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The Vision Scenario for the European Union

2011 Update for the EU-27

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Executive Summary

Global climate change, finite fossil and nuclear resources and the vulnerability of economies and consumers to increasing and volatile prices of fossil energies are the challenges which will determine energy and climate policies for the next decades.

The Vision Scenario represents a pathway which consistently combines short- and medium-term objectives with the long-term objectives. Furthermore it is in line with the greenhouse gas emission budget, which could allow the increase of the global mean temperature to be kept to a level below 2°C compared to pre-industrial levels.

The quantitative scenario analysis of the energy system and all greenhouse gas emissions sources (except land use, land-use change and forestry) and of different ambitions in energy and climate policy outlines significantly different pathways for future energy and climate policies:

- In the Reference Scenario, which is based on recent ambitions in energy climate policies, an emission reduction of 19% (compared to 1990 levels) by 2020, 25% by 2030 and 38% by 2050 is achieved. Renewable energies contribute 13% of the primary energy supply in 2020, 16% in 2030 and 24% in 2050. The share of power generation from renewable energies in total electricity generation represents 24% in 2020, 29% in 2030 and 46% in 2050. The level of nuclear power production remains at recent levels for the next two decades and decreases from 2030 onwards.
- The Vision Scenario is based on a greenhouse gas emission reduction target in accordance with the EU's long-term goal. The total greenhouse gas emission reduction amounts to 35% in 2020, 57% in 2030 and 91% in 2050. Additional measures in land use, land-use change and forestry could enable a 95% emissions reduction. Renewable energies represent a share of 20% in the total primary energy supply in 2020, nearly 40% in 2030 and about 90% in 2050. The power sector undergoes a process of early decarbonisation; the share of renewable energies in total net power generation is 39% in 2020, 60% in 2030 and 94% in 2050. Nuclear power in the EU is phased out in this scenario by 2040.

To achieve the transition to a zero-carbon economy as outlined in the Vision Scenario three main subjects need to be addressed.

Firstly, significant energy efficiency improvements must be achieved in all sectors in the next decades. Addressing the efficiency potentials in a timely manner is one of the key challenges, especially for sectors with durable capital stocks (e.g. the building sector). The reduction of transport demand and the shift from road or air transport to rail transport are some of the key components in increasing energy efficiency. Ambitious standards for vehicles, new and existing buildings and electrical appliances are other key requirements for the pathway outlined in the Vision Scenario.

Secondly, the transition to carbon-free energy sources is necessary in all sectors. In the end-use sectors the direct use of renewable energy sources and electricity or heat

produced from renewable energy sources must assume the major share of energy supply. The power sector must undergo an early transition to the use of renewable energy sources in order to phase-out carbon-intensive energy sources at an early stage. Furthermore, the electrification of transport and possibly the use of electricity in the heat market is only a sustainable option if a sufficient share of renewable energies is in place as a result of the early transition of the power sector to renewable energies. The Vision Scenario outlines a transition pathway whereby renewables have a 60 % share and natural gas nearly a 30% share in total power generation in 2030. In combination with a modernised electricity infrastructure and storage technologies this power generation mix can ensure the necessary flexibility for a massive uptake of renewable energies in power generation. The full range of renewable energy sources (hydro, onshore and offshore wind, photovoltaics, concentrated solar power, solar heating and cooling, biomass, geothermal energy) will be necessary for the transition outlined in the Vision Scenario. The supply of sustainable biomass and the phase-in of sustainable biofuels are key enabling options, especially for the transport sector.

Thirdly, a wide range of other measures is necessary to achieve greenhouse gas emission reductions of 90% and more. Industrial processes, waste management, and agriculture must be subject to significant emission reduction efforts. Increasing the efficiency of resource use (steel, cement, etc.) and putting carbon capture and storage (CCS) in place will be necessary, at least for industrial processes and in combination with biomass use, to create net carbon sinks (bio-energy with carbon capture and storage – BECCS).

A transition of the energy system as outlined in the Vision Scenario could also decrease significantly the imports of fossil and nuclear fuels and the overall dependence on imports. In the transition outlined in the Vision Scenario, energy imports will already be well below recent levels in 2020 and will significantly decrease in the subsequent decades. This trajectory would also significantly limit the wealth transfer from the EU to non-EU producers of mineral oil, natural gas, hard coal and nuclear fuel (approx. € 130 bn annually in 2020, € 260 bn in 2030 and € 455 bn in 2050), making the EU economy as a whole more resilient to the emerging high energy prices and energy and price volatilities. Furthermore, the trajectory could ensure that the EU remains a lead market for sustainable future energy technologies and systems.

Meeting the long-term targets (keeping the increase of global mean temperature less than 2°C and the realisation of a corresponding 95% greenhouse gas emission reduction by highly industrialised regions like the EU) will require consistent short- and medium-term targets. If the durable capital stocks (power plants, buildings, infrastructures) and innovation are to be addressed appropriately, greenhouse gas emission reduction goals should be complemented by targets for energy efficiency and renewable energies in key sectors (power sector, buildings, transport sector).

With regard to emission trajectories it should be highlighted that the level of cumulative emissions is a key parameter for assessing the sustainability. Ambitious and early emission reductions are essential to limiting the EU's exhaustion of the global greenhouse gas emission budget for achieving the 2°C target. Only a reduction target of 30%

or more by 2020 can be seen as in line with the global 2°C target. Even in the ambitious Vision Scenario the EU will use about 11% of the global emissions budget which is nearly the double of the EU's share of 5.7% in the projected world population and far from a pure equity- and per-capita-based budget sharing.

A smart policy mix for this necessary transformation should create a robust and accountable political framework which also provides the necessary level of certainty to investors, consumers and policy-makers. It should include:

- a series of consistent and transparent targets for greenhouse gas emissions, energy efficiency, renewable energies and innovation;
- comprehensive approaches to putting a robust price on greenhouse gas emissions by tightening the EU ETS cap consistently to the 30% target, ensuring the integrity of the scheme and significant energy or CO_2 taxes in non-ETS-regulated sectors;
- ambitious policies to increase energy efficiency in its different dimensions (new and existing buildings, vehicles, electrical appliances, etc.) drastically;
- robust and accountable support schemes for renewable energies which provide incentives for innovation as well as providing certainty and reflecting the national and regional dimension of infrastructure upgrades and roll-outs with long lead-times;
- ambitious approaches to upgrading and the roll-out of the necessary infrastructure for energy (at the transmission and distribution level as well as for storage) and transport, reflecting planning and regulatory issues as well as long lead-times and public acceptance;
- a carefully developed scheme to enable the supply of sustainable biomass and to manage strategically the use of limited potentials of sustainable biomass; and
- comprehensive strategies to trigger a wide range of necessary innovations in key enabling technologies and services (energy and resource efficiency, energy supply, infrastructures, etc.)

Last but not least, the development of comprehensive, consistent and flexible policies and measures within the framework of the European Union, which features many distributed responsibilities, requires a high degree of transparency in terms of interactions and gaps between the different policies and instruments on the one hand and the gaps in compliance with targets on the other hand. A suitable approach to dealing with this challenge is policy-oriented modelling. Significantly increased efforts should be undertaken in order to develop a transparent bottom-up modelling framework for the EU which enables the assessment and the development of policies and measures on a consistent and transparent basis.

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1 Introduction and scope of the paper

Energy and climate policy faces manifold and far-reaching challenges in the 21st century:

- The problem of global climate changes requires fast and significant reductions in greenhouse gas emissions to stabilise the concentrations of these gases at a level which is sufficient to limit the increase of the global mean temperature to a level not exceeding 2°C above pre-industrial levels;
- Finite fossil and nuclear fuel resources and the foreseeable concentration of fuel production in some politically sensitive regions increasingly highlight the problem of energy security;
- The integrated world energy markets and liberalised energy markets increasingly face the problem of highly volatile energy prices, which leads to the increased vulnerability of economies.

Against the background of these challenges, a business-as-usual approach in energy policy is increasingly being seen as no longer acceptable.

For the emerging transformation of energy policy, the challenge of global climate change is of huge importance. To keep global warming within a mean global temperature increase of no more than 2ºC, which is considered still manageable and to which it will presumably still be possible to adapt, worldwide greenhouse gas emissions must be reduced to less than one metric ton of CO_2 equivalent per capita per year, and must be stabilised there (Ecofys 2009). The latest research findings (Meinshausen/Meinshausen 2009) indicate that for the period from 2005 to 2050, the remaining global budget is approx. 800 billion metric tons in the case of CO_2 emissions, and 1,230 billion metric tons of CO_2 equivalent in the case of all greenhouse gas emissions, if there is to be a sufficient probability (75%) that the increase in mean global temperature compared to pre-industrial levels can be kept to less than 2ºC. Hence the rapid, sharp, and sustainable reduction of emissions is essential, especially among large emitters. If an international agreement to this end, which includes today's emerging economies, is to have a chance of being implemented, industrialised nations must commit to significant emission reductions. Moreover, they must provide the technologies to make these reductions possible.

Against this background the European Union has decided to set an 80 to 95% reduction of emissions by 2050 compared to 1990 levels as an EU objective (CEU 2010, EP 2010). This long-term objective is a key reference, also for short- and medium-term policies.

The energy system tends to be slow to change; the main drivers and influencing factors are durable goods and long-term capital investments like buildings, vehicles and power plants. Today's investments, because of their long service lives, will undoubtedly have effects up to 2050 and beyond. Conversely, this means that a drastic reduction in greenhouse gases by 2050 may already require changes in energy-related investments and strategic investment priorities today.

However, there is no silver bullet for solving the majority of the problems that energy and climate policy faces today. Many options must be explored and it will be necessary to implement many options.

Risk minimisation is the key strategic approach to meeting the various challenges. The proven advantages for the options to be used must be greater than the risks and the uncertainties connected to these options.

There is a wide consensus about some options which can be seen as favorable for energy-related activities:

- There is huge potential for energy efficiency in the end-use sectors and the energy sector which can be exhausted to a much greater extent than can be assumed in the business-as-usual case;
- Renewable energies must play a key role in the future energy system, in power production, heating and cooling as well as in the transport sector.

In addition to these options, there is another emerging technology which could play a role in the medium term:

- Carbon capture and storage (CCS) could contribute significantly to future CO_2 emission reduction at least for industrial processes or the creation of net carbon sinks by bio-energy with CCS (BECCS). However, many scientific, technological and economic problems must be solved; the regulatory framework for this technology is predominantly lacking; and public acceptance is crucial for this technology pathway.

Besides the matured and consensual, and the emerging and potentially consensual, options for the development of a future energy system, the debate is affected by a strong controversy:

- There is no foreseeable consensus on the acceptability of nuclear power against the background of the possibility of large nuclear accidents and the manifold problems related to the handling of nuclear materials (from mining to the processing of nuclear materials and the management of nuclear waste).

Although there is much consensus on the future role of energy efficiency, renewable energies or potentially CCS in general, many questions remain regarding the potential and the contribution of the different options to the necessary transformation of the energy system. A key challenge of the debate is to identify the potential of these options and the extent to which these potentials must be tapped so that the overarching goals of climate protection and energy security can be met at acceptable costs.

The purpose of the analysis presented in this paper is to examine potential combinations of the manifold options of energy efficiency and renewable energies as well as the shift to low carbon fossil fuels and the medium-term option of CCS over time, to identify key challenges and areas of action and to derive some technical and political conclusions. As a result of the analysis, a vision of the fundamental transformation of the energy system should evolve to assess the outcome of recent policies and measures and to contrast it with activities which go significantly beyond the business-as-usual case. Special focus was placed on the analysis of the relations between different technical or political measures and their outcome in terms of greenhouse gas emissions and in terms of changes in the final and primary energy consumption.

Against this background, the analysis presented in this paper should be understood as a contribution to the necessary discussion on how and how quickly the energy system in the European Union could be restructured so as to meet the challenges of climate change, energy security and other dimensions of sustainable development.

This paper presents the results of an update of the modelling exercise for the EU-25 which was presented in 2006 (Öko-Institut 2006). However, the scope of the analysis was extended significantly:

- The scenario analysis was extended to the year 2050 which is an important marker for the assessment of climate policies with regard to the 2°C target.
- The analysis includes the full range of greenhouse gases regulated by the Kyoto Protocol.
- The analysis was adjusted to the European Union of the 27 Member States.

The work on the study was conducted in a varied process of dialogue and fruitful discussions within the project team and with the project sponsor, as well as with various colleagues from other institutions and organisations who delivered data and further information which was extremely valuable given the time and resource constraints for this study. For this extensive support the authors would like to express their thanks. Special thanks go to Vanessa Cook and Sean Healy of Öko-Institut who worked on the English editing of the text. Responsibility for the contents of the study naturally resides with the authors.

