_2/toe)	2462.3	2412.8	2032.1	1654.2	1194.3	707.1
Gross inland consumption						
Natural gas (Mtoe)	1555.3	1421.9	1709.9	1584.6	1345.6	920.4
Oil (Mtoe)	2197.4	1913.1	1883.1	1654.2	1344.5	969.8
Coal (Mtoe)	1211.5	1382.9	866.7	704.6	535.2	377.1
Nuclear (Mtoe)	638.3	645.8	828.2	1098.4	1449.4	1874.8
Other (Mtoe)	341.9	497.1	818.9	1110.8	1501.9	1964.5
Total	5944.5	5860.8	6106.8	6152.6	6176.8	6106.6
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	497.2	466.0	645.1	609.6	542.6	413.5
Oil (Mtoe)	105.6	55.1	41.8	29.7	21.7	10.9
Coal (Mtoe)	885.6	1015.9	634.5	509.1	408.3	312.8
Nuclear (Mtoe)	638.3	645.8	828.2	1098.4	1449.4	1874.8
Others (Biomass) (Mtoe)	60.8	74.9	237.4	314.4	366.3	422.0
Total	2187.6	2257.7	2387.1	2561.2	2788.3	3034.0
Net generation capacities						
Natural gas (GW)	675.4	698.9	789.8	800.1	747.2	635.2
Oil (GW)	260.2	224.1	161.5	114.2	81.5	58.2
Coal (GW)	733.1	741.9	661.2	598.3	453.2	350.7
Nuclear (GW)	336.9	333.0	439.9	592.1	780.7	1002.9
Hydro (GW)	443.7	450.9	468.7	481.7	490.1	494.5
Renewables (GW)	546.5	621.9	952.4	1296.3	1663.8	2131.4
Total	2995.8	3070.7	3473.5	3882.7	4216.5	4672.9
Net electricity generation						
Natural gas (TWh)	2227.0	2046.9	3146.1	3014.2	2592.4	1907.4
Oil (TWh)	417.6	237.5	181.9	128.7	94.4	47.5
Coal (TWh)	3577.0	4193.2	2829.1	2378.8	1937.1	1512.1
Nuclear (TWh)	2449.9	2478.5	3178.5	4215.7	5562.7	7195.1
Hydro (TWh)	1432.8	1593.8	1661.0	1709.2	1739.8	1754.3
Renewables (TWh)	1787.6	2113.0	3389.3	4456.3	5509.4	6735.8
Total	11891.9	12662.9	14385.9	15902.9	17435.8	19152.2
Final Energy Demand						
Demand of fuel by sectors						
Industry	1407.9	1359.2	1397.0	1388.0	1359.0	1285.5
Commercial and households	1334.7	1252.6	1365.0	1366.4	1312.7	1242.3
Transport	1277.4	1206.9	1227.7	1149.5	1068.2	983.9
Agriculture	73.9	76.9	90.8	105.1	117.7	128.4
Total final energy demand						
Electricity (Mtoe)	785.8	846.8	981.7	1104.9	1239.8	1395.6
Heat (Mtoe)	199.0	183.5	188.5	194.4	199.1	200.1
Natural gas (Mtoe)	816.9	746.6	824.8	762.5	620.7	384.8
Oil (Mtoe)	1953.8	1766.2	1736.0	1543.4	1263.4	916.8
Coal (Mtoe)	210.2	226.6	164.3	123.7	71.7	30.6
Biomass (Mtoe)	127.7	123.5	181.5	271.1	444.8	679.0
Other (Mtoe)	0.5	2.3	3.8	9.0	18.1	33.3
Total	4093.9	3895.6	4080.4	4009.0	3857.6	3640.2
Emissions						
CO_2 Total (Mt CO_2)	14637.4	14141.1	12409.7	10177.5	7377.1	4317.8
CO_2 Power Sector	4992.3	5249.8	3992.1	2863.7	1664.3	609.6
CO_2 other conversion + process emissions	2032.4	1943.3	1769.4	1583.9	1351.9	1013.1
CO_2 industry	2070.8	2026.7	1842.8	1626.0	1300.6	850.0
CO_2 transport	3599.7	3264.4	3085.5	2583.2	1914.6	1153.4
CO_2 residential, services	1942.2	1656.9	1719.9	1520.7	1145.7	691.7
GHG Total (Mt CO_2eq)	16194.1	15678.9	13427.1	11025.0	8084.5	4858.3
GHG Power Sector	4338.7	4620.9	3630.5	2604.1	1450.8	461.0
GHG other conversion + process emissions	2752.8	2579.7	1827.1	1425.2	1124.6	741.6
GHG industry	3031.6	3038.6	2837.4	2620.1	2154.2	1465.5
GHG transport	3669.3	3329.3	3147.3	2633.7	1951.8	1176.3
GHG residential, services	2401.7	2110.4	1984.8	1741.9	1403.1	1013.9

