Energy savings in drastic climate change policy scenarios

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Abstract
This paper reports a climate change policy scenario compatible with long-term sustainable objectives set at EU level (6th Environment Action Plan)[1]. By setting ambitious targets for GHG emissions reduction by 2030, this normative scenario relies on market-based instruments and flexible mechanisms. The integrated policy that is simulated (i.e. addressing energy, transport, agriculture and environmental impacts) constitutes a key outlook for the next 5-year report of the European Environment Agency (EEA). This scenario highlights what it would take to drastically curb EU GHG emissions and how much it might cost. The findings show that such a 'deep reduction' climate policy could work as a powerful catalyst for (1) substantial energy savings, and (2) promoting sustainable energy systems in the long term. The implications of this policy lever on the energy system are many-fold indeed, e.g. a substantial limitation of total energy demand or significant shifts towards energy and environment-friendly technologies on the supply side. Clear and transparent price signals, which are associated with market-based instruments, appear to be a key factor ensuring sufficient visibility for capital investment in energy efficient and environment-friendly options. Finally it is suggested that market-based policy options, which are prone to lead to win-win situations and are of particular interest from an integrated policy-making perspective, would also significantly benefit from an enhanced energy policy framework.

Introduction
This paper reports the quantitative results of a climate change policy scenario compatible with long-term sustainable objectives set at EU level. The findings show that such a 'deep reduction' climate policy could work as a powerful catalyst for substantial energy savings. This paper starts with the baseline energy scenario to which the climate change scenario is compared. The second part of this paper is dedicated to reporting the results of the 'deep reduction' climate change policy scenario in which EU GHG emissions are drastically curbed to be compatible with long-term sustainable objectives set at EU level (6th Environment Action Plan). Key results of this so-called 'Low GHG emissions' scenario are discussed in connection with climate change pressures, impacts and associated energy savings.

The energy baseline scenario

THE ANALYTICAL FRAMEWORK AND SOCIO-ECONOMIC CONTEXT
The assumed socio-economic context surrounding the European baseline scenario is characterised by a sustained economic growth with a further predominance of the service sector in the economy, and by a European population, which

1. The opinions expressed here do not necessarily reflect those of the European Environment Agency and are the sole responsibility of the authors.

is stabilising and ageing. Technological progress is moderate but essential in key areas such as energy, agriculture or water, yet no technological breakthroughs are taking place in the period to 2030. The political sphere exhibits no marked shifts in terms of sectoral and environmental policies targeting European production and consumption patterns.

Overall, the European baseline projection depicts developments reflecting current expectations in demographic, economic and technological terms, taking into account implemented and current policies only[2]. In this framework, European targets as set in Directives (e.g. Combined Heat and Power) and Regulations are not assumed to be reached a priori. At global level, trade agreements underpin economic growth, productivity gains (for physical and labour capitals) and competitiveness, while environmental issues receive limited attention.

EEA's outlooks across the various sectors and themes have made use of a common reference set of assumptions for key driving forces in order to ensure consistency across the board and facilitate cross-cutting analysis. This reference set largely builds upon the socio-economic assumptions developed though extensive stakeholder consultation for DG TREN baseline projections 'European Energy and Transport Trends to 2030' (European Commission, 2003)[3]. Within this framework, the assumptions have been developed as a consistent set and cover the following key driving forces: Population growth; Macro and meso-economic (i.e. sectoral) growth; Households' expenditure; Number of household; Average household size; Energy flows. The same assumptions are also used within the CAFE (Clean Air for Europe, DG ENV) programme[4], and therefore this ensures the consistency of EEA's outlooks in terms of key driving forces and results with recent European Commission projections.

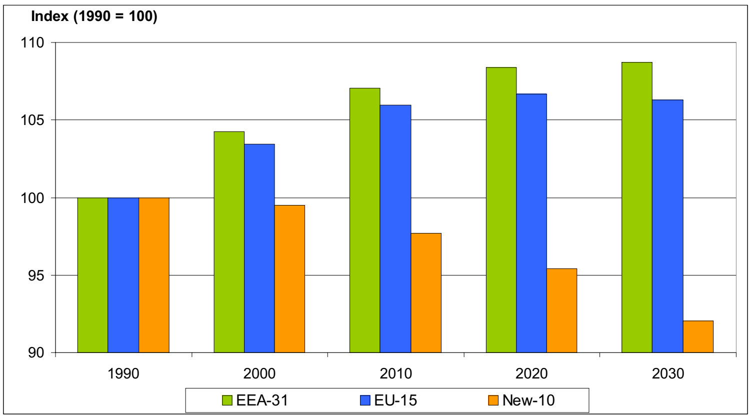


Figure 1. *Demography – Population development 1990-2030.*

Demography

Over the period until 2030 the population of the EU-25 is expected to stay fairly constant, increasing by less than 1% over today's level. The slight increase of population in the EU-15 (+1.5% over current figures) sharply contrasts with the New Member States (New-10) situation, where a dramatic decrease of 7% is projected (see Figure 1). Totalling across the EEA31 countries, a population increase of +3% is expected since Turkey's continuous very fast population growth (i.e. + 27% over today's level by 2030) is only partially offset by the overall population decline in the other EU candidate countries (i.e. Bulgaria and Romania, -13% in total)[5].

Of growing concern, in particular in terms of pension and health expenditures, is the age distribution in European Union countries. While the accession of the ten new Member States in 2004 has somewhat rejuvenated the EU population, it failed to reverse the trend of increasing old age dependency from 30% in the 1960s to 39% today (Eurostat, 2004) in the EU-25. And this trend is expected to continue over the 2000-2030 period, with the share of elderly people of 65 years and older increasing from 15% to 25% in the EU-15, and from 10% to 22% in the New-10. In addition, the ageing European society might conflict with the objectives of the Lisbon Strategy/Agenda, which aims at making the EU 'the world's most competitive and dynamic knowledge-driven economy by 2010'. Under the strategy, a stronger economy will drive job creation alongside social and environmental policies that ensure sustainable development and social inclusion.

In the recent past, the size of an average household decreased, leaving the number of households in the EU growing much faster than the population (see EEA 1999, p55). This trend is expected to continue over the next decades, both in the countries of the EU-15 and New-10, reducing the average household size to below 2.5 by 2030. Despite the expected stability of EU population over 2000-2030, this leads to a marked increase in the number of households, which in turn is bound to increase per capita consumption and increase pressure on the environment.