2 Methodological approach

The analysis presented in this study is based on the scenario approach. The development of scenarios offers the possibility of assessing the implications and interactions and the total effects of certain energy and climate policy strategies in a transparent manner. The analysis is based on two scenarios:

- The business-as-usual scenario (Reference Scenario) indicates a development that could result if recent energy and climate policies are not strengthened;
- The Vision Scenario is a normative scenario based on four main assumptions:
    - All non-controversial greenhouse gas mitigation options should be used for the time horizon of 2050 so that an emission reduction of at least 90% can be reached by the year 2050 compared to 1990 levels and a greenhouse gas emission reduction of at least 30% should be achieved by 2020;
    - The use of nuclear power should be phased out based on the existing phase-out policies of different Member States of the EU or a technical lifetime of 40 years; in other words, no significant lifetime extension of existing nuclear power plants should be assumed and no new investments in nuclear power should be taken into account.
    - The technology of carbon dioxide capture and storage (CCS) is only used as a mitigation option for those greenhouse gas emission sources for which there are no alternatives. This includes CO_2 emissions from industrial processes like crude steel production in blast furnaces, the calcination within the production of cement clinker as well as the creation of net carbon sinks from the combination of biomass transformation with CCS (bio-energy with CCS – BECCS).
    - The potential of sustainable biomass for energy use is limited to the sustainable biomass potential of the EU-27 and biomass imports at a level which is acceptable from an equal access rights perspective, as developed by Prognos/Öko-Institut (2009). According to this concept the total use of biomass should not exceed the global sustainable biomass potential for energy use on a per capita basis. Based on this principle, the total biomass use in the EU-27 (domestic production plus imports) should not exceed the level of about 30 GJ per capita. For the domestic bio-energy potential the underlying assumption for the modeling is 10,000 PJ for the EU-27.[1]

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[1] This level of domestic bioenergy potential is based on a rough indication of the upcoming results from EEA's work on environmentally compatible bioenergy potentials in the EU-27, and preliminary results from the EU FP7 project "Biomass Energy Europe". The potential of

The starting point for the development of the Reference Scenario is the results from the EU energy trends to 2030 project of DG Energy (2010) which were slightly modified to the most recent information and extended to 2050, based on an analysis of the respective energy consumption or emission trajectories in relation to the underlying driving forces. In a first step, the underlying projection for the Reference Scenario was analysed on the basis of the data and information given in the scenario report. In addition to the information which could be derived directly from the documentation, additional expert estimations were carried out to fill in the remaining data gaps.

The modelling of the Vision Scenario is based on a series of other studies on EU projections:

- The analysis for the power sector is chiefly based on the modelling exercise of the German Aerospace Center for Greenpeace/EREC (2010).
- The analysis of the transport sector is based on key assumptions and the modelling tools of the Transport 2050 project (Skinner 2010).
- The analysis for the other end-use sectors as well as the CO_2 emissions from industrial processes and the non-CO_2 greenhouse gas emissions are based on the trends and dynamics in the Blueprint Germany project conducted for WWF (Prognos/Öko-Institut 2010), which were adjusted to the EU-27 on the basis of existing literature and supplementary expert estimations.

The different sector projections were integrated and made consistent with an integration model which was originally developed for the Vision Scenario project (Öko-Institut 2006) and was significantly extended for the analysis presented in this paper.

All historic time series (for the years from 1990 to 2008) are based on data from Eurostat (energy data) and from the EU Member States inventory submissions to the United Nations Framework Convention on Climate Change (UNFCCC) in 2010.

The analysis was carried out on an aggregate level for the European Union with 27 Member States (EU-27). The greenhouse gases regulated by the Kyoto Protocol (carbon dioxide – CO_2, methane – CH_4, nitrous oxide – N_2O, hydrofluorocarbons – HFCs, perfluorocarbons – PFCs, and sulfur hexafluoride – SF_6) formed the scope of the analysis. Greenhouse gas emissions from international air transport were included in the analysis; emissions from international maritime operations as well as from land use, land use change and forestry (LULUCF) were not included due to a lack of available information or modelling capacities.

10,000 PJ until 2030 can be expected to be domestically available without adding additional pressure on EU land use and biodiversity. Approx. 35% of this potential would be based on residues and wastes, and two thirds would come from energy crops, especially so-called "second generation" perennial plants delivering lignocellulose, e.g., short-rotation coppices, and energy grasses.

If not otherwise indicated, the metrics of all calculations are in tons of oil equivalent (toe) or in billion kilowatt hours (TWh). Greenhouse gas emissions are expressed in tons of carbon dioxide equivalent (t CO_2e) for the non-CO_2 greenhouse gases and the respective totals; and in tons of carbon dioxide (t CO_2) for the energy-related emissions.

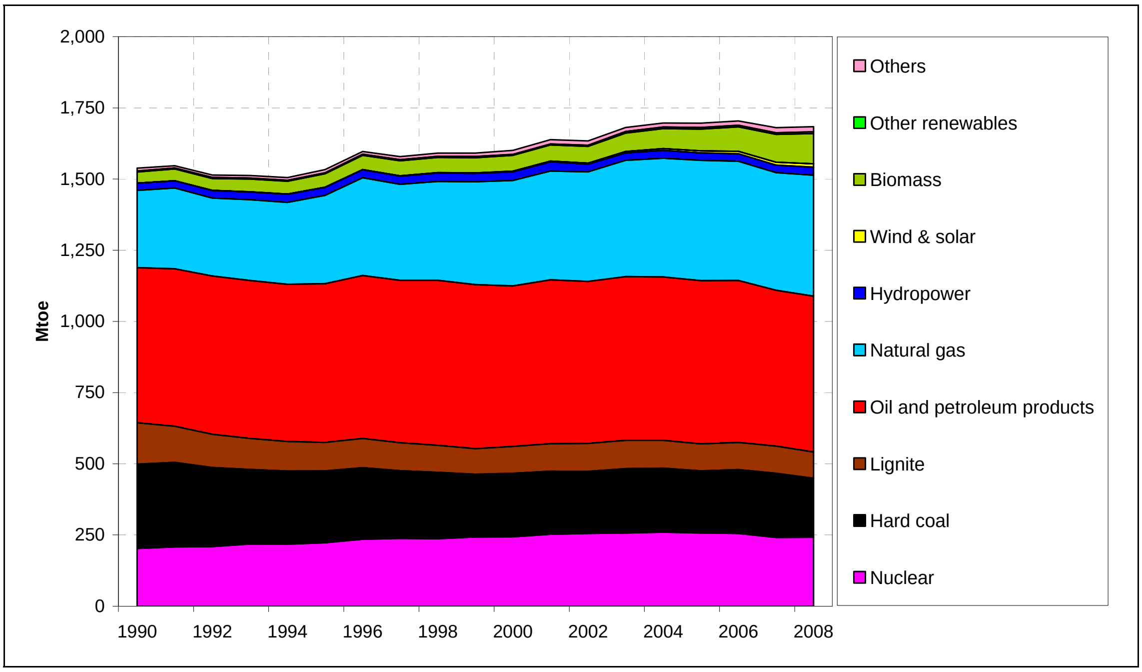
For all calculations the statistical definitions and classifications of Eurostat and the International Energy Agency (IEA) were used.

3 Recent trends in energy supply and greenhouse gas emissions in the EU-27

The development of the total primary energy supply (TPES) of the EU-27 in the period between 1990 and 2008 is characterised by two main trends (Figure 1).

Firstly, the years directly after 1990 show that the economic crisis had a significant impact on the new Member States and the eastern part of Germany, which led to a slight decrease in primary energy consumption for the EU-27. However, apart from this special trend in the eastern economies in transition, the TPES rose steadily. The TPES peaked in 2006 and then subsequently decreased slightly in recent years. In 2008 the TPES amounted to 146 million tons of oil equivalent (Mtoe) above the 1990 level, which is equivalent to an increase of about 9%.

Figure 1 Total primary energy supply by fuel in the EU-27, 1990-2008



Source: Eurostat, Öko-Institut.

Secondly, significant changes in the structure of primary energy can be observed. The share of hard coal and lignite decreased, while the role of natural gas expanded and the contribution of renewable energies increased significantly. In 1990 the share of hard coal in the TPES was 19% and the share of lignite amounted to 9%. By 2008, these shares decreased to 12% and 5.5%, respectively. The contribution of natural gas to the TPES increased from 18% to 25%. The highest growth rates occur in renewable energies, which supplied 124% more primary energy in 2008 than in 1990. However, because of the low base level, the share of the TPES only increased from 4% in 1990 to 9% in 2008. Only small changes can be observed for the contribution of oil and nuclear energy. The share of oil in the TPES decreased slightly from 35% in 1990 to 33%

in 2008 and the contribution of nuclear energy increased from 13 to 14%. In absolute terms the level of oil consumption was still at the 1990 level in 2008 and the supply of nuclear energy increased by about 19% from 1990 to 2008 in the EU-27. However, the level of oil and nuclear consumption has declined since 2004.

Last but not least, the share of fuel imports increased significantly. The import dependency of the EU-27's energy system grew significantly. The total share of imported fuels in the TPES rose from 62% in 1990 to 75% by the year 2008.[2]

In total, the increase in TPES was compensated by the trend towards fuels with lower carbon emissions, which results in a slight decrease of carbon dioxide (CO_2) emissions from energy use. Nevertheless, it should be highlighted that the decrease of energy-related CO_2 emissions occurred essentially by the mid-1990s. Since then the CO_2 emissions have been almost stable at a level of 6% below 1990 levels.[3]

The decrease of energy-related CO_2 emissions results from very different trends among the energy and end-use sectors:

- CO_2 emissions from power productions decreased in the 1990s to levels which were 10% below 1990 but increased again in the first years of the last decade and almost reached 1990 levels in the period from 2003 to 2007. In 2008 the emissions decreased again to a level of 5% below 1990.
- Energy-related CO_2 emissions from industry declined steadily in the last two decades and were 31% below 1990 levels in 2008.
- A general declining trend also can be observed for the CO_2 emissions from private households and the tertiary sectors. In 2008 the respective levels were 12% (private households) and 18% (tertiary sectors) below the 1990 levels.
- The only sector with a significant increase of energy-related CO_2 emissions is the transport sector. From 1990 to 2008 the total emissions increased by about 30%. During recent years the emissions growth slowed down and decreased slightly in 2008.

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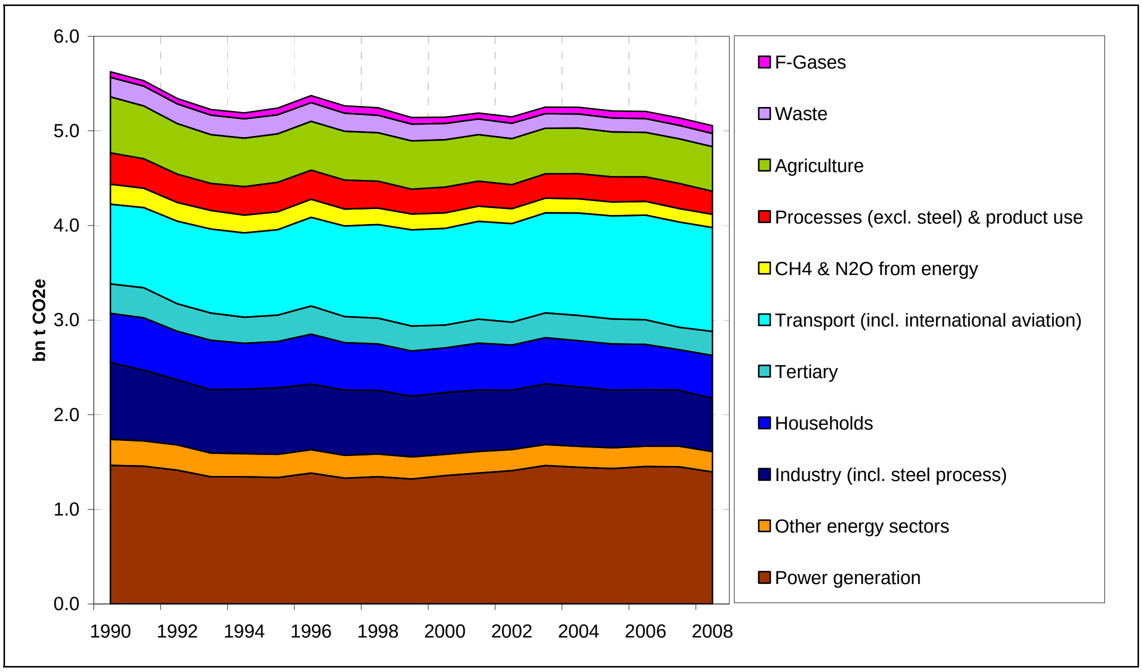
2 In most of the official statistics, the share of imported fuels is lower than the data indicated above. The main reason for this is the fact that nuclear fuels are not considered as imported fuels in this approach. In this study we consider nuclear fuel as that which it is: a fuel that is more or less completely imported to the European Union.

3 CO_2 emissions from land use, land-use change and forestry (LULUCF) were not taken into account although some Member States intend to do so for the first commitment period of the Kyoto Protocol. Furthermore, it is important to mention that CO_2 emissions from international air transport are not included in the totals of GHG emissions reported under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Against the background of the exceptional growth of air transport in the course of the last decade GHG emissions from international air transport were fully included in the analysis presented in this report. Last but not least, it should be mentioned that CO_2 emissions from fossil fuel use in the iron and steel industry as a reduction agent is attributed to energy-related emissions in the model used for this study. In the GHG inventory reports to the UNFCCC a significant share of these emissions is accounted for GHG emissions from industrial processes.

Figure 2 Greenhouse gas emissions in the EU-27, 1990-2008



Source: Inventory reports of the EU and Member States, Eurostat, Öko-Institut.

The total decrease of GHG emissions in the period from 1990 to 2008 amounts to 10%. This is because non-energy and non-CO_2 emissions decreased much more significantly than energy-related CO_2 emissions:

- GHG emissions from industrial processes and product use, mainly CO_2 and N_2O, decreased by approximately 26% from 1990 to 2008.
- GHG emissions from agriculture, mainly CH_4 and N_2O, declined significantly from 1990 to 2005 and have stagnated since then at a level which is about 20% below the 1990 levels.
- GHG emissions from waste management decreased steadily over the last two decades and reached a level of 33% below 1990 in 2008.