Baseline Scenario - Developing countries

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	21950.4	29906.2	47802.3	68478.3	92589.1	121511.0
Population (Mcap)	5327.1	5701.0	6437.7	7078.5	7585.2	7961.6
GDP per capita (€/cap)	4120.5	5245.8	7425.4	9674.2	12206.5	15262.2
Gross inland consumption per capita (toe/cap)	998.6	1124.4	1366.1	1597.9	1817.4	2040.5
Gross inland consumption/GDP (toe/€)	242.4	214.3	184.0	165.2	148.9	133.7
CO_2/Gross inland consumption (tCO_2/toe)	2546.6	2619.0	2595.7	2509.6	2413.5	2270.4
Gross inland consumption						
Natural gas (Mtoe)	815.1	935.5	1394.7	1730.4	2082.2	2434.1
Oil (Mtoe)	1649.8	1754.4	2177.0	2432.7	2623.0	2689.7
Coal (Mtoe)	1704.3	2346.3	3289.5	4358.7	5301.4	6013.4
Nuclear (Mtoe)	81.3	154.7	346.9	673.6	1094.8	1707.5
Other (Mtoe)	1069.3	1218.9	1586.4	2115.4	2684.3	3401.2
Total	5319.8	6409.9	8794.5	11310.7	13785.7	16245.9
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	318.5	353.4	518.4	639.2	764.1	906.5
Oil (Mtoe)	182.0	229.0	130.0	119.5	131.4	150.7
Coal (Mtoe)	1018.3	1351.1	2010.6	2846.5	3673.7	4368.6
Nuclear (Mtoe)	81.3	154.7	346.9	673.6	1094.8	1707.5
Others (Biomass) (Mtoe)	12.0	37.5	118.2	238.7	374.7	548.9
Total	1612.0	2125.6	3124.1	4517.5	6038.7	7682.2
Net generation capacities						
Natural gas (GW)	257.6	309.3	561.3	896.1	1173.8	1387.7
Oil (GW)	201.8	244.4	213.8	167.6	160.7	172.2
Coal (GW)	591.3	1003.5	1673.2	2465.6	3196.0	3850.5
Nuclear (GW)	44.6	79.9	184.6	364.0	590.9	915.2
Hydro (GW)	361.7	434.3	545.1	614.1	675.6	726.6
Renewables (GW)	409.5	524.3	816.9	1172.4	1634.5	2293.1
Total	1866.5	2595.7	3994.9	5679.8	7431.5	9345.3
Net electricity generation						
Natural gas (TWh)	1352.9	1569.6	2644.9	3487.3	4114.1	4658.1
Oil (TWh)	747.7	944.8	552.5	511.6	566.7	661.8
Coal (TWh)	3510.0	5062.3	8878.6	13807.1	18345.5	22256.2
Nuclear (TWh)	312.1	593.7	1331.5	2585.4	4201.5	6553.3
Hydro (TWh)	1279.7	1545.2	1938.4	2186.1	2407.9	2593.5
Renewables (TWh)	1356.7	1842.4	2918.0	4262.8	5997.7	8472.2
Total	8559.1	11558.0	18263.9	26840.3	35633.4	45195.1
Final Energy Demand						
Demand of fuel by sectors						
Industry	1543.2	1877.6	2597.6	3097.7	3374.0	3428.5
Commercial and households	1382.8	1492.5	1944.6	2458.0	2963.7	3505.9
Transport	697.8	793.2	1103.3	1367.7	1679.7	2050.5
Agriculture	106.7	125.5	175.0	233.6	291.5	355.2
Total final energy demand						
Electricity (Mtoe)	499.9	687.4	1116.9	1690.3	2290.9	2961.5
Heat (Mtoe)	48.7	56.0	65.9	78.1	89.4	95.6
Natural gas (Mtoe)	335.9	399.1	595.6	739.7	888.9	1026.3
Oil (Mtoe)	1322.2	1419.5	1916.8	2199.4	2398.2	2471.0
Coal (Mtoe)	605.5	767.3	997.7	1113.7	1118.6	1037.8
Biomass (Mtoe)	917.9	957.9	1122.7	1321.1	1493.1	1697.2
Other (Mtoe)	0.3	1.6	5.0	14.9	29.7	50.8
Total	3730.5	4288.8	5820.5	7157.1	8308.8	9340.2
Emissions						
CO_2 Total (Mt CO_2)	13547.1	16787.8	22827.7	28385.3	33271.5	36884.4
CO_2 Power Sector	5253.9	6782.8	9416.4	12899.0	16435.2	19530.0
CO_2 other conversion + process emissions	1895.4	2652.9	3531.3	4283.3	4932.9	5456.4
CO_2 industry	3084.4	3783.5	5055.3	5699.3	5884.9	5628.3
CO_2 transport	1986.4	2170.3	2827.6	2968.8	3051.8	2969.0
CO_2 residential, services	1327.0	1398.3	1997.1	2534.9	2966.7	3300.7
GHG Total (Mt CO_2eq)	16046.7	19739.6	26654.6	33057.2	38647.0	42851.9
GHG Power Sector	4142.8	5451.2	7751.5	10947.7	14301.2	17258.1
GHG other conversion + process emissions	3334.9	4264.8	5429.0	6572.4	7503.0	8276.8
GHG industry	3973.7	4978.0	6699.7	7583.2	7901.0	7706.9
GHG transport	1993.0	2177.9	2837.6	2979.7	3063.6	2981.4
GHG residential, services	2602.3	2867.7	3936.8	4974.2	5878.2	6628.7