Macro-economy

The average annual economic growth in the EU is expected to be 2.4% between 2000 and 2030; the Gross Domestic Product (GDP) per capita in the EU-15 is almost doubled, while it is tripled in the New-10. Although the average annual growth rate in the New-10 is expected to be 3.5%, their economic weight in Europe will continue to stay marginal as its share in EU's GDP is expected to slightly increase from 4.4% in 2000 to 6% in 2030. In view of the economic growth experienced during the 1990s and the most recent economic developments, these macro-economic assumptions are considered as moderately optimistic.

2. Please note that the baseline projection does not take into account the EU Emissions Trading Scheme, as too few information about its implementation and national allocation plans across Europe were available by end of 2004.
3. The LREM (Long-Range Energy Modelling) project has been undertaken by the National Technical University of Athens (NTUA) using the PRIMES model.
4. Details on the CAFE (Clean Air for Europe, DG ENV) programme and the associated thematic strategy on air pollution under the Sixth Environmental Action Programme can be accessed at the following address: http://europa.eu.int/comm/environment/air/cafe/. The International Institute for Applied Systems Analysis (IIASA) and the National Technical University of Athens (NTUA) undertakes the project using the RAINS and PRIMES models.
5. The term 'EU-15' refers to the 15 EU member states prior to 1st of May 2004, while the term 'New-10' refers to the 10 new member states of the EU that joined on this date. The term 'EEA31' refers to the 31 member states of the European Environment Agency.

At sectoral level, the EEA31 economic growth is expected to primarily take place in the service and industry sectors. The service sector, which current share in total GVA is about 70%, is projected to progress at an average annual growth rate of 2.7% and to keep its predominance in the European economy by 2020. At EU-15 and New-10 levels, more contrasted developments can be highlighted. For example, the agriculture sector is expected to decrease its share in total GVA in the EU-15 by 24%, but in the New-10 by 38%. In the New-10, the service sector is projected to represent 62% of total GVA in 2020 (i.e. +9% from 2000 level) while the energy sector would represent only 2.9% of total GVA in 2020 (i.e. -45% from 2000 level).

Technological developments

Since the 1980s, the average energy intensity gains in the EU-25 energy system (i.e. calculated as the gross energy consumption per unit of GDP including therefore both supply and demand sides) have been estimated around 2% per year (1.7% annually between 1990 and 2000); in the baseline projection, it is assumed that intensity gains in the energy sector progress at an annual rate of 1.8%, as a result of primarily increasing prices of energy commodities (i.e. fossil fuels in particular).

Agriculture

Harvested land will continue to be primarily used for fodder activities and production of cereals (80% of total area, see Figure 3). Yields increase will be the main source of production growth in Europe over the next 20 years. Environmental pressures are expected to significantly increase in the New Member States, as a result primarily of considerable increases in fertilizers use.

In view of the key driving forces and pressures on Europe's environment that have been described above, and without anticipating on the environmental impacts that are presented below, one should however highlight the likelihood of unsustainable environmental developments in a baseline projection framework. Indeed, the analysis has pointed out an expected increase of economic growth and welfare, which without any breakthrough in technological developments or sectoral and environmental policies targeting our production and consumption patterns, is likely to strengthen the pressures and impacts on Europe's environment.

THE RESULTS OF THE ENERGY BASELINE

Under the baseline assumptions (i.e. implemented and adopted policies and measures for the year 2003 only), a continuing increase of energy demand in Europe over the 2030 horizon is expected (see Figure 4). Total energy consumption in the EEA member countries is projected to increase by 20% over today's level, with very similar annual growth rates in the EU-15 and the New-10 (about +0.6% per year on average). Of particular interest is the dramatic relative decoupling expected to take place in the New-10 (see Figure 5). However, the New-10 represents in volume only 12% of EU's consumption, so the contribution to lowering the EU-average is marginal. Overall, the doubling of EU's GDP between 2000 and 2030 is expected to be accompanied by a 19% increase in energy requirements, which represents an important improvement in terms of energy intensity. This is primarily due, in the short term, to the effect of improved demand-side management and, in the long term, to efficiency gains and the adoption of new technologies.

With regard to final energy demand, all sectors over the 2030 horizon are expected to relatively decouple from GDP. Significant energy intensity improvements are expected to occur in the New-10, in particular in the industry where the

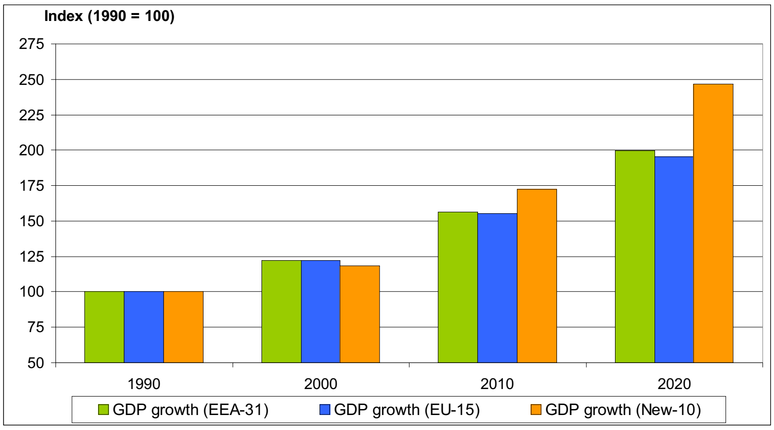
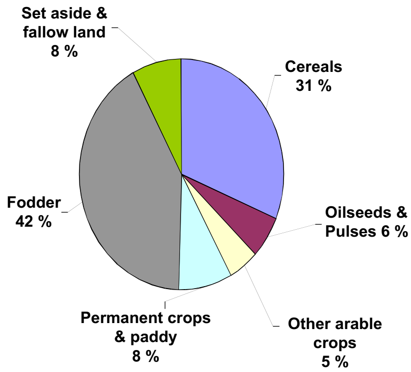


Figure 2. *Income – GDP growth 1990-2020.*



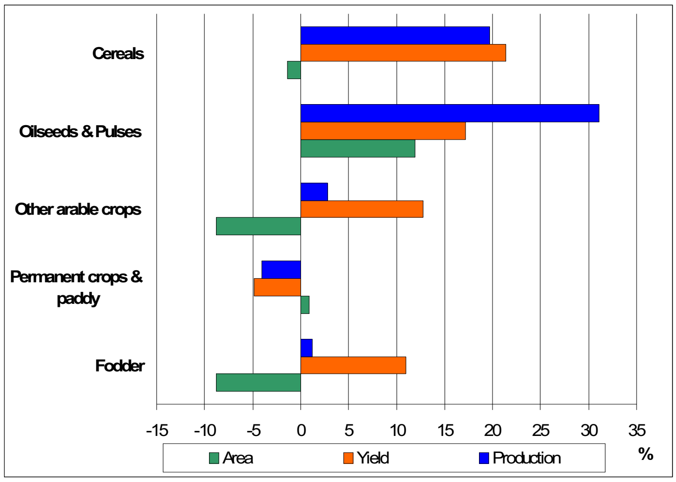


Figure 3. *Agriculture – Use of arable land (2020) and sources of crop growth (2020/2001).*