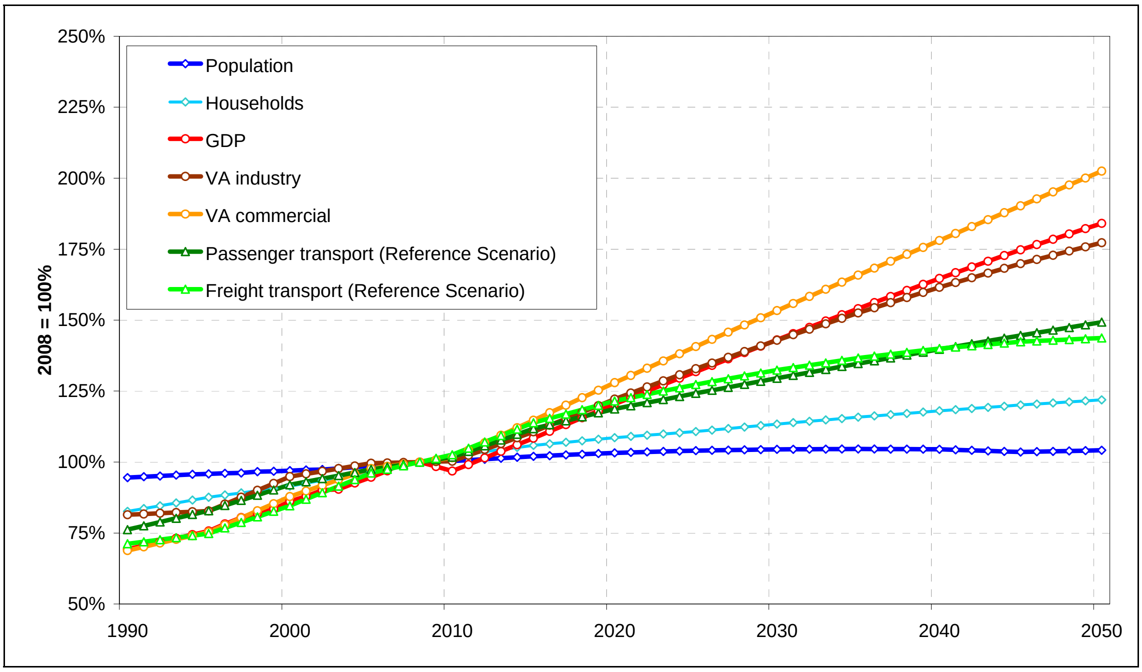
The only segment of non-CO_2 emissions with permanently increasing GHG emissions is the release of HFC, PFC and SF_6 to the atmosphere. In 2008 these emissions were about 40% above 1990 levels.

The trends for the total level of primary energy supply as well as for the structure of TPES and the GHG emissions clearly indicate that major efforts will be necessary to achieve major emission reductions for all GHG with a special focus on CO_2 as the most important greenhouse gas.

4 Main economic and demographic drivers

Figure 3 indicates some of the key drivers for the economic and demographic development considered for the scenarios. These assumptions were taken from the recent projections of DG Energy (2010) and extended to 2040 and 2050.

Figure 3 Economic and demographic drivers for the scenarios, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

The main assumptions regarding population, households, gross domestic product (GDP) and the value added from the industrial and commercial sectors remain unchanged for the different scenarios. Only for the transport sector were different assumptions considered in the Reference Scenario and the Vision Scenario, which were derived from the assumptions on model shift, etc.

- As regards population development, only a small increase is projected; in the period from 2008 to 2030 the population in the EU-27 grows by about 4.5% and slightly decreases beyond 2030. The EU-27 population amounts to approx. 514 million inhabitants in 2020, approx. 520 million in 2030, and approx. 518 million in 2050.
- However, the number of households is projected to grow significantly, mainly because of the trend in many Member States towards smaller families and single households. During the period from 2008 to 2020 the number of households increases by about 9%; and by another 13 percentage points up to 2050.
- The growth of GDP in the period from 2008 to 2020 is significant; the level of GDP, in constant terms, will be 20% higher compared to the 2008 levels (the effects of the economic crisis in 2008/2009 are fully reflected in this projection). In

2050 the total level of GDP will exceed the 2008 levels by more than 80%. The economic growth for the next four decades amounts to 1.5% on average.

- Industrial production will increase at a slightly lower rate, which is based on the assumption that major dynamics in the economic development of the EU-27 will result from growth in the tertiary sectors. The value added in the commercial sector will grow by about 22% from 2008 to 2020 and by a further 55 percentage points from 2020 to 2050.
- A significant growth is projected in transport activities. In 2020 the level of passenger transport activities in the Reference Scenario will exceed the levels from the year 2008 by 19%; from 2020 to 2050 the passenger transport activities are projected to increase by additional 30 percentage points. Freight transport activities increase from 2008 to 2020 by 21.5% and another 22% for the period from 2020 to 2050.

In general, the trends, dynamics and the interactions between the different driving forces are in line with the trends observed for the last 30 years.

5 Reference Scenario and Vision Scenario

5.1 End-use sectors

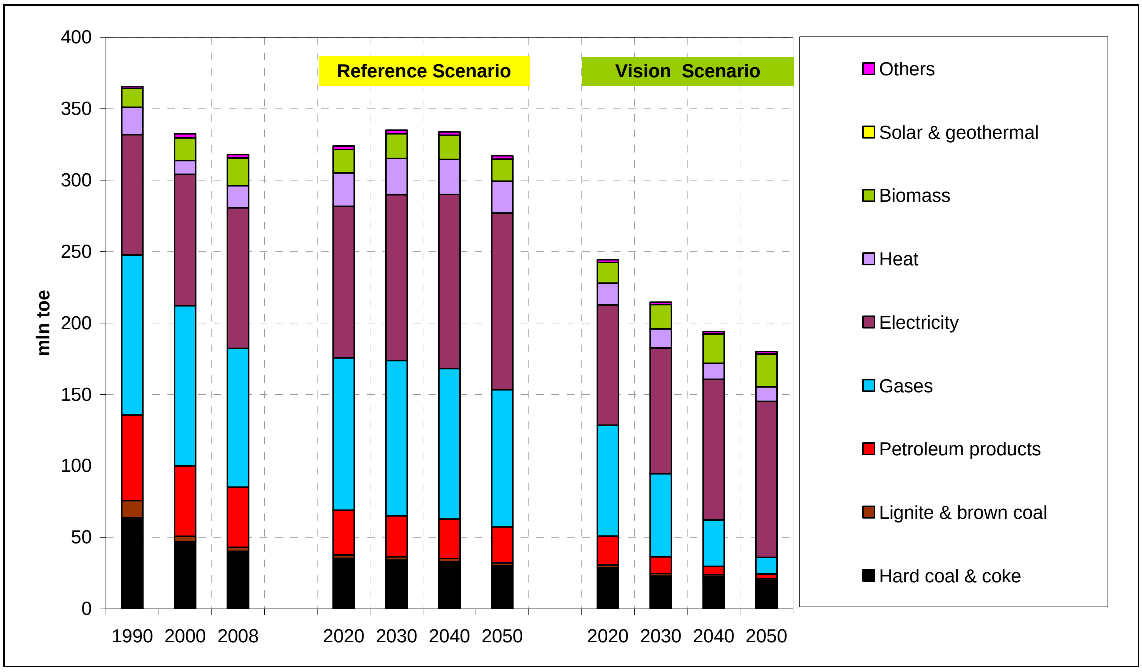
5.1.1 Industry

The final energy consumption of industry was the main energy consuming sector in 1990. With a share of 34% in total, final energy consumption of industry was by far the most important sector compared to private households, tertiary sectors and transportation.

In the decade between 1990 and 2000, this pattern changed. The energy consumed in the transport sectors (including international air transport) was higher than in industry. This is mainly because the energy consumption in industry decreased from 366 Mtoe in 1990 to 318 Mtoe in 2008 and the energy consumption in all other sectors rose significantly.

However, industry is still the largest consumer of electricity among the final energy sectors. More than 40% of the total electricity consumed in the final energy sectors came from industrial consumers. Industry also makes up the largest share of fuel consumption in terms of final energy for solid fuels and for natural gas.

Figure 4 Final energy consumption by fuel in EU-27 industry, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

In the Reference Scenario, the final energy demand is projected to rise by 2030 and to decrease slightly beyond 2040 (Figure 4). The total final energy consumption increases by 2% by the year 2020 compared to 2008 levels. In the period from 2030 to 2040 the final energy consumption reaches a level of 5% above the 2008 levels and then returns to the 2008 consumption levels by 2050. Whereas the consumption of solid fuels and petroleum products is projected to decrease further, the consumption of natural gas is projected to moderately increase from 2008 to 2030 by 12% and then to decrease to the 2008 levels by 2050. It is considered that the electricity consumption will rise steadily by 8% in the period from 2008 to 2020 and by another 18 percentage points from 2020 to 2050. The role of renewable energies in industry remains slight, amounting to approx. 5% of total final energy consumption in the period from 2020 to 2050.

The Vision Scenario for industry is based on four key assumptions for the industrial sectors:

- The structural change between energy-intensive industries and the other industrial sectors will continue. In addition to the structural change assumed in the Reference Scenario, the Vision Scenario includes further changes driven by innovations in efficiency (e.g. changes in construction and in upgrade work, the production of new materials). As a result, there are slight shifts compared to the structure in the Reference Scenario.
- Energy intensity will improve slightly. Considering the fact that an improvement of energy intensity in many industrial sectors is seen to lie between 21% by 2030 and 46% by 2050 in the Reference Scenario, additional measures for improving the energy efficiency could provide additional efficiency gains of 20 to 25 percentage points in 2020 and 2050, respectively.
- The use of renewable energies (mostly biomass) will significantly increase, reaching a level of 6% by 2020 and 13% by 2050. Taking into account the contributions of renewable energies to the power and district heating production the (direct and indirect) use of renewable energies reaches a level of 21% in 2020 and 75% in 2050.

The remaining share of fossil fuels in industry in 2050 can be mainly attributed to the iron and steel sector where coal continues to be used for crude steel production because coal is needed as a reduction agent in blast furnaces. If the hard coal consumption in the iron and steel production is excluded, the share of carbon-free energy sources in the industrial sectors amounts to 90% in 2050.

The EU Emissions Trading Scheme will play a major role in creating additional potential in energy efficiency. However, other focused policies and measures will uncover and implement additional technical and organisational options. Regarding electricity consumption, improved standards for electrical motors, pumps and pressured air installations are crucial measures. However, focused innovation policies are essential to reach the efficiency gains in the Vision Scenario. The innovations reflected in the Vision Scenario include:

- Miniaturised and “decentralised” production (3D printing); process energy applications “within” rather than “outside” the workpiece (e.g. concentrating infrared lasers);

- New specific energy-efficient materials, provided especially through micro-technology and nanotechnology, and in functional plastics;
- Replacement of steel with customised ceramic and composite materials in static and elastic applications;
- Surfaces "customised" with specific materials to reduce friction, and thus the need for force, in mechanical processes;
- Less use of strategic metals, due to new organochemical-based materials;
- Widening use of catalytic and biological processes, especially in chemistry, materials production, surface treatment, etc.;
- Use of focused infrared lasers to generate "local process heat";
- Replacement of drying processes;
- Wider use of optoelectronics.

The major differences between the Reference Scenario and the Vision Scenario can be summarised as follows:

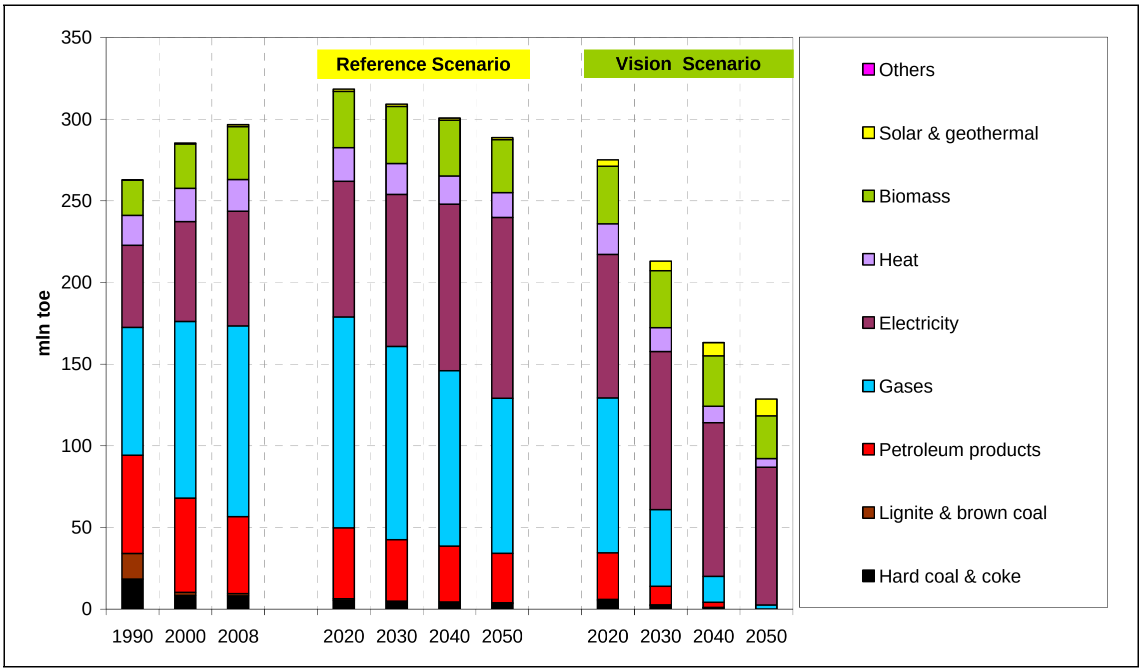
1. The trend of hard coal and lignite consumption in industry differs by about one third in the Reference Scenario and the Vision Scenario. This is caused mainly by the limited potential for substitution of coal in the iron and steel industry.
2. The consumption of oil is essentially phased out by 2050 in the Vision Scenario. In 2020 the consumption of oil is about 36% less in the Vision Scenario compared to the Reference Scenario.
3. Compared to the levels of the Reference Scenario, the consumption of gas is 27% lower in the Vision Scenario in 2020 and about 88% lower in 2050.
4. The demand for electricity in the Vision Scenario is 20% less than in the Reference Scenario for the period from 2020 to 2040 and 10% less in 2050.
5. The use of renewable energies (mostly biomass) in the Vision Scenario exceeds the levels projected for the Reference Scenario by 50% in 2050.