Mitigation Scenario - Developing countries

	2005	2010	2020	2030	2040	2050
Indicators						
GDP (M€ PPP)	21950.4	29906.2	47802.3	68478.3	92589.1	121511.0
Population (Mcap)	5327.1	5701.0	6437.7	7078.5	7585.2	7961.6
GDP per capita (€/cap)	4120.5	5245.8	7425.4	9674.2	12206.5	15262.2
Gross inland consumption per capita (toe/cap)	998.6	1093.1	1198.9	1209.4	1282.4	1347.9
Gross inland consumption/GDP (toe/€)	242.3	208.4	161.5	125.0	105.1	88.3
CO_2/Gross inland consumption (tCO_2/toe)	2546.6	2616.7	2431.9	1876.7	1266.6	640.8
Gross inland consumption						
Natural gas (Mtoe)	815.1	890.6	1260.3	1407.6	1373.1	1031.0
Oil (Mtoe)	1649.8	1694.6	1993.3	2105.8	1927.9	1385.9
Coal (Mtoe)	1704.3	2292.8	2474.3	1908.5	1631.3	1301.1
Nuclear (Mtoe)	81.3	155.5	471.0	1094.8	1922.5	2921.7
Other (Mtoe)	1069.2	1198.1	1519.4	2043.7	2872.4	4092.0
Total	5319.7	6231.7	7718.3	8560.4	9727.3	10731.7
Electricity generation						
Fuel input for power generation						
Natural gas (Mtoe)	318.5	334.6	498.2	566.9	552.8	434.7
Oil (Mtoe)	182.0	222.8	149.7	115.5	81.3	38.9
Coal (Mtoe)	1018.3	1308.0	1421.0	1185.8	1154.1	1039.6
Nuclear (Mtoe)	81.3	155.5	471.0	1094.8	1922.5	2921.7
Others (Biomass) (Mtoe)	12.0	36.9	148.7	336.1	577.3	987.4
Total	1612.0	2057.9	2688.5	3299.0	4287.9	5422.3
Net generation capacities						
Natural gas (GW)	257.6	305.6	479.7	616.7	703.1	734.9
Oil (GW)	201.8	243.2	219.5	161.5	127.0	102.2
Coal (GW)	591.3	981.4	1349.7	1319.8	1154.7	1131.8
Nuclear (GW)	44.6	80.3	250.5	592.9	1040.3	1570.0
Hydro (GW)	361.7	433.8	551.7	637.4	700.2	741.4
Renewables (GW)	409.5	523.8	898.6	1454.4	2085.6	3055.3
Total	1866.5	2568.1	3749.7	4782.7	5810.9	7335.6
Net electricity generation						
Natural gas (TWh)	1352.9	1481.1	2463.9	2927.5	2804.6	2173.0
Oil (TWh)	747.7	918.6	632.0	489.0	344.6	165.8
Coal (TWh)	3510.0	4906.2	6296.8	5648.2	5547.7	5127.6
Nuclear (TWh)	312.1	596.8	1807.5	4201.9	7378.3	11213.2
Hydro (TWh)	1279.7	1543.4	1961.7	2266.6	2492.5	2643.5
Renewables (TWh)	1356.6	1839.4	3224.6	5331.2	7849.6	11755.2
Total	8559.0	11285.5	16386.5	20864.4	26417.3	33078.3
Final Energy Demand						
Demand of fuel by sectors						
Industry	1542.8	1845.4	2296.9	2101.0	2002.8	1842.0
Commercial and households	1382.5	1452.2	1772.7	2058.0	2234.3	2246.2