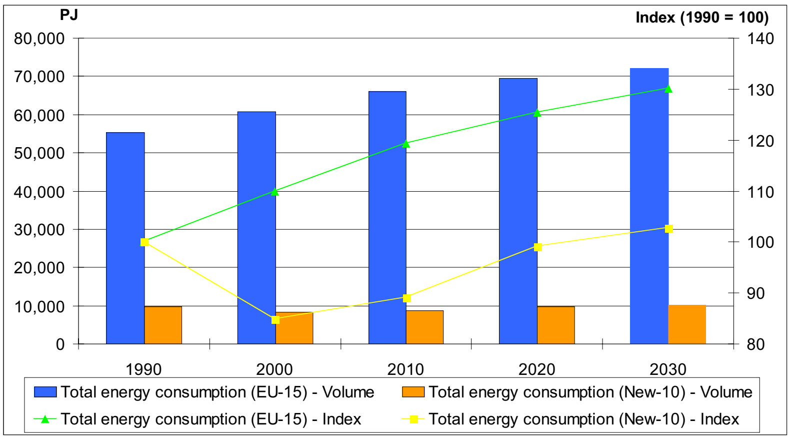


Figure 4. *Total Energy Consumption 1990-2030.*

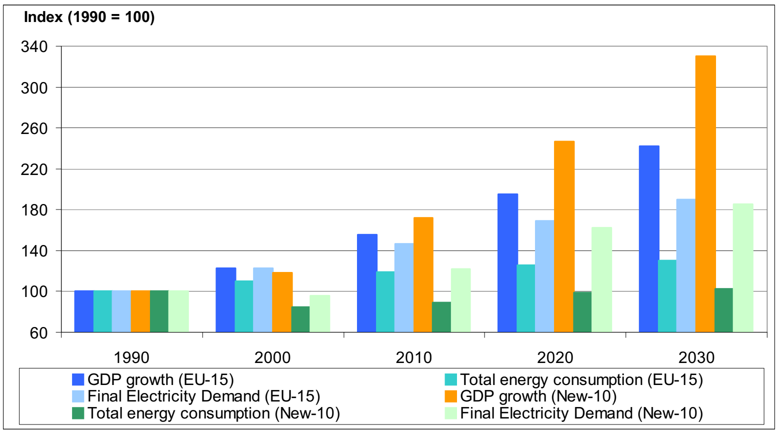


Figure 5. *Total Energy Consumption and Final Electricity Demand vs. GDP Growth 1990-2030.*

economic recovery might provide opportunities for efficiency gains and new technologies. These expected improvements are also explained by the increasing share of the service sector in the economy at the expense of the traditional industries that are energy-intensive (e.g. iron and steel, chemicals, pulp and paper, textiles) and the energy sector itself. However, the further development of the service sector in the European Union continues to be a key driver of final energy demand. On the other hand the transport sector, without any drastic shifts in infrastructure or mobility modes, is expected to continue to significantly grow in terms of energy requirements. In the New-10, a total increase of 80% from 2000 level is projected, and the transport share in final energy demand is to increase from 19% in 2000 to 25% in 2030. In the absence of promising technological alternatives to current vehicles based on liquid fuels, these developments might significantly enhance the pressures on the environment. As with households' final energy consumption, it is expected to exhibit an increase of 20% and 40% respectively in the EU-15 and New-10. In addition, gas and electricity are expected to enhance their pre-dominance in final energy demand of EEA countries (from about 20% in 2000 for each of them to 24% in 2030).

As far as final electricity demand is concerned, it is also expected to relatively decouple from GDP in EEA's member countries, specifically in the New-10. However, the reliance on electricity as the main energy carrier, in particular for services and the domestic sector, is expected to continue to growth at an average annual rate of 1.7% between 2000 and 2030; electricity requirements are therefore expected to increase by 50% over this period of time.

Finally, one should mention that if current levels of oil prices were to continue in the medium and long term, this might significantly affect the developments of the energy system over the next decades. Futures and forward markets for energy commodities reflect developments, which significantly affect the physical balance between supply and demand at global level. In the case of oil, the strong economic growth in China and India (see also the global steel market), the geopolitical uncertainty in the Middle East and the fear of supply shortage in Russia (i.e. Yukos) and Venezuela are the main explaining factors.

To sum-up, total energy consumption is expected to significantly decouple from GDP over the next decades, consolidating the past improvements in energy intensity; in addition, without technological breakthroughs, the transport sector is projected to continue to significantly grow in terms of energy requirements, and therefore to crystallise environmental concerns due to enhanced pressures on the environment.

GHG EMISSIONS AND CLIMATE CHANGE IMPACTS

This section reports the baseline projections for GHG emissions and climate change in Europe, for key timeframes and deadlines such as 2008-2012, 2030 and 2100. By definition, the baseline projection includes (all and only) current policies and measures, i.e. no assumptions are made on the development and implementation of additional measures and policies on the time horizon considered. The six greenhouse gases addressed by the Kyoto Protocol are considered, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorcarbons (HFCs), perfluorcarbons (PFCs) and sulphur hexafluoride (SF_6). According to the baseline projection, the following developments are projected:

- The EU-15 Kyoto targets are not expected to be met with current policies and measures, as increasing trends in GHG emissions are projected from 2000 onwards (see Figure 6). This is primarily due to the combination of sustained economic growth and a lack of incentives for significant energy efficiency gains or technological shifts in the energy and transport sectors. By 2008-2012, the EU-15 GHG emissions are indeed expected to increase by about 1.1% compared to 1990 levels, reaching 4 107 $MtCO_2$ eq. per year. This expected trend would significantly fall short of the Kyoto target by 370 $MtCO_2$ eq., i.e. 9.1 points of percentage.
- On the contrary, the New-10 are expected to largely meet their Kyoto target with current policies and measures, as they are not projected to have fully recovered yet from the 1990s economic breakdown. By 2008-2012, the New-10 GHG emissions (i.e. including Cyprus and Malta which have no Kyoto Protocol targets though) are expected to be about 18% below 1990 levels, reaching about 725 $MtCO_2$ eq. per year. This expected trend would over-comply with the Kyoto target by 89 $MtCO_2$ eq., i.e. as much as 10 points of percentage.
- As a consequence, the EU-25 countries are not expected to meet their 'combined' Kyoto target, reducing their GHG emissions over the 2008-2012 period only by 2.3% below 1990 levels to 4 832 $MtCO_2$ eq. per year, i.e. falling short of the target by 5.7 points of percentage.
- By 2030, EU-25 GHG emissions are projected to be 8.4% above 1990 levels (+12.1% for the EU-15 and –8.9% in the New-10), while the EEA member countries would exhibit GHG emissions 13.2% above 1990 levels. In EU-25, the share of energy-related CO_2 emissions is projected to further increase from 76% back in 1990 (78% in 2000) to 80% in 2030. The other gases are expected to stay constant or decline, with the exception of the F gases which could increase from 1% in 1990 and represent 2.8% in 2030. When looking at the EU-15 and the New-10 separately, there are no striking differences as CO_2 represents the bulk of the emissions and could reach similar levels of about 80% by 2030, leaving the other gases to be quite marginal.
- As far as per capita emissions are concerned, the expected developments would lead to a significant convergence between EU-15 and New-10 contributions towards a level of about 11.7 tCO_2 eq. per year by 2030 (from 10.5 and 9.5 respectively in 2000).