A key result of the Vision Scenario for the industry sector is that the total level of final energy consumption is reduced by 25% by 2020 in the Vision Scenario compared to the Reference Scenario and decreases by 42% from 2008 to 2050. However, the effects of the increasing role of electric technologies (which shift transformation losses from the final energy sectors to the power sector) should be taken into account for the classification of this progress in end-use energy efficiency. The share of non-fossil energy sources (renewable energies, electricity and heat) expands from 52% in the Reference Scenario in 2050 to 80% in the Vision Scenario.

5.1.2 Households

In contradistinction to the projected trend in industry, the final energy consumption rises substantially in the Reference Scenario for the period from 2008 to 2020. However, for the period beyond 2020 the modelling results in a steady decline of final energy consumption of households. The peak of energy consumption will be reached in 2020 at a level of 318 Mtoe which is 7% above the 2008 levels. The total final energy consumption then falls by 2040 to the level of 2008 and is 3% below 2008 levels in 2050. Among the traditional energy sources, the consumption of electricity represents the most marked increase. It is projected that the electricity consumption in households will reach a level 18% above 2008 levels in 2020 and 58% above 2008 levels by 2050. The consumption of natural gas is projected to rise significantly in the period from 2008 to 2020, by 11%. However, after the peak of gas consumption in private households in 2020 (11% above the 2008 levels) the gas demand decreases steadily. In 2030 the consumption level of 2008 is reached and in 2050 about 20% less gas is consumed than in 2008. In contrast to the trends for gas, the consumption of petroleum products is projected to decline over the whole period. In 2020 the demand corresponds to 92% of the 2008 levels; in 2050 the oil consumption reaches 87% of the 2008 levels. Solid fuels will only play a minor role in 2020 and 2050. The share of directly used renewable energies in the residential sector is comparatively stable at a level of 11 to 12% (Figure 5).

Figure 5 Final energy consumption by fuel in EU-27 households, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

The consumption pattern of the residential sector in the EU-27 is dominated by heating, cooling and cooking applications, which represent about 85% of the total final energy consumption. Electrical appliances and lighting only represent a share of less than 15% of total final energy consumption in private households. It is worth mentioning that about half of electricity consumption in the EU-27 is used for different heating purposes and cooling at present.

The following seven key assumptions form the basis of the alternative projection of the Vision Scenario:

- The energy efficiency standards for the construction of new buildings are based on the zero-energy standard from 2020 onwards.
- Compared to the baseline scenario, 2.5 times more existing buildings are retro-fitted in terms of energy efficiency during renovations in the Vision Scenario.
- The share of electric space heating and electric hot water heating in non-retrofitted buildings is significantly reduced.
- More efficient heating installations reduce the final energy demand for heating purposes.
- More efficient electrical appliances and installations and lighting systems (based on the top runner approach) lead to a more efficient use of electricity.
- The contribution of renewable energies reaches a significant market share, especially for heating and hot water. In 2020 the share of renewable energies in the residential heat market is 17% and is increased to approx. 50% in 2050.
- Electrical systems, including highly efficient heat pumps play an increased role for heating purposes in highly efficient buildings beyond 2025.

As a result, the total final energy consumption in the Vision Scenario stabilises by 2020 at a level that is 7% lower than the consumption in 2008. In 2050 the remaining energy consumption of households is only 43% of the 2008 levels, or 45% below the level in the baseline scenario. The use of oil and gas for the residential sector is almost phased out by 2050. The increase of electricity consumption, driven by more appliances and an increasing share in the residential heat market beyond 2030, is limited to 20% above the 2008 levels or 24% below the consumption projected for the Reference Scenario in 2050.

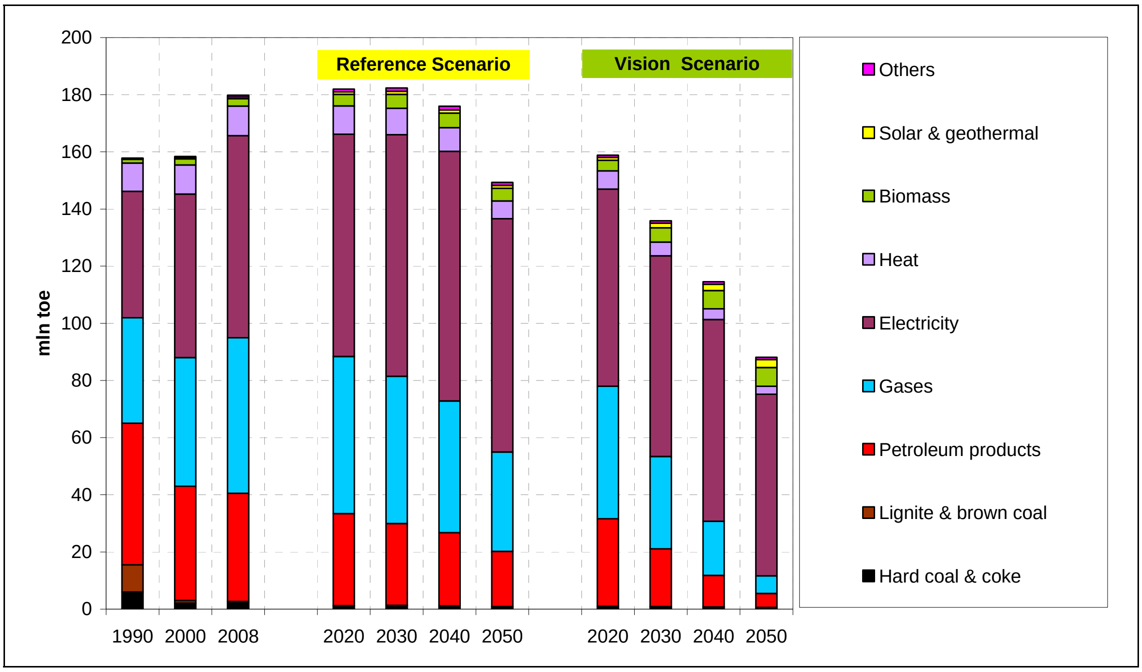
The use of solar energy for hot water and heating increases by a factor of 8 from 2008 to 2050 and reaches a share of 8% of total residential final energy consumption. However, the use of biomass forms the largest share of renewable energies in the residential sector with a share of 20% of the total final energy consumption. The total direct contribution of renewable energies amounts to 14% of the total final energy consumption in the year 2020 and 28% in 2050. Taking into account the contributions of renewable energies to the power sector and district heating sector, the (direct and indirect) use of renewable energies in the Vision Scenario reaches a level of 28% in 2020 and 93% in 2050.

5.1.3 Tertiary sectors

The tertiary sectors comprise the non-industrial sectors of the economy, i.e. the energy consumption from the service sector, the public sector, and agriculture.

In accordance with the economic growth in the service sector and the energy efficiency improvements in the Reference Scenario, the energy consumption of the tertiary sectors remains almost on the 2008 levels by 2040 and decreases slightly in the subsequent decade (Figure 6). The total final energy consumption in 2050 is 17% below the 2008 levels. The only energy source with a steady growth trend in the next two decades is electricity, the demand for which is projected to grow by 20% from 2008 to 2030. The electricity demand of the tertiary sectors will peak in 2040 and slightly decrease by 2050 in the Reference Scenario. For all other conventional fuels the future consumption will be below the recent levels. However, the demand for natural gas will stagnate for the next two decades whereas the demand for petroleum products in the tertiary sectors will fall more sharply. Solid fuels only represent a minor share of the total final energy consumption in 2020 and 2050.

Figure 6 Final energy consumption by fuel in EU-27 tertiary sectors, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

The share of energy consumption for heating and cooling is about 20 percentage points less than in the residential sector. Other energy uses (most of which is based on electricity) amount to approx. 40% of the total final energy consumption.

Taking into account the same measures as for the residential sector (major energy efficiency improvements for buildings, best available technologies for electrical appliances, and increasing use of renewable energies), the total final energy consumption of the tertiary sectors can be decreased by 10 to 15% per decade in the Vision Scenario. In 2020 the final energy demand is 12% below the 2008 levels; in 2050 the final energy consumption decreases by an additional 39 percentage points. The electricity consumption can be stabilised in the Vision scenario for the next three decades and falls 10% below the 2008 levels by 2050. Fossil fuels will be gradually phased out by 2050; the share of renewable energies (mainly solar and ambient heat as well as some biomass) increases to 3% in 2020 and to 11% in 2050. Taking into account the contributions of renewable energies to the power heating and district heating production, the (direct and indirect) use of renewable energies in the Vision Scenario reaches a level of 21% in 2020 and 81% in 2050.

5.1.4 Transport

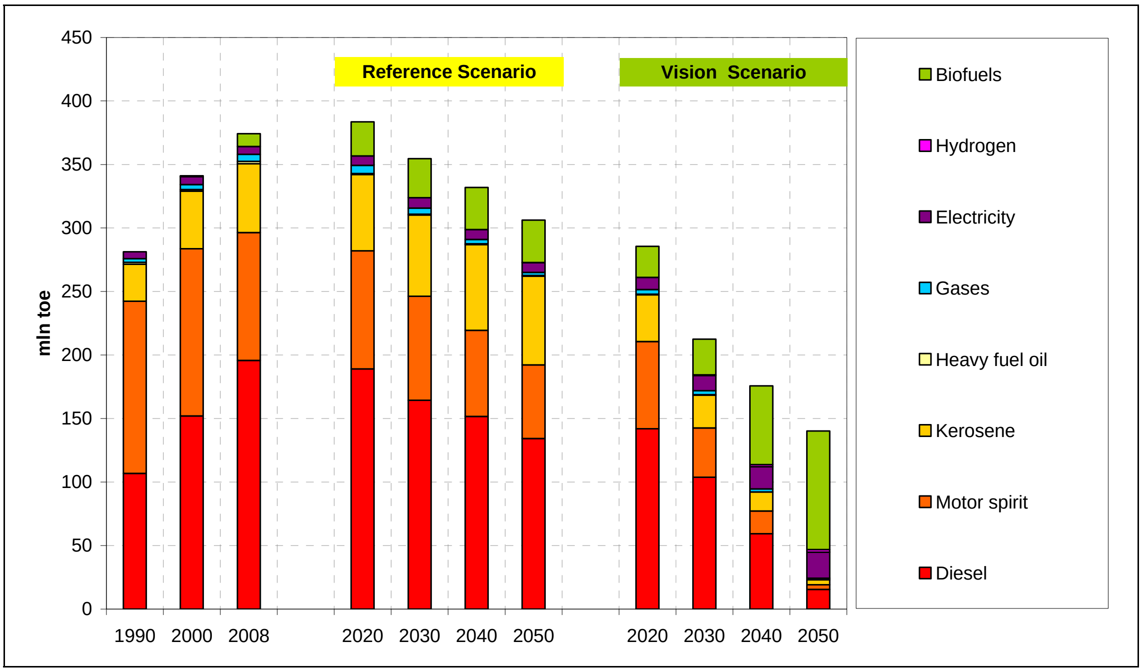
The transport sector is the fastest-growing sector in terms of activities. In the Reference Scenario both passenger transport and freight transport activity is projected to continue to rise. The energy demand of the transport sector is projected to grow in the next decade. After 2020, the energy demand slowly decreases as a result of enhanced efficiency. In 2030 the energy use of the transport sector is around 5% lower than in 2008 and decreases to a level which is 19% below 2008 levels in 2050. A strong increase is assumed in the use of kerosene and jet fuels, which is estimated at 11% in 2020 and 29% in 2050 above the 2008 levels of consumption. Although the role of biofuels slightly increases over time, their share in terms of the total final energy consumption of the transport sector is approx. 7% in 2020 and 11% in 2050 for the Reference Scenario (Figure 7).

A wide range of additional measures were considered in the Vision Scenario so that the transport sector fulfils its contribution to achieving significantly higher CO_2 emission reductions. Central elements for the reductions in the transport sector are changes in modal shift together with transport demand reduction, significant improvements of vehicle efficiencies, electrification of passenger car transport and the switch to renewable energy sources for the long distance freight transport as well as for air transport.

Projections relating to a modal shift and transport demand reduction in the Vision Scenario were calculated using the SULTA tool (Skinner 2010). This tool models a series of measures on a given baseline scenario. The key assumptions made in Skinner 2010 are:

- 5% less demand of road transport in 2020 and 10% less demand of road transport in 2050 brought about by optimised spatial planning.
- 30% urban car traffic and 10% non-urban car traffic is shifted to other modes,
- 20% intra-EU air transport is shifted to rail (accompanied by an increase to high-speed rail) and 15% from heavy lorries to other modes in 2050.
- In parallel, the transport demand is significantly reduced.

Figure 7 Final energy consumption by fuel in EU-27 transport sectors, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

These effects are induced by investments in cycling and walking infrastructure, high investments in public transport (for reducing travel and waiting times and improving its attractiveness) combined with measures reducing the attractiveness of cars like urban charging systems and parking restrictions. With regard to freight transport, measures for advanced distribution concepts and an optimisation of logistics by supporting inter-modal connections for freight transport are taken into account. Furthermore, the fuel tax is assumed to equal the current road petrol tax rate per unit of energy across all modes including VAT and additionally includes a carbon price of up to €180 in 2050. NO_x, PM pollutant emission costs and energy security costs are internalised for road modes and the company car tax is revised to eliminate subsidy.