Transport	696.2	762.1	947.4	1145.7	1321.2	1492.1
Agriculture	106.7	123.0	161.4	202.0	243.9	284.5
Total final energy demand						
Electricity (Mtoe)	499.7	669.0	985.7	1272.7	1654.6	2130.1
Heat (Mtoe)	48.7	56.0	65.9	78.1	89.4	95.6
Natural gas (Mtoe)	335.7	382.2	513.3	560.1	538.5	373.2
Oil (Mtoe)	1320.5	1371.0	1711.8	1851.4	1729.5	1273.4
Coal (Mtoe)	605.5	761.2	849.6	556.6	333.0	150.9
Biomass (Mtoe)	917.8	941.8	1049.1	1181.1	1438.3	1787.6
Other (Mtoe)	0.3	1.5	2.9	6.7	19.0	54.2
Total	3728.2	4182.7	5178.4	5506.7	5802.2	5864.9
Emissions						
CO_2 Total (Mt CO_2)	13547.2	16306.3	18770.2	16065.2	12321.0	6877.1
CO_2 Power Sector	5253.9	6552.7	7131.8	5122.2	2926.9	602.0
CO_2 other conversion + process emissions	1901.5	2596.9	3069.9	3100.5	2965.1	2408.3
CO_2 industry	3084.0	3736.2	4353.1	3167.3	2318.3	1407.4
CO_2 transport	1981.3	2080.8	2442.2	2584.1	2273.7	1380.5
CO_2 residential, services	1326.5	1339.7	1773.2	2091.1	1837.0	1078.9
GHG Total (Mt CO_2eq)	16046.7	19234.4	21483.9	18263.5	13772.9	7926.9
GHG Power Sector	4142.8	5238.6	6351.3	4379.1	2277.7	118.5
GHG other conversion + process emissions	3340.9	4173.7	3216.0	3033.0	2708.1	1995.6
GHG industry	3973.3	4930.6	5853.1	4765.1	3889.1	2788.2
GHG transport	1988.0	2088.1	2450.9	2593.9	2283.2	1387.9
GHG residential, services	2601.7	2803.4	3612.6	3492.4	2614.8	1636.7

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Abstract

This report documents the JRC/IPTS modelling activities of the 2009 European Commission Communication "Towards a comprehensive climate change agreement in Copenhagen", which establishes the EU's position in the Copenhagen negotiations. According to the POLES model, the estimated global direct abatement costs of an emission reduction scenario compatible with the EU 2 degrees target are €175 billion by 2020. The report also highlights the crucial importance of energy efficiency improvements in achieving the overall emission reduction targets. Finally, the analyses with the POLES and GEM-E3 models underline the fundamental role that a global carbon market can play in implementing climate policies in a cost-efficient way.

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