To sum up, without additional policies and measures, the European Union is expected to fall short of its Kyoto target. In addition, the ability to reach the Kyoto Protocol target in the European Union significantly depends, besides current implemented policies and measures, on potential additional initiatives (such as an enhanced diffusion of renewables) as well as on the economic situation. Finally, by 2100, global temperature change is expected to be well above the long-term sustainable objective set in the 6th Environment Action Programme (6th EAP, see next section for further details).

With 137 signatories, the Kyoto Protocol constitutes the first international framework and attempt to curb anthropogenic emissions of GHGs; the overall reduction target (essentially on industrialised countries' emissions) is –5% over the 2008-2012 period compared with 1990 levels. Without the commitment of the USA, China or India, the end effect on global environment is uncertain though. In that perspective, the Kyoto Protocol appears as a first step in the right di-

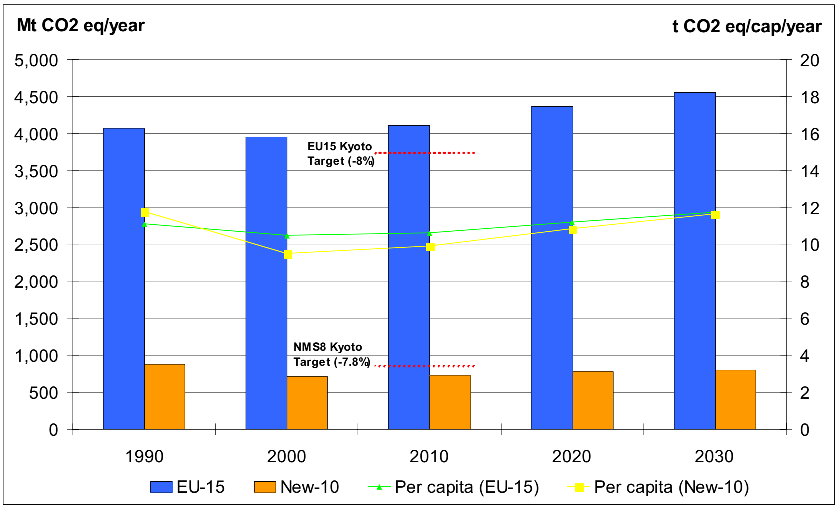


Figure 6. *Total GHG emissions in Europe 1990-2030.*

rection. However, if the 6th EAP long-term sustainable objective is to be achieved, drastic changes and shifts towards sustainable sectoral developments (e.g. energy system) and consumption in Europe are needed to reach a deep reduction of global GHG emissions in the longer term. The future of GHG emissions and climate change impacts and adaptation options will therefore largely depend on the negotiations, which will take place for a second commitment period and whether those will lead to far-reaching targets.

The 'Low GHG emissions' scenario: a drastic climate change policy

This section reports the 'Low GHG emissions' scenario that assumes a deep reduction of GHGs emissions in Europe over this century to a level that would be consistent with EU's long-term sustainable objective as set in the 6th EAP. This scenario has also to be considered within the context of national initiatives, studies and political debate across the EU (e.g. United Kingdom, Germany and France) for such far-reaching climate change policies. A common characteristic of these initiatives is to assess post-Kyoto needed developments to reach long-term sustainable targets. The implications of such scenarios are thought to be numerous, and in that context the EEA intends to provide an assessment of how challenging that could be and what might be the key trade-offs associated with such policy options.

GHG EMISSIONS AND CLIMATE CHANGE TARGETS

The key policy package addressing European GHG emissions is the Kyoto Protocol adopted in December 1997 at the third Conference of the parties (COP3) to the United Nations Framework Convention on Climate Change (UNFCCC) and entered into force on 16th February 2005. It sets a binding reduction target for EU-15 GHG emissions of -8% on average over the 2008-2012 period compared to 1990 levels, and -7.8% for the eight New Member States having a Kyoto Protocol target; the 'combined' target for the EU-25 is therefore to reduce its emissions by about -8% on average over the 2008-2012 period compared to 1990 levels (or any other base year values). The EU-15 target has been negotiated within its member states and led to the so-called 'burden-sharing' agreement (European Council, 2002) that is differentiated levels of effort and contribution to countries. With regard to climate change impacts, the key EU policy package is the 6th Environment Action Programme (6th EAP), which sets EU's long-term sustainable target in those words: '*Thus a long term objective of a maximum global temperature increase of 2°Celsius over pre-industrial levels and a* CO_2 *concentration below 550 ppm shall guide the Programme. In the longer term this is likely to require a global reduction in emissions of greenhouse gases by 70% as compared to 1990 as identified by the Intergovernmental Panel on Climate Change (IPCC)*' (Article 2, paragraph 2). In this context, the EEA has developed the 'Low GHG emissions' scenario, which aims at identifying the implications of such a target for EU's future GHGs patterns and sectoral developments as well as estimating the costs of associated policies.

The 'Low GHG emissions' scenario reported below is a normative climate change (or environmental) scenario that includes binding reduction targets on European GHG emissions. Its implementation is market-based via the introduction of a (high) carbon price in an emissions trading scheme. The actors in the energy system therefore adjust their investments and behaviour in line with these new measures (e.g. substitution, renewables), leading *in fine* to energy savings. It is important to stress that environmental measures impacting the energy sector across the board are the driver for energy savings in this exercise, and not dedicated energy savings policy per se. It is equally important to note that the choice between supply and demand options to reduce the emissions of GHGs is made on a cost-effective basis only, in line with the introduction of a uniform carbon tax. The results of the scenario is therefore an indicator of how much a particular sector (e.g. power section, services, industry, transport) is 'elastic', i.e. how much it is flexible and can shift to new fuels and technologies, or even reduce its energy demand. The substitution process taking place depends on the relative costs and emission factors of the technological options that the sectors/actors face.