The modelling of these assumptions using the SULTAN tool results in a reduction of 35.5% in passenger transport demand and of 25% in freight transport demand compared to the development in the Reference Scenario in 2050. In essence this implies a medium- and long-term stabilisation of transport activities at recent levels.

More than half of the energy use in road transport stems from the demand of private cars. It is therefore essential to realise the potential for energy efficiency gains of private cars. However, the improvement of the efficiency of heavy duty vehicles and the other transport modes is still of high importance. To enhance the fuel efficiency of vehicles and to accelerate the development and introduction of new propulsion technologies, different measures should be taken into account:

- EC regulation 443/2009 should be further developed and tightened. A new driving cycle which reflects the real-world driving energy consumption levels and includes new propulsion technologies to an appropriate extent should be developed and implemented. To decrease the emissions of passenger cars, the emission standards for passenger cars should be set as a minimum at 70 g CO_2/km in 2030 in the revised test and be further tightened during the whole period up to 2050. The double counting of measures and the automatic classification of electric vehicles as zero emission (independently of the upstream chain) should be ruled out in the future; one way of doing this would be to take the upstream emission of the energy source (fuel, electricity, hydrogen) into account (well-to-wheel emissions).

- Like passenger cars, lorries also have technical potentials for reducing energy consumption. These potentials will amount to at least 30% in 2030 compared to current levels. Combined with additional steering measures such as the urgently necessary emission-based vehicle tax, the introduction of a type approval test for determining fuel consumption which applies to all the EU and covers the entire vehicle forms the basis for setting emission standards for heavy utility vehicles.
- The introduction of a speed limit would substantially reduce fuel consumption. In addition, a long-term and standardised speed limit can have a positive effect on the manufacturers' designs of passenger cars: Lower speeds involve lower material strength and safety requirements for vehicles, which allow the weight and thereby the fuel consumption of passenger cars to be further reduced. So motorway limits should be harmonised and lowered to 100 kilometres per hour for light duty vehicles (LDVs) and 80 kilometres per hour for heavy duty vehicles (HDVs). The better enforcement of speed limits across all roads has to be guaranteed as well.
- At the moment, there is no EU policy in place to regulate CO_2 emissions or efficiency from other modes, although some initiatives are being undertaken in the international context. This gap should be bridged to support the improvement of efficiency of transport modes for public transport, rail, aircraft and ships as well.
- The broad promotion of a fuel-efficient driving style combined with in-car devices which indicate the actual fuel consumption of the car to the driver should be supported to further reduce the real world energy consumption of vehicles.
- Additionally, economic instruments such as higher fuel taxes, efficiency based vehicle taxes and road tolls can strongly encourage the consumer to buy more fuel-efficient cars.

In the Vision Scenario the key assumptions for energy efficiency improvements and the increase of load factors for the different transport modes and propulsion systems up to 2050 were mainly made according to Skinner 2010:

- efficiency improvements of 60% for private vehicles with conventional power trains and an increase in average load factors of 10%;

- efficiency improvements of 30% for conventional lorries and an increase in average load factors of 10%;
- efficiency improvements of 30% for conventional vehicles in public road transport and an increase in average load factors of 14%;
- efficiency improvements of 44% for air transport and an increase in average load factors of 11%; and
- efficiency improvements of 10% for rail freight and 15% for passenger rail transport, combined with an increase in average load factors of 10 and 12%; respectively.

The assumed share of vehicles mileage driven using different powertrain technologies in the Vision Scenario is as follows:

- 3% electric mode for private cars in 2030 and 41% in 2050;
- 6% fuels cell powertrains for private cars;
- 3% electric mode for lorries (short distance transports) in 2030 and 5% in 2050; and
- an increase of electric powertrains for rail transport from 71% in 2008 to 82% in 2050.

Electric vehicles will be chiefly introduced in the passenger car fleet. In 2050 around 40% of the transport activity of passenger cars (plug-in and battery-electric vehicles) is driven in the electric mode, more than 80% of rail is electrified. In freight transport for long distances, electrification of the fleet cannot be assumed due to a lack of alternatives. In consequence, renewable energies for freight fuels – and for air transport as well – have to be strongly supported to realise the climate protection targets. Research and development should be accelerated, e.g. for biofuels of the so-called second and third generation, such as the conversion of biomass to transport fuels by gasification and thermochemical routes and the conversion of cellulose to sugars. The advantages of these kinds of biofuels are the unspecific feedstock and that their greenhouse gas emissions are clearly lower in the pre-chain than biodiesel from rapeseed or sunflowers and bioethanol from grain or sugar beet (i.e. by agriculture).

In the Vision Scenario it is envisaged that the second and third generation biofuels together with biogas will assume an 80% share in 2050, most of which is used in freight transport. International quality standards for the production of biofuels, including standards for imported fuels, are an essential means of introducing high shares of such fuels in a way that is compatible with sustainability. In the transport sector the share of biofuels substituting gasoline, diesel and CNG in the Vision Scenario amounts to 5.75% in 2010, 10% in 2020, 25% in 2030 and 80% in 2050. The use of bio-kerosene starts a little later in 2020 with 2.5% and reaches the 80% in 2050 as well.

Figure 7 also shows the final energy demand in the transport sector for the Vision Scenario. The overall energy use in the Vision Scenario is reduced by about a quarter in 2020 compared to the Reference Scenario and compared to 2008 levels. The contribution of electricity to the total final energy consumption in the transport sector increases from 2% in 2008 to 3% in 2020 and 15% in 2050. In absolute terms the electricity demand in the transport sector increases by a factor of 3.35 from 2008 to 2050. However, the total increase of about 170 TWh for electric powertrains in the transport sector corresponds to a share of only 6% in the total electricity consumption by end-use sectors in 2008.

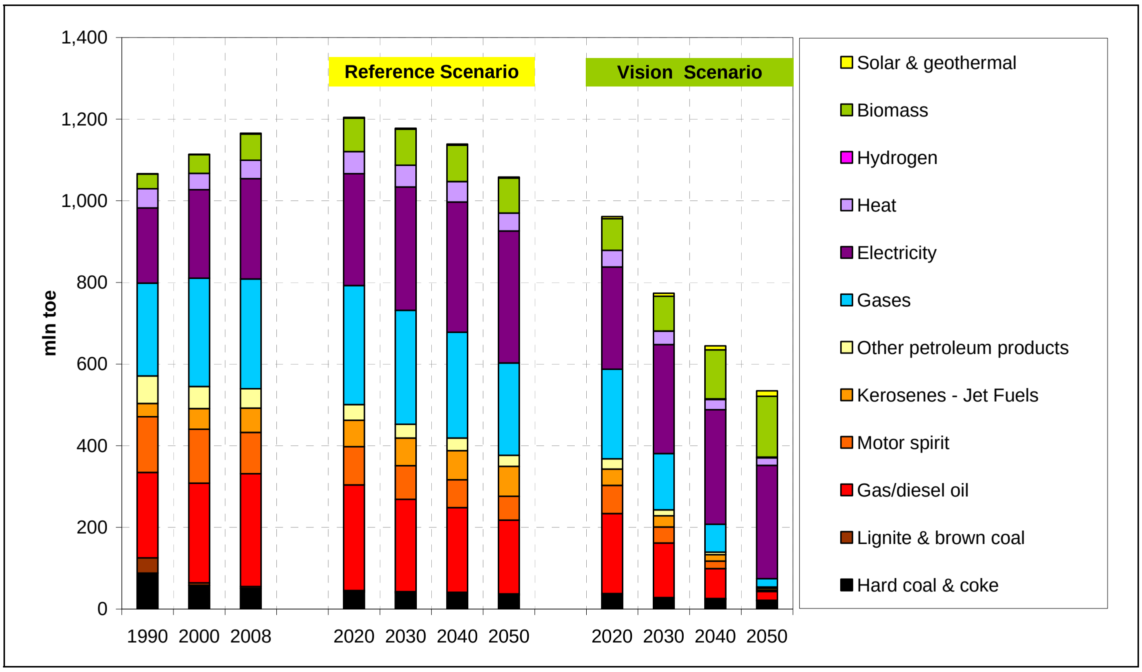
In the Vision Scenario the share of renewable energies in the total final energy demand of the transport sector rises significantly to 9% in 2020 and 67% in 2050. Taking into account the contributions of renewable energies to power and hydrogen production the (direct and indirect) use of renewable energies in the Vision Scenario increases to 10% in 2020 and to 82% in 2050.

5.1.5 Total final energy consumption

As a summary of the sectoral scenario analysis presented in the previous chapters, the total final energy consumption results are as follows (Figure 8):

- In the Reference Scenario the total final energy consumption is almost stabilised at 2008 levels for the next three decades. Beyond 2040 the final energy demand decreases slightly to a level which is 9% below the 2008 levels. In the Vision Scenario the final energy consumption peaks in 2008 and falls steadily to a level which is 18% below 2008 levels in 2020 and 54% below 2008 levels in 2050. However, it should be mentioned that a part of this decrease of final energy consumption results from electrification, e.g. in the transport sector, because within a strategy of electrification energy transformation losses are shifted from the end-use sectors to the power generation.
- The structure of final energy consumption differs significantly between the Reference Scenario and the Vision Scenario. The use of petroleum products is phased out much more quickly in the Vision Scenario than in the Reference Scenario and also the demand for natural gas is much lower in the Vision Scenario compared to the consumption trend in the Reference Scenario. Although the share of electricity in the total final energy demand increases significantly in both scenarios (from 21% in 2008 to 23% in 2020 and 30.5% in 2050 in the Reference Scenario and 26% in 2020 and 52% in 2050 in the Vision Scenario), the level of electricity demand is very different in the two scenarios. In the Reference Scenario the electricity demand increases to 12% above 2008 levels, grows by an additional 11 percentage points up to 2030 und is stabilised at a level of about 30% above 2008 levels in 2040 and 2050. In the Vision Scenario the net effect of aggressive energy efficiency improvements for 'traditional' uses and strategic electrification (e.g. for the transport sector and in the longer term for some parts of the heat market) represents an increase of only 2% for the period from 2008 to 2020 and a consumption of 13% above 2008 levels in 2050.

Figure 8 Total final energy consumption by fuel in the EU-27, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

The most important contribution to the decreased final energy consumption in the Vision Scenario is made by the transport sector, which assumes a 40% share. The second most important sector is the residential sector, which contributes 27% of the total final energy savings. The industry and the tertiary sectors provide energy consumption reductions which are also significant (22% and 15%, respectively).

However, for different energy sources, varying patterns result for the sectors in terms of the changes in the Vision Scenario compared to the Reference Scenario:

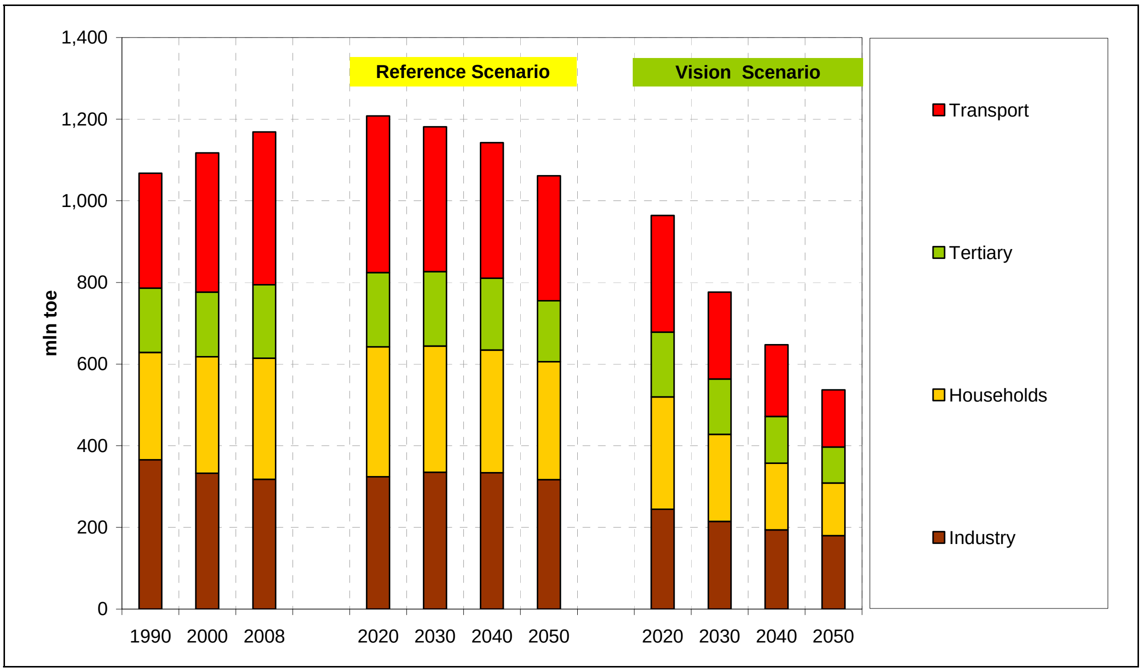
- The total electricity demand increases slightly in the Vision Scenario compared to 2008 levels but it is still significantly lower than in the Reference Scenario. The transport sector is the only sector which shows a higher electricity demand in the Vision Scenario due to strategic electrification in this sector. The electricity savings in the Vision Scenario compared to the Reference Scenario in the non-transport sectors can be attributed to households (45%), the tertiary sectors (31%) and industry (25%).

- The breakdown of the reduction in gas consumption is as follows: 45% comes from measures in the residential sector, 14% from the tertiary sectors and 41% from industry.