The GHGs reduction targets assumed for the European Union over the 2000-2100 period are derived from an assumption of global per capita emissions convergence by 2075 and are as follows: –20% by 2020 compared to 1990 levels, -40% by 2030 and -65% by 2050. Introducing carbon permit prices corresponding to these targets will induce substantial changes in the European energy system. It will stimulate improvements in energy intensity in both supply and use of energy, and the further expansion of technology and fuels with low or zero carbon dioxide emissions. Model results describe the optimum solution in cost-effective terms to respond to binding GHG emissions reduction targets, i.e. to the introduction of a carbon permit price that rises up to 65 Euro/tCO_{2eq} by 2030. However, the model results do not take into account the wider benefits of sustainable energy system, such as reduced emission of air pollutants or increased energy security.

Under the 'Low GHG emissions' scenario, the capacity of the energy system to adjust depends crucially on key technologies and fuels, both in the energy supply and demand sides, which will determine opportunities for substitution and the overall energy intensity. In that context, the following effects are to be expected:

- A reduction of energy demand, resulting from behavioural changes and adaptation.
- Technologies and fuels substitution, both on the supply and demand-sides, in order to:
  - Improve the technological energy efficiency,
  - Switch to fossil fuels with lower carbon content, and
  - Expand the use of technology and fuels with low or zero carbon dioxide emissions (e.g. renewable energies; nuclear power; fossil fuels with carbon capture and storage).

In terms of environmental pressures and impacts, the 'Low GHG emissions' scenario induces the following patterns:

- By 2030, the EU-25 domestic GHG emissions are expected to decrease by about 23% compared to the baseline, and by 16% compared to 1990 levels, reaching about 4 140 MtCO_2 eq. per year. The Marginal Abatement Cost (MAC) associated with the scenario targets is estimated at 30 Euros/tCO_2 in 2020, 65 Euros/tCO_2 in 2030 and 115 Euros/tCO_2 in 2050.

- The main relative contribution to this overall reduction comes from methane (-40% compared to 1990 levels), nitrous oxide (-26%) and carbon dioxide (-11%). Sinks exhibit a significant increase over the 2030 period, contributing to a reduction of GHG emissions by 2.3% in 2030.
- In terms of global GHGs concentration, this scenario leads to a stabilisation at about 550 ppm CO_2 eq. by 2100, which is about 40% lower than in the baseline projection.
- With regard to global temperature change over the 2000-2100 period, an increase of about +1.6°Celsius over the 1961-1990 average is projected. This is about 1.15°Celsius lower than in the baseline, and in line with the EU long-term sustainable objective set in the 6th EAP (+2 °Celsius over pre-industrial levels, i.e. +1.7°Celsius over the 1961-1990 average).

To sum-up, a deep reduction of GHG emissions in Europe by 2030 seems technologically and economically feasible, although requiring drastic shifts for sectoral developments (the energy system in particular). The benefits of such developments in terms of limited climate change impacts and security of energy supply have to be properly assessed along side the associated economic impacts. In addition, significant scientific and analytical uncertainty characterises the assessment of climate change impacts. This has to be systematically acknowledged and addressed in climate change assessments. While this assessment takes into account the sectors and activities that drive GHG emissions, the analysis of the economic impacts has yet to be conducted with appropriate tools addressing the macro-economic and sectoral effects as well as the socio-economic context as a whole.

SUBSTANTIAL ENERGY SAVINGS

The energy system has various means of responding to binding reductions on GHG emissions and maintaining the same level of GDP. On the one hand, it can reduce the level of energy used per unit of GDP (the energy intensity). On the other it can change the fuel mix in order to reduce the carbon intensity. Analysing the division of the system's response between these two effects demonstrates where the system is most flexible. A reduction in the carbon intensity of the energy system signifies that substitution opportunities among fuels are more cost effective than substitution of energy by other goods.

Almost half of the emission reductions between the baseline and the 'Low GHG emissions' scenario are achieved through improvements in energy intensity in 2010 but their share declines to about one third towards 2030. This result reflects the increased difficulty that the European energy system will face in further reducing energy requirements. Modifications in the fuel mix will become more cost effective than the substitution of energy by other goods towards 2030, i.e. at the margin it is more difficult for the system to reduce overall energy demand than it is to change the mix in primary fuels. The use of solid fuels will be 70% lower than in the baseline and renewable energies would increase by 40%. As most of the fuel mix will occur in power generation, this sector will contribute to more than 70% of emission reduction in 2030 while the demand's side contribution will decrease over the projection period. However, all end-use sectors except transport exhibit declining emissions over the period 1990 to 2030.

As a result of the introduction of a wide variety of technologies to improve energy intensity and an expanded use of fuels with low or zero carbon dioxide, energy-related emissions of carbon dioxide in the EU-25 could be reduced to be 11% below 1990 levels in the 'Low GHG emissions' scenario while they would be 14% higher in 2030 than in 1990 un-

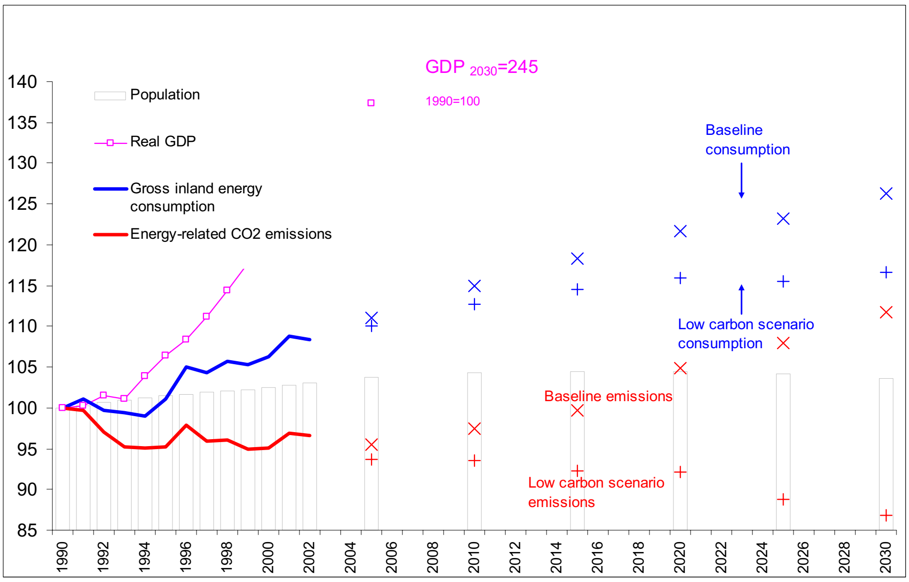


Figure 7. GDP, Population, Gross Inland Energy Consumption and energy-related CO_2 emissions in EU-25 *(1990-2002 historical data from Eurostat; 2010-2030 projections according to baseline and 'Low GHG emissions' scenario).*

Table 1. Indicators for the EU 25 energy system in the baseline and the 'Low GHG emissions' scenario.