- The most relevant sector for oil savings is the transport sector. 78% of the total decrease in oil consumption stems from this sector (including international air transport). Households contribute 10%, industry 7% and the tertiary sectors 5% of the total reduction in oil consumption in the Vision Scenario compared to the Reference Scenario.

- The increasing direct use of renewable energies mainly occurs in the transport sector (81%). 5% comes from the tertiary sectors (including agriculture), 4% from households, and 10% from industry (including organic waste).

Figure 9 Total final energy consumption by sector in the EU-27, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

In the Vision Scenario the share of renewable energies in the total final energy demand rises significantly from 6% in 2008 to 9% in 2020 and 30% in 2050. Taking into account the contributions of renewable energies to power, heat, and hydrogen production, the (direct and indirect) use of renewable energies in the Vision Scenario increases to 20% in 2020 and to 82% in 2050.

In summary, the Vision Scenario is based on two major pillars:

- Aggressive improvements in energy efficiency for all energy sources; and.
- For all sectors the long-term transition to carbon-free energy sources is a key factor. For some sectors and energy uses this means direct use of renewable energies; for other sectors and energy uses (e.g. in the transport sector) the switch to electricity (supplied from renewable energies).

The importance and contributions of these factors vary over time and between the sectors. Thus, the consistent and early transition of the power sector to renewable energy sources is a one of the determinants of the Vision Scenario.

5.2 Energy sectors

The energy sector comprises the power generation sector and the production of heat, petroleum products, biofuels and other secondary energy carriers (hydrogen, coke, etc.) as well as the production of primary energies (crude oil, natural gas, hard coal, lignite, etc.) in the EU-27. The most significant energy sector in terms of GHG emissions is the power generation sector.

The net electricity production in the EU-27 rose by 32% in the years from 1990 to 2008. The most significant increase occurred from 1990 to 2005. From 2005 to 2008 power production in the EU-27 increased only by 2 percentage points, which is equivalent to less than 10% of the total growth from 1990 to 2008. Electricity imports and exports from and to the EU played only a negligible role in the last two decades.

In the Reference Scenario the strong growth in power production continues steadily, driven by a steadily increasing demand. In 2020, power production exceeds 2008 levels by 12%, in 2020 by 22% and 31% by 2050. However, the structure of power generation changes significantly in this period:

- The level of nuclear power generation is almost constant for the decades ahead, a few new-built plants and some lifetime extensions increase the level by approx. 12% in 2030. For the period beyond 2030 nuclear power production decreases steadily to a level which is about 30% below the 2008 levels, mainly driven by the economic challenges of nuclear power in a system with approx. 45% of power generation coming from renewables. Against the background of increasing total power production, the share of nuclear power drops from 28% in 2008 to 26% in 2020 and 2030 and 15% in 2050.
- Power generation from hard coal is more or less constant by the year 2030 but the level of hard coal power generation in 2050 decreases by 27% compared to 2008 levels. Against the background of increasing total power production, the share of power generation from hard coal drops from 16% in 2008 to approx. 14% in 2020 and 9% in 2050.
- Electricity production from lignite is an important source of power production in some EU-27 Member States. However, it represented 10% of the total power generation in 2008. Again, the power production remains almost constant by 2030 and then decreases to a level which is 44% below 2008. The share in total power generation drops by 3 percentage points by 2030 and a further 4 points by 2050.
- The power production from natural gas is assumed to increase by 17% in the period from 2008 to 2020, remains then almost constant until 2030 and increases further after 2030, reaching a level 28% above 2008 levels in 2050. The share of natural gas-based electricity generation remains almost constant at a level of 23 to 25% for the whole scenario period.

- Power production from renewable energies rises substantially. The share in terms of the total power generation increases from 17% in 2008 to 24% in 2020 and 29% in 2030. In 2050 the share of renewables in total power generation is 46%, which corresponds to a total increase of 255% compared to 2008 levels. Whereas the production from hydropower plants increases only slightly, the main growth results from the dynamic development of wind power, solar power and some biomass. The production from wind energy increases by 800 TWh from 2008 to 2050; the electricity generation from biomass rises by 160 TWh.

For the Vision Scenario, some changes to key policies and measures are assumed:

- The cap under the EU ETS is substantially tightened and incentivises the full decarbonisation of the power sector.
- Supplementary support programmes and changes in market design enable renewable energies to supply the electricity demand fully.
- The necessary infrastructure is rolled-out with a sufficient lead-time for the beginning of planning, licensing and implementation.

The final consumption of electricity and the electricity demand from the energy sector (non-power energy transformation, electricity losses from storage) determines the total net power generation. The following factors are considered in the transformation of final energy consumption to the net production of electricity in the Vision Scenario:

- The grid losses in the EU-27 network[4] remain constant at a level of about 7%, which is equivalent to a total loss of about 230 TWh in 2050.
- The losses from electricity storage that are associated with the higher share of power production from variable sources are specifically considered. However, as an EU wide integration and exchange of electricity was assumed, losses attributed to storage are only 1% of total electricity generation.
- The electricity imports remain constant at the low level considered in the Reference Scenario.

The first significant difference between the baseline and the Vision Scenario is the significantly lower level of electricity demand in the Vision Scenario, which results from different trends:

- Lower electricity consumption from conventional appliances in the end-use sectors as a result of increased efforts on energy efficiency improvements;
- Higher demand from new sectors, e.g. the strategic electrification and the use of electricity in the heat market (for highly efficient buildings and with highly efficient technologies), which starts to play a significant role beyond 2030;

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[4] The relative grid losses are expressed as the share of grid losses in the total of net power production and the net electricity imports.

- Lower electricity from the energy sector (e.g. mineral oil refineries) as a result of higher energy efficiency and fuel switching in the transport sector;
- Higher electricity demand from new segments in the energy sector (e.g. biofuel production) as a result of the phase-in of new fuels;
- Increased demand from electricity storage facilities for the period beyond 2030 based on an estimate on the need for storage capacities.

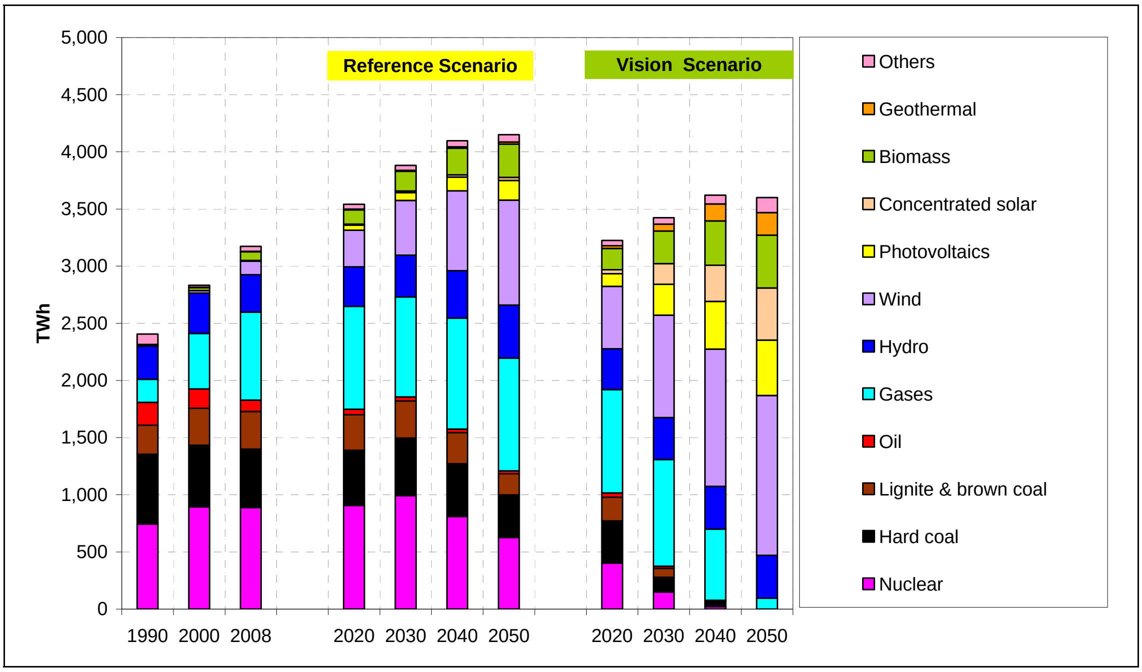
As a result, the demand for power generation lies approximately at the 2008 level in 2020 but about 10% below the Reference Scenario. In 2030 the demand for power production is about 8% above the 2008 levels and increases by an additional 5 percentage points by 2050. For the period from 2020 the 2050 the total demand for electricity in the Vision Scenario is 12 – 13% below the Reference Scenario. In other words: The increase of electricity demand from 2008 to 2050 in the Vision Scenario is less than half of the increase in the Reference Scenario although strategic electrification of the transport sector plays a much more prominent role in the Vision Scenario.

Alongside this difference in production levels, there are major structural changes in power generation in the Vision Scenario (Figure 10):

- Nuclear power generation is phased out according to the planned lifetime of the plants. In 2030, the remaining power production from nuclear power plants amounts to about 150 TWh, which corresponds to a 4% share of the total power generation. By 2050 nuclear power generation is phased out completely.
- No new investments in coal-fired power generation are considered beyond those plants already under construction. The level of electricity generation from coal decreases significantly. Compared to 2008 levels the hard coal-based power generation decreases by about 28% by 2020 and 92% by 2040. The production from lignite power plants drops by 37% by 2020 and 96% by 2040. By 2050 electricity generation from coal-fired power generation is phased out completely.
- Compared with 2008 levels, the power generation from gas rises by about 18% by 2020 and 21% by 2030. For the period after 2030 the role of natural gas in power generation is reduced considerably. In 2050 the level of power production from gas is 88% below 2008 levels. In the next two decades the share of gas in total power productions amounts to between 27 and 28% (which is 4 points above the base level of 2008) and subsequently falls significantly to 3% in 2050.
- Power production from renewables is extended from 533 TWh in 2008 to 1,260 TWh in 2020 and 2,085 TWh in 2030. This is equivalent to growth of a factor of 2.4 by 2020 and 3.9 by 2030. In 2050 the share of renewables reaches 94% of total power production. Compared to the Reference Scenario, this means a further expansion of power production from renewable energies by 1,480 TWh over the next four decades. The main contribution to the growth of renewable energies in power production comes again from wind energy, which expands to

about 1,400 TWh in 2050 (920 TWh in the Reference Scenario). Electricity generation from biomass reaches a level of 460 TWh in 2050 (compared to 290 TWh in the Reference Scenario). Solar, geothermal power and other renewable energies make up only a small share of the total production in 2030, but become increasingly important up to 2050. In 2050, the share of solar and geothermal energy amounts to 26% and 5%, respectively. The power generation from solar energy is distributed approximately equally among almost decentral photovoltaic installations and concentrated solar power plants in Southern Europe.

Figure 10 Net electricity generation in the EU-27, 1990-2050



Source: Eurostat, DG Energy, Greenpeace/EREC, Öko-Institut.

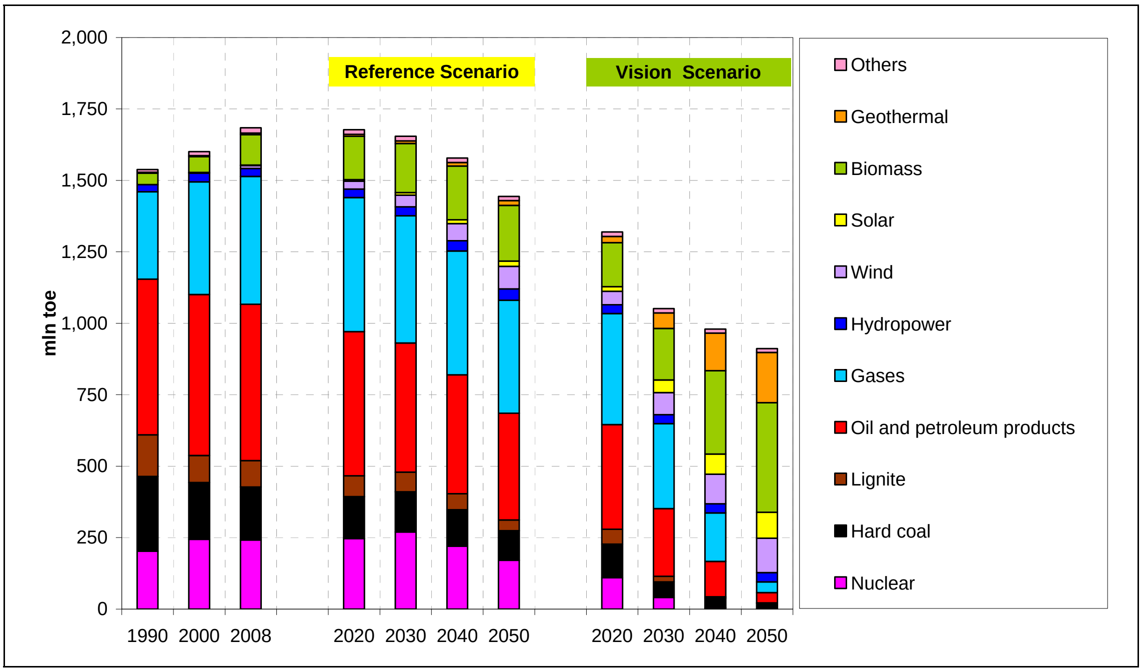
In the Vision Scenario the electricity supply is chiefly based on variable electricity sources such as wind and solar power. Additional storage capacities and increased transport capacities between countries and regions will be required. Demand response is also important in the future electricity systems. There will be a trade-off between more decentralised storage and back-up capacities and an increased EU-wide integration and exchange in the electricity system. Other analysis has shown that an EU-wide integration and increased cooperation between Member States significantly reduces costs, the need for electricity storage and the associated energy losses (ECF 2010).