		1990	2000	2030	
				Baseline	'Low GHG emissions' scenario
GDP (billions Euro 2000) (index)		7 315.2 (100)	8 939.3 (122)	18 020.3 (246)	18 020.3 (246)
Population (Millions) (index)		441.1 (100)	453.4 (103)	458.2 (104)	458.2 (104)
CO_2 emissions (Mt CO_2) (index)		3 769.5 (100)	3 664.9 (97.2)	4 303.6 (114.2)	3 345.8 (88.8)
Gross inland energy consumption (GIEC, Mtoe) (index)		1 554.3 (100)	1 650.7 (106)	1 959.7 (126)	1 810.8 (117)
Share of fuels in GIEC (%)	Solids	27.7	18.4	15.3	4.9
	Oil	38.4	38.5	34.4	34.7
	Gas	16.7	22.8	32.1	35.1
	Nuclear	12.7	14.4	9.5	12.0
	Renewables	4.5	5.8	8.6	13.1
Carbon intensity of GIEC (t CO_2 /t Mtoe) (index)		2.43 (100)	2.22 (91)	2.20 (91)	1.85 (76)
Final Energy Demand (Mtoe) (index)		1 009.2 (100)	1 074.4 (106)	1 394.1 (138)	1 291.7 (128)
Electricity demand (GWh)	Total (index)	-	2 509 104 (100)	3 944 614 (157)	3 795 090 (151)
	Industry (including refineries)	-	1 069 253	1 524 627	1 525 864
	Tertiary	-	651 453	1 208 037	1 135 735
	Households	-	694 722	1 114 413	1 041 556
	Transports	-	68 752	75 ,670	70 067
	Energy sector (excl. auto-consumption)	-	24 924	21 867	21 867
Energy intensity index (1990 = 100)	Industry (Energy on Value added)	-	82.7	51.3	48.7
	Residential (Energy on Private Income)	-	85.8	52.7	48.5
	Tertiary (Energy on Value added)	-	86.8	58.2	52.4
	Transport (Energy on GDP)	-	99.3	66.5	61.7
Carbon Intensity indicators	Electricity and Steam production (t of CO_2/MWh)	0.44	0.37	0.30	0.18
	Final energy demand (t of CO_2/toe)	2.26	2.12	1.83	1.77
	Industry	2.18	1.96	1.42	1.29
	Residential	1.94	1.66	1.44	1.39
	Tertiary	1.83	1.54	1.17	1.09
	Transport	2.90	2.91	2.80	2.80
Efficiency of thermal power production (%)		-	37.1	48.7	50.6
Import Dependency (%)		44.8	47.2	67.3	62.4

der baseline assumptions. This would also lead to a reduced import dependency compared with the baseline.

Total energy consumption (or: gross inland energy consumption) in the EU-25 increased during the period 1990-2002 by 8% at an average rate of 0.6 % per year. This was less than half the average growth rate of the economy over the same period but an absolute decoupling of GDP and energy consumption was however not achieved. Under baseline assumptions, total energy consumption is expected to continue to increase by 19% between 2000 and 2030, although the rate of growth is expected to slow over time. Under the 'Low GHG emissions' scenario, gross inland energy consumption is expected to increase less than under baseline consumption, being 9.7% above 2000 levels in 2030. This means that absolute decoupling is not achieved either.

Improvements in supply-side energy intensity

This sector reports fuels and technology substitution processes, both affecting the fuel mix of gross inland energy consumption. Under the 'Low GHG emissions' scenario, improvements in the overall intensity of energy supply are largely driven by improvements in the efficiency of electricity production based on fossil fuels. These improvements arise due to improvements in the technology used for any given fuel, through alternative combinations of technologies and fuels and from changes in the allocation of available plants in the merit order of dispatching. The further use of CCGTs (Combined Cycle Gas Turbines) as opposed to conventional thermal coal plant plays an important role. The result of these changes is that the overall efficiency of thermal electricity production in 2030 increases from 48.7% under the baseline scenario to 50.6% under the 'Low GHG emissions' scenario. While this improvement does not sound very much, it is sufficient to reduce CO_2 emissions by around 60 $MtCO_2$.

The power and steam generation sector of the European energy system appears to be the sector that can adjust in the most cost effective way to emission constraints. The introduction of a carbon permit price results in CO_2 emissions from power generation being 31% lower in 2030 than in 1990 instead of rising by 20% over this period under baseline assumptions. These reductions are achieved despite electricity consumption being only slightly under baseline levels (-4.3%) and well above 1990 levels (+45%). They are the result of a continuous shift from coal to gas and improved efficiencies as well as higher shares of non-fossil fuels in the 'Low GHG emissions' scenario. While under baseline assumptions the share of electricity produced from hard coal and lignite would decrease in the short term but increase after 2015, it will substantially decline over the entire period in the 'Low GHG emissions' scenario. A further penetration of natural gas-fuelled technologies is expected in both scenarios. In the long term, this growth is projected to decline as a result of higher natural gas import prices. In the 'Low GHG emissions' scenario, this change in trend is less important, leading to a slightly (3 percentage points) higher share of gas in gross inland energy consumption in 2030 than in the baseline. The efficiency of thermal power plants for electricity production is higher in the 'Low GHG emissions' scenario than in the baseline. Compared to the baseline, the emissions of this sector are between 35% and 52% lower in 2030. Fossil fuels, which have continued to be the dominant fuel for electricity production over the past years with a share of over half of total production in 2002, are expected to slightly decrease their share between 2000 and 2030 under the 'Low GHG emissions' scenario, while their share would increase by almost 11 percentage points in the baseline projection. Natural gas, which causes less pollution than other fossil fuels, is becoming the fuel of choice for new fossil-fuelled power plants; indeed CCGTs present considerable advantages over alternative options in technological, economic, and environmental terms. However, a lower growth of electricity demand as in the 'Low GHG emissions' scenario actually induces the expansion rate for new power plants and therefore the diffusion/adoption of more efficient technologies.

Most of the increase in renewable energy occurs in the electricity production sector. The share of non-fossil fuels (i.e. renewable energies and nuclear power) is expected to grow moderately compared with 1990 in the 'Low GHG emissions' scenario. However, it will be 40% higher than in the baseline, which projects the share of nuclear energy to decline steadily and the share of renewable electricity to increase only slightly. The share of renewables in electricity production is 28% and 17.4% respectively in the 'Low GHG emissions' and baseline scenarios. The expansion of renewables for electricity production is driven mainly by increases in the deployment of wind energy and biomass, whereas the role of solar energy becomes increasingly important in the long run. Under the 'Low GHG emissions' scenario and the baseline, the share of renewables in gross inland energy consumption would however fall short of the indicative EU target of 12% by 2010 and potential future targets. It demonstrates that the introduction of a 65 Euro/tCO_2 carbon price alone would not be sufficient to achieve ambitious targets for renewable energies. On the other hand, large and small hydro exhibit a less pronounced growth on top of baseline levels as their additional potential are relatively low. Under all scenarios the increase in the share of renewables is largely at the expense of coal and its share of total energy consumption declines to between 4.2% and 6.3%.

The share of nuclear power in electricity production falls from current levels as some of the existing plants are retired and no new nuclear power stations are built under the baseline scenario. In contrast, under the 'Low GHG emissions' scenario, new nuclear power stations are built in the EU-25 from 2015 onwards in response to the increased carbon permit price. In the 'Low GHG emissions' scenario, there are 26.4 GW of additional capacity compared to the baseline scenario by 2030, which brings the total installed capacity of nuclear power in Europe almost back to the level seen in 2000. It should be noted that both scenarios respect the existing phase-out policies in some European member countries.

Improvements in demand-side energy intensity

As on the supply side, CO_2 emission reductions on the demand side can be achieved through a combination of reduced final energy demand and changes in the fuel mix of final energy demand. Contrary to the power generation sector, most of the emission reductions on the demand side are due to a reduction in final energy demand. While final energy demand will increase to be 30% above 2000 levels in 2030 under baseline assumptions, further intensity improvements in the 'Low GHG emissions' scenario could limit this growth to 20% over this period, resulting in relative emissions reductions of almost 190 $MtCO_2$ (between baseline and 'Low GHG emissions' scenario). This relative decline in final energy demand contributes to more than 70% of the CO_2 emission reductions achieved on the demand side, with the rest being realised through fuel switching. However, changes on the demand side imposed by the introduction of allowance prices will decrease to 27% in 2030, while they accounted for about 43% of total reduction in CO_2 emissions in 2010. This reflects the increasing difficulty that the demand side will face in the long run in reducing CO_2 emissions, shifting the focus further to the supply side (i.e. power generation and energy branch).

Final energy consumption in the EU-25 increased at an average annual rate of just over 0.5% during the period 1990 to 2002, although between 2001 and 2002 it actually fell by just over 1%. It is projected to increase by about 0.9% per year between 2000 and 2030 (almost +30% over the period), although final energy intensity is projected to decline (see Figure 8). The 'Low GHG emissions' scenario demonstrates the importance of reducing final energy demand – with total final energy consumption being 7.3% lower in 2030 than under baseline projection.

Regarding final energy demand, the services and the household sectors are the most sensitive to the imposition of the carbon constraint (10% and 8% less final energy demand than in the baseline respectively), reflecting the existence of a significant potential for a more rational use of energy and the adoption of more efficient technologies. Also for transport, reductions in the energy demand of the sector are more important than changes in the fuel mix. This is due to the limited fuel substitution possibilities. On the other hand, additional reductions in final energy demand remain limited in the industry sector (5%). Changes in the fuel mix remain here the key driver for reducing CO_2 emissions of this sector by 14% ('Low GHG emissions' scenario compared to baseline).

The results of the 'Low GHG emissions' scenario show that the transport sector will be one of the most difficult areas to reduce carbon dioxide emissions, which will continue to grow over the next 30 years under all scenarios (to 25-58% above 1990). This is both because of the rapid increase in passenger and freight demand projected over the next 30 years and of a lack of alternative technological options to oil-fuelled vehicles. The impact of these two factors is that the transport sector is the only sector that shows continuously growing carbon dioxide over the next 30 years under all the scenarios that have been considered. Incentives towards a higher share of biofuels mixed in gasoline and diesel oil could however lead to a slowdown in CO_2 emissions growth. Despite the potential for further CO_2 emissions reductions as a result of a shift in transport modes, the 'Low GHG emissions' scenario suggests that a carbon-price alone would not be sufficient to initiate this shift, but additional policies are needed.

Final electricity consumption grew across the EU-25 at an average annual rate of just under 2% between 1990 and 2002. The increases in electricity consumption were due not only to a growing economy, but also because the share of electricity in final energy consumption increased. The attractiveness of electricity is due to its flexibility of use and the importance placed by consumers on the variety of energy services that it provides. Further substantial growth in electricity generation is expected. In the baseline scenario, electricity consumption would increase by 52% between 2000 and 2030. The 'Low GHG emissions' scenario shows an increase of 45 % compared to 2000 (-4.3% compared to baseline. Electricity production declines at rates lower than those affecting the total final energy demand, as efficiency gains in the demand side are largely counterbalanced by shifts in the fuel mix towards the use of electricity.

The baseline projections show substantial reductions in energy intensity in all sectors over the period 1990 to 2030 and further decreases are seen under the 'Low GHG emissions' scenario. However, given that the baseline assumptions result in significant energy intensity gains in all demand sectors, additional improvements in the 'Low GHG emissions' scenario are rather limited. On a sectoral basis, all end-use sectors (industry, household, services and transport sectors) show decreases in CO_2 emissions in 2030 compared to the baseline. They range from 16% in the services sector to 7.5% in the transport sector. Compared with 1990, the highest reductions are achieved in the industry sector (33%). Changes in the fuel mix remain the key driver for reducing CO_2 emissions from this sector in response to the carbon permit price. Services and household sectors' emissions are

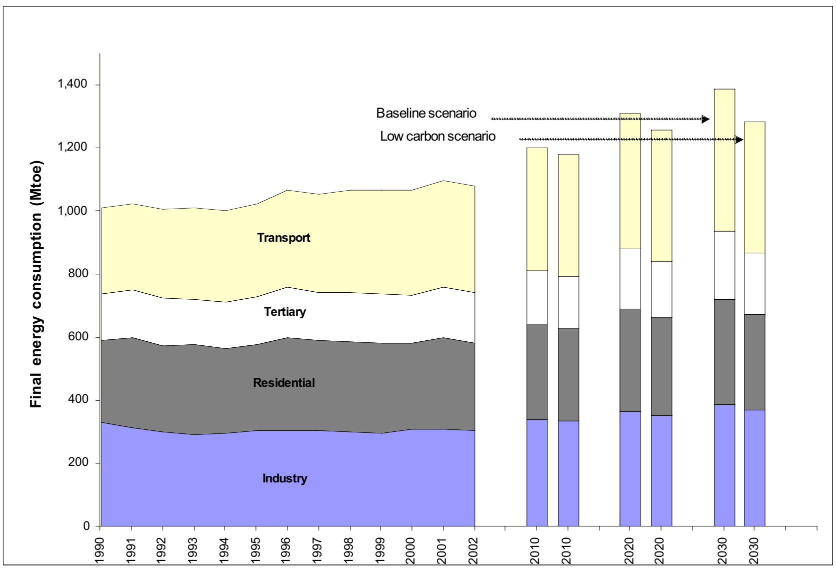


Figure 8. Final energy consumption by sector in EU-25 *(1990-2002 historical data from Eurostat; 2010-2030 projections according to baseline and 'Low GHG emissions' scenario).*

Table 2. Supply-side energy costs for the EU-25.