The other sub-sectors of the energy sector are directly linked to the demand for the respective energy carriers. The energy consumed in these sectors was projected proportionally to the use or production of petroleum products, natural gas, heat, hydrogen biogas, and biofuels.

5.3 Primary energy supply

The total primary energy supply (TPES) is calculated on the basis of the final energy consumption and the energy use in the energy sectors. The non-energy use of primary energies is excluded from the totals and the analysis below.

Figure 11 Total primary energy supply in the EU-27, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

Following the general trends in final energy consumption and the energy sectors, the primary energy supply in the Reference Scenario is almost constant for the next two decades and decreases beyond 2030; by 2050 it has fallen to a level 14% below 2008 levels. In terms of the structure of the TPES, the trends can be divided into two main groups:

- The contribution of nuclear and natural gas is only subject to small changes in terms of their level of supply during the next two decades. In 2050 the supply of nuclear energy drops by 29% compared to recent levels in the scenario period, the contribution of lignite decreases by 18%, the supply of hard coal increases by 7% and total oil consumption by 5%. The use of natural gas peaks in 2020 at a level which is 5% above 2008 levels; by 2040 it has reached 2008 levels, after which it decreases by about 12% by 2050.
- The primary energy supply from coal, mineral oil and gas decrease steadily over time. In 2020 the total coal consumption is 20% lower than in 2008 and shrinks by an additional 30 percentage points until 2050. The oil demand in 2020 is 10% lower than 2008 levels for 2020 and 30% lower than 2008 levels in 2050. Natural gas and renewable energies show much stronger dynamics, but are limited by the low base level in 2000. The consumption of natural gas rises

by 32% and the contribution of renewable energies increases by 160% in the period from 2000 to 2030.

- The primary energy supply from renewable energies shows strong dynamics. In the period from 2008 to 2020 the contribution of renewable energies increases by 45%. In 2050 the supply from renewable energies will exceed 2008 levels by a factor of 2.3 in the Reference Scenario.

As a result, the structure of the TPES changes significantly even in the Reference Scenario. However, the most significant changes in the structure occur after 2020. The contribution of renewable energies is extended from 9% in 2008 to 13% in 2020 and 24% in 2050.

In the Vision Scenario, the TPES steadily decreases in the course of the scenario. In 2020 the primary energy demand is about 20% below 2008 levels; in 2050 the modelling results in a level which is 46% below 2008.[5] When the structure of primary energy in the Vision Scenario is considered, the following trends need to be highlighted:

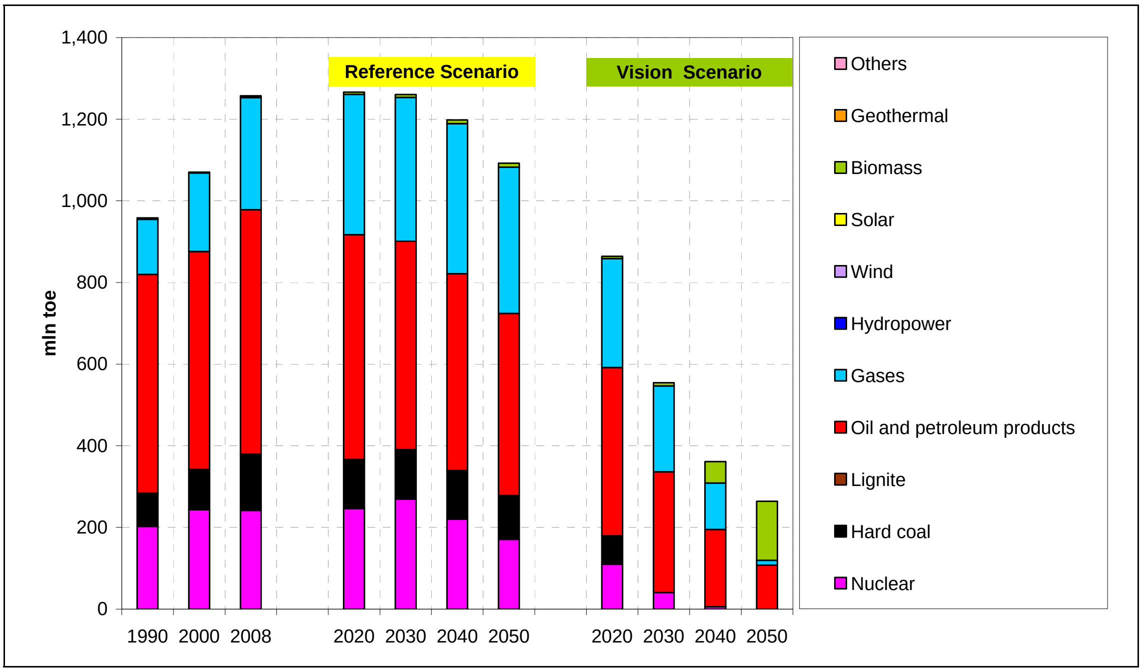
- The contribution of nuclear energy decreases by about 55% in absolute terms for the period from 2008 to 2020 and is almost phased out by 2040. The contribution to the TPES is 9%.
- The role of coal significantly decreases in terms of both the overall level of supply and the share of the TPES. In 2020 the level of coal demand is 39% lower than in 2008. In 2050 it comprises only 8% of the level of coal consumption in the base year 2008; this quantity of coal is mainly used in the iron and steel industry for crude steel production. In 2020 the contribution of coal to the TPES is 17% in 2020 and 2% in 2050.
- The use of oil in 2020 is about 33% less than in the year 2008 and decreases further to 6% in 2050. Mineral oil contributes 30% to the total TPES in 2020 and 4% in 2050.
- Even for the total consumption of gas, the level of consumption decreases for the full scenario period compared with the 2008 levels. In 2020, the consumption of natural gas is 13% less than in 2008; in 2050 it is about 92% below the 2008 levels. However, the share of gas in the TPES rises from 20% in 2008 to 29.5% in 2020 but decreases to 4% in 2050.
- The most significant change in terms of consumption levels and shares in the TPES occur for renewable energies. From 2008 to 2020 the total use of renew-

[5] It should be highlighted that the reduction in total primary energy supply is partly a result of the statistical treatment of renewable energies and the decreasing role of nuclear energy. Whereas the relation between power production and fuel input is assumed to be 0.33 for nuclear power (modern fossil power plants amounting to 50% or more), the electricity from hydro, wind and solar is translated into primary energy using the factor 1.0. For power generation from geothermal plants an efficiency of 10% must be assumed. The reduction of primary energy resulting from this statistical definition is only a statistical artefact.

able energies increases by a factor of 1.8 and reaches a share of 20% in the TPES. In 2050 renewable energies represent 88% of the TPES which is equivalent to growth by a factor of 5.3 in the period from 2008 to 2050.

The major differences in the structure of primary energy supply lead to significant changes in the role of energy imports to the EU-27. In 2008, the share of imported energies amounted to approx. 75%. In the Reference Scenario, this share grows slightly to approx. 76% in 2030 and subsequently remains constant at this level. In the Vision Scenario, the share of imported energies decreases to 65% in the period from 2008 to 2020 and decreases further to 29% in 2050. From 2040 onwards the domestic potential of sustainable biomass in the EU-27 will no longer be sufficient to cover the total demand; significant biomass imports occur. However, the restriction of a maximum biomass demand of about 30 GJ per capita is not exceeded at any time in the period from 2008 to 2050.

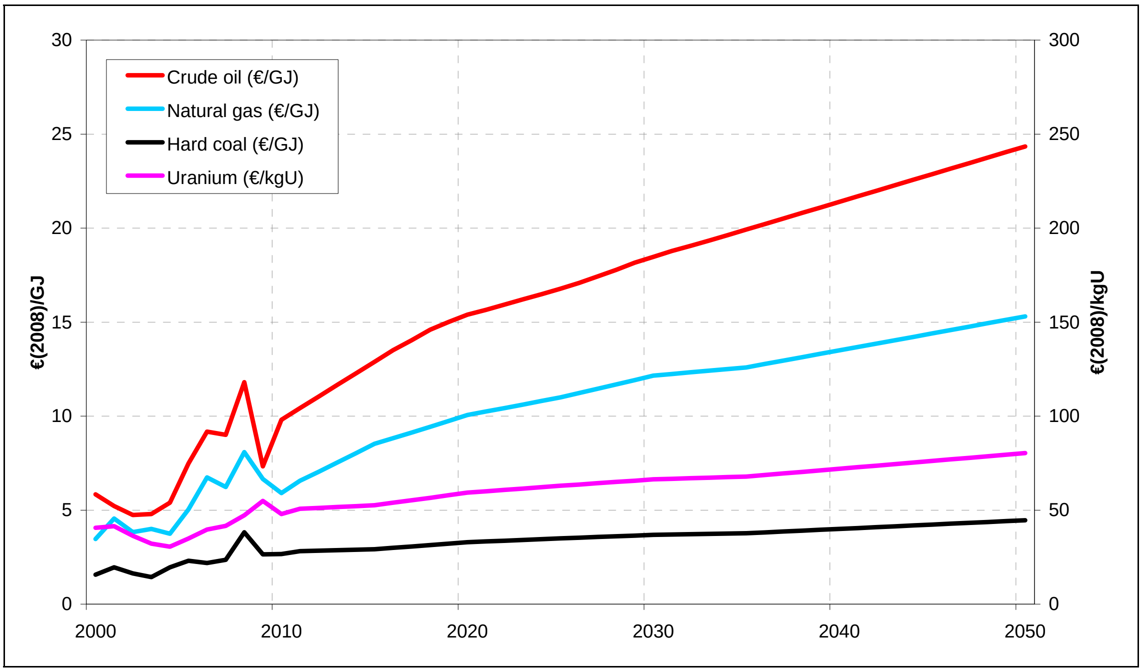
Figure 12 Primary energy imports to the EU-27, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut.

To summarise the effects on import dependence, the Vision Scenario makes a major contribution to decreased import dependence by means of diversification of energy sources and energy savings. Thus, the vulnerability of the EU-27's economies to price spikes and volatilities on the global energy markets is significantly lower.

Figure 13 Primary energy import price projections, 2000-2050



Source: IEA, ESA, Öko-Institut.

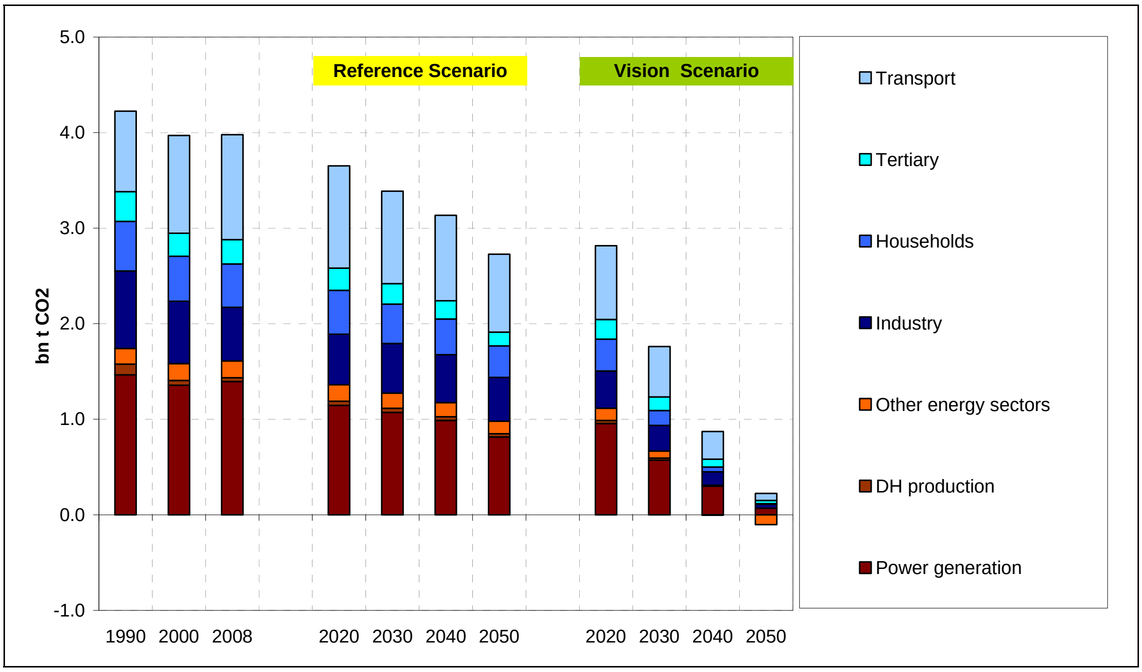
Figure 13 highlights the economic relevance of future primary energy imports. If the oil price projections of the World Energy Outlook 2010 (IEA 2010) are extended to 2050 and the price sensitivities of natural gas, hard coal and nuclear fuel to the oil price trends are considered (Matthes 2011), the imports of primary energy will lead to a significant wealth transfer from the EU to non-EU primary energy producers. The primary energy supply in the Vision Scenario will require about € 130 bn less than in the Reference Scenario in 2020 (at 2008 prices and assuming that biomass is imported at the respective oil prices in future), € 260 bn in 2030, € 390 bn in 2040 and € 455 bn in 2050.

6 Greenhouse gas emissions

6.1 Energy-related CO_2 emissions

The calculations of energy-related CO_2 emissions were based on the total balance for final energy consumption, the energy use in the energy sectors and the total primary energy supply.[6] Figure 14 indicates the general trend and sectoral breakdown of energy-related CO_2 emissions in the Reference Scenario and the Vision Scenario.

Figure 14 CO_2 emissions from energy use in the EU-27, 1990-2050



Source: UNFCCC, Eurostat, Öko-Institut.