EU-25	Baseline			'Low GHG emissions' scenario
	2000	2020	2030	2030
Investment costs	61	61	91	94
Yearly operational and transmission costs	100	130	140	133
Fuel costs	48	76	87	154
Total (billion Euro (2000))	209	267	318	381
Average production cost (eurocents/KWh)	5.3	5.0	5.4	6.8

Table 3. Demand-side energy costs for the EU-25.

	Baseline			'Low GHG emissions' scenario
	Demand-side excluding transport (% value added or private income)			
EU-15	2000	2020	2030	2030
Industry	8,8	6,9	6,2	7,6
Services	1,5	1,4	1,3	1,5
Agriculture	6.6	7.2	7,6	8.9
Households	5,4	7,2	7,6	7,8
All categories	5,8	6,4	6,4	6,9
New-10				
Industry	18,2	9,9	9,0	11,6
Services	3,1	2,3	2,1	2,5
Agriculture	14.2	11.3	11.2	13.6
Households	8,8	15,8	15,6	16,0
All categories	13,0	16,1	15,4	16,6
EU-25	6,2	6,9	6,9	7,5
	Transport (Euro per pkm or tkm travelled)			
EU-15				
Passenger	0.21	0.22	0.24	0.24
Freight	0.28	0.30	0.33	0.32
New-10				
Passenger	0.22	0.25	0.27	0.28
Freight	0.21	0.28	0.31	0.30
EU-25				
Passenger	0.21	0.22	0.24	0.25
Freight	0.27	0.30	0.32	0.32
	Households (Euro (2000)/household)			
EU-15	1 660	2 940	3 580	3 690
New-10	930	3 280	4 340	4 460
EU-25	1 550	2 990	3 690	3 800

16-17% below 1990 levels in 2030. This means that under the 'Low GHG emissions' scenario, all sectors except transport, exhibit declining emissions over the period 1990 to 2030.

Costs and prices associated with the 'Low GHG emissions' scenario

Tables 2 and 3 below report respectively the supply-side and demand-side energy costs (i.e. all fuel and technology costs) for the baseline and the 'Low GHG emissions' scenario. Please note that supply-side and demand-side energy costs cannot be added since the former are partly passed on to end-users.

As far as supply is concerned (i.e. this includes the power and steam generation but excludes refineries), the additional costs of the 'Low GHG emissions' scenario compared to the baseline would be about 63 billion Euro in 2030. In EU GDP terms, which is projected to more than double between 2000 and 2030, this would represent 0.35%, which in turn translates into an increase of more than 25% of the average production cost. The investment costs in the 'Low GHG emissions' scenario is the net result of two off-setting effects: on the one hand, lower investments due to a lower overall electricity demand growth, and on the other hand, higher (substitution) investments to comply with the GHG emissions targets. The considerable increase in fuel costs directly reflects the introduction of carbon permit prices (rising to 65 Euro/tCO_2 in 2030 and 120 Euro/tCO_2 by 2050).

As far as demand is concerned, the various sectors are affected differently depending on their energy and carbon intensities. The additional cost of the 'Low GHG emissions' scenario is estimated at 0.6% of the EU GDP by 2030, on top of which the transport costs have yet to be added. Since this estimate reflects net costs, i.e. it takes into account the considerable savings due to lower energy demand, it represents a non-negligeable cost. Under baseline assumptions, the energy bill for households is projected to increase by 1 900 Euro/household in the EU-15 and 3 400 Euro/household in the New-10 in 2030 compared to 2000. In comparison, the add-on in the 'Low GHG emissions' scenario would be relatively small with about 110-120 Euro per household.

In the above, the macro-economic impacts of the 'Low GHG emissions' scenario have not been estimated, nor the feedback effects of climate change policies on economic activities been included in the modelling tools. These effects are currently been estimated within a separate project.

A NEED FOR AN ENHANCED ENERGY POLICY FRAMEWORK

The modelling results demonstrate that the transition towards a low-carbon energy system would be substantially enhanced by the introduction of a carbon permit price, that rises up to 65 Euro/tCO_2 in 2030. Achieving a sustainable energy system requires however additional policies and measures in addition to a carbon price, which would reflect the wider benefits of a sustainable energy system, such as reduced import dependency. An enhanced policy framework would be required to support low and zero-carbon technologies and the exploitation of further possibilities to reduce energy demand and practices. These include the removal of harmful subsidies; the setting of long-term targets for improving energy intensity and reducing energy consumption and increasing the share of renewable energies; greater support for research, development and demonstration into sustainable energy technologies in order to support and promote innovation and yield significant cost reductions and performance improvements. Furthermore, awareness-raising could contribute to change consumer's choice and behaviour (e.g. buying energy-efficient appliances, using public transport instead of cars), resulting in additional reductions in final energy demand in the household, services and transport sectors. Finally, there is a need for more integrated approaches to policy-making. This means that climate change along with other policy areas such as energy, transport, development or regional and structural funds, need to come together.

Conclusion

This paper reported the results of a baseline projection and a climate change scenario, suggesting that substantial energy savings are technologically achievable through market-based instruments tailored to combat climate change drastically. The respective contributions of fuel and technology substitutions and energy demand reductions have been discussed and suggest contrasted results depending on whether the supply or the demand sectors are considered. However, it seems that at the margin it is more difficult for the system to reduce overall energy demand than it is to change the mix in energy fuels. One should also note that the possible impacts of the 'Low GHG emissions' scenario on the EU economic competitiveness and innovation are currently being assessed and shall be reported in additional dedicated articles. However, as the previous section highlighted, additional energy policies are thought to be necessary to accompany climate change policies as catalysts for energy savings, and make the most of possible co-benefits and synergies. In this respect, bottom-up approaches to energy policies and savings, in which agents' behaviour, detailed implementation of policies and investments are given specific attention, could adequately complement the study reported here.

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