In the Reference Scenario, the energy-related CO_2 emissions decrease slightly in the next decades of the scenario period. In 2020, the total energy-related CO_2 emissions amount to about 3,650 Mt, which is 13.5% below 1990 levels. In 2030, the emissions are 20% lower than the base level of 1990 and reach a level of -35% in 2050, which is far off any ambitious emission reduction targets.

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6 The emissions from coal use in the iron and steel industry are considered as energy-related CO_2 emissions for modelling reasons. The major share of these emissions is counted as process emissions in the official greenhouse gas inventories submitted to the United Nations Framework Convention on Climate Change. Furthermore, emissions from international air transport are included in the total emissions of the transport sector.

CO_2 emissions from power production also constitute – at 25% – the major share of total emissions in 2020 and beyond.[7] However, in line with the overall emission trend, the emissions of the power sector decrease by 22% in 2020, 27% in 2030 and 44% in 2050.

The least ambitious emission decrease is to be found in the transport sector. Although the CO_2 emissions decrease for the next four decades, because of the strong emission increase from 1990 to 2008 the total emissions from transport emissions can only be reduced to 1990 levels by 2050. CO_2 emissions from transport decrease by 3% in the period from 2008 to 2020, by 15% by 2030 and by approx. 30% by 2050. Different dynamics result for air transport. The total emissions from kerosene and jet fuel use increase by approx. 9% in the period from 2008 to 2020, 14% by 2030 and 14% by 2050. In 2020, CO_2 emissions from air transport constitute a share of the total energy-related CO_2 emissions of 5%, by 2030 this share will increase to 6% and reach a level of 8% in 2050.

In the Vision Scenario, the energy-related CO_2 emissions decrease significantly, reaching a level of about 33% below 1990 emissions in 2020. By 2030 they are approx. 58% below and by 2050 97% below 1990 emissions. As a result the energy sector is nearly fully decarbonised by 2050 on the basis of significant improvement of energy efficiency and the switch to renewable energies.

Although the emission levels change drastically in the Vision Scenario, the structure of emissions is subject to smaller changes only. For the period from 2008 to 2020 the emissions for most energy sectors decrease by 20 to 30%, from 2008 to 2030 by about 40 to 60% and almost 70 to 90% from 2008 to 2050. However, the most significant emission reduction comes from the power sector and the transport sector. Compared to 2008 levels, the decrease of emissions from the transport sector amounts to approx. 1,000 Mt CO_2 by 2050. In the same period, the emissions from power production drop by 80%, which corresponds to approx. 1,300 Mt CO_2.

A special mitigation option is introduced in industry and the energy transformation sector from 2030 onwards. In combination of biofuel production and carbon capture and storage (CCS) the organic CO_2 which is produced as a by-product of the process is captured and taken out of the carbon cycle. With this application of CCS an additional net carbon sink is created, which amounts to 50 Mt CO_2 in 2040 and approx. 115 Mt CO_2 in 2050. This corresponds to 3 percent of the total reduction of energy-related emissions from 2008 to 2050.[8]

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7 All data referred to in this chapter are direct emissions. Emission reductions brought about by increased efficiency in electricity or heat consumption are attributed to the power sector and the district heating sector.

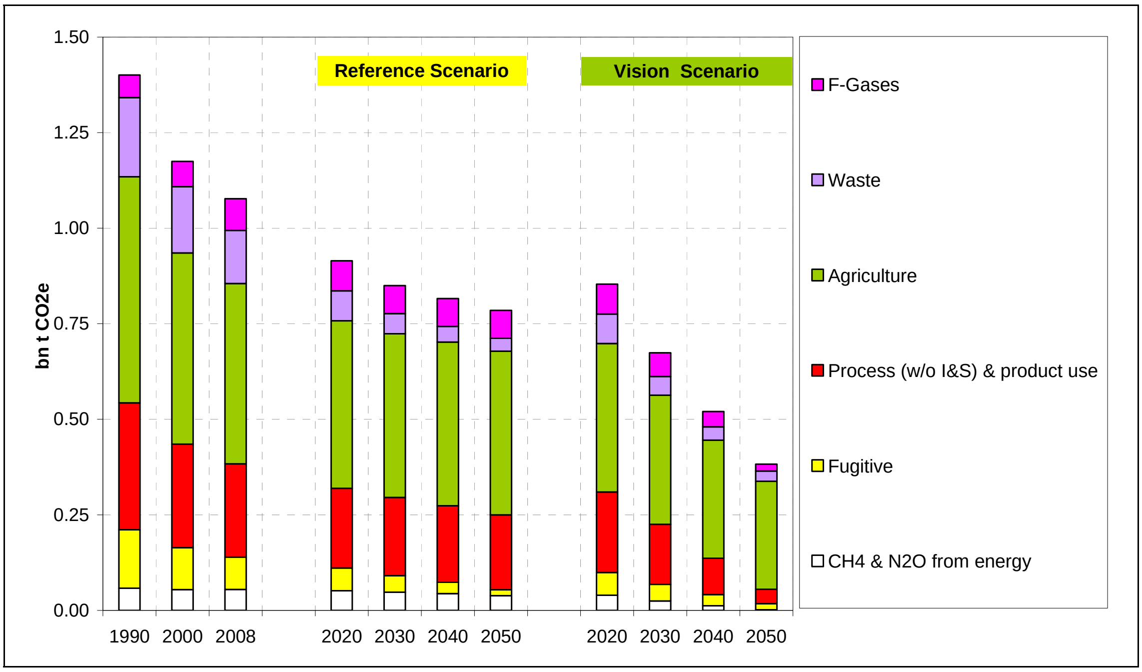
8 CCS is also considered for the iron and steel industry. These emission reductions are included in the totals of energy-related emissions for modelling reasons. See chapter 6.2 for more details.

6.2 Non-energy and non-CO_2 greenhouse gas emissions

The main sources of non-energy and non-CO_2 greenhouse gas emissions are process emissions, emissions from agriculture and waste management. Fugitive emissions from the energy sectors as well as methane (CH_4) and nitrous oxide (N_2O) from combustion depend largely on energy production and use.

Figure 15 indicates the non-energy and non-CO_2 emission trends for the Reference Scenario and the Vision Scenario. The Reference Scenario is based on an extension of the existing pattern of production and emissions of the respective sectors, which were projected for the scenario period. The scenario is characterised by slightly decreasing emissions and only small changes in the emission patterns. The significant decrease of emissions from 1990 to 2008 is projected to slow down in the next four decades. From 2008 to 2020 an emission decrease of -10% will be achieved and by 2050 the emissions are expected to be approx. 20% below 2008 levels.

Figure 15 Non-energy and non-CO_2 greenhouse gas emissions in the EU-27, 1990-2050



Source: UNFCCC, Öko-Institut.

In the Vision Scenario a wide range of measures for all relevant sectors is assumed. The full range of mitigation measures that were reflected in the Vision Scenario are described in more detail in Prognos/Öko-Institut (2009). Key mitigation measures include:

- a significant increase of resource efficiency to decrease the demand for crude steel and cement;

- the use of CCS for crude steel and cement clinker production from 2030 onwards;
- switch to hydrogen supply from renewable energy sources for ammonium and methanol production;
- higher ratios of recycling and a greater use of cullet in glass production;
- large-scale introduction of high efficient catalytic converters for adipic acid and nitric acid production;
- substitution of HFCs in cooling applications by natural coolants, phase-out of HFCs use in production of polyurethane foam products, XPS hard foams, and aerosols (dispensing and technical aerosols);
- phase-out of dumping untreated waste (and thus also the organic substances which release gas) to landfills;
- use of organic waste for biogas and biofuel production and use of the remaining landfill gas for energy production;
- protein-optimised nutrition strategy leading to substantial livestock reduction;
- gas-tight storage of liquid animal waste and greater fermentation of such waste in biogas plants;
- expansion of organic farming; and
- improved fertilizer management.

Emissions from industrial processes can be reduced by about 10% from 2008 to 2020, 26% to 2030 and approx. 60% by 2050. The most significant contribution in the short term stems from the reduction of N_2O emissions from industrial processes, the most important emissions reduction in the long term is provided by CCS in the steel and cement industry.[9] About 115 Mt CO_2 will be avoided by CCS from process emissions in 2040 and about 180 Mt CO_2 in 2050. The contribution of CCS in terms of process emissions amounts to about 4% of the total greenhouse gas emission reduction from 2008 to 2050.

Agriculture provides the second largest contribution (about 190 Mt CO_2e or -32% compared to 2008) to the total emission reduction for non-energy and non-CO_2 greenhouse gases. The total emission mitigation in agriculture results from reductions in CH_4 (90 Mt CO_2e) and N_2O (100 Mt CO_2e) emissions.

[9] As mentioned in chapter 6.1, process emissions from coal use in the iron and steel industry are accounted for in the energy-related emissions for modelling reasons. In 2040 the application of CCS in the steel industry will avoid 60 Mt CO_2 in 2040 and 90 Mt CO_2 in 2050. CCS in the cement industry will avoid 55 Mt CO_2 in 2040 and 90 Mt CO_2 in 2050.

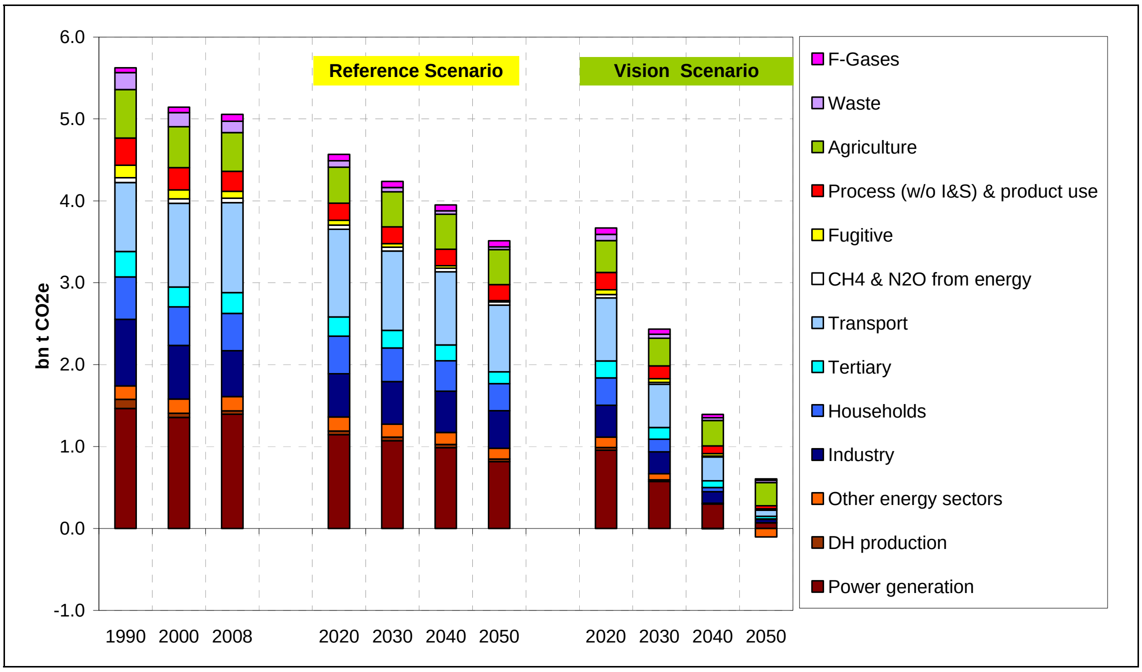
Other significant emissions reduction contributions can be attributed to the waste sector (about 110 Mt CO_2e from 2008 to 2050), mainly from avoided methane emissions from landfills.

Mitigation measures with regard to HFC, PFC and SF6 provide a further contribution of 64 Mt CO_2e from 2008 to 2050.

6.3 Total greenhouse gas emissions

The total GHG emission trends for the scenario period were derived from the Reference Scenario and the Vision Scenario for CO_2 and non-CO_2 greenhouse gases (Figure 16).

Figure 16 EU-27 greenhouse gas emission trends the Reference Scenario and the Vision Scenario by sectors, 1990-2050



Source: UNFCCC, Öko-Institut.

The total GHG emissions reduction from 2008 to 2050 amounts to approx. 1,540 Mt CO_2e in the Reference Scenario. This decrease of 27% is equivalent to an overall emissions reduction of 38% compared to 1990 levels. In 2020 an emissions reduction of 19% compared to 1990 levels is achieved.

- The main share of the emission reductions results from energy-related CO_2 emissions. From 2008 to 2050 these emissions decrease by about 1,270 Mt CO_2, from 2008 to 2020 the respective emission reduction is about 330 Mt CO_2 and from 2008 to 2030 about 600 Mt CO_2. The power sectors contribution is about 250 (2020), 320 (2030) and 580 Mt CO_2 (2050). The second most important emissions reduction stems from the transport sector, which contributes 30

(2020), 130 (2030) and 280 Mt CO_2 (2050) to the total CO_2 emission reductions. All other end-use sectors bring about an emission reduction of about 40 Mt CO_2 by 2030 and between 100 and 120 Mt CO_2 by 2050.

- The CH_4 emissions decrease by about 100 Mt CO_2e from 2008 to 2020, about 150 Mt CO_2e from 2008 to 2030 and 190 Mt CO_2e for the period 2008 to 2050. The major share of the emission reduction results from waste management (about 100 Mt CO_2e from 2008 to 2050) and fugitive emissions from energy production and distribution (about 50 Mt CO_2e).
- The trend of N_2O emissions is largely determined by process emissions and the agricultural sectors. The total emission reduction of about 60 Mt CO_2e from 2008 to 2050 results from 30 Mt CO_2e of mitigation measures in industrial processes and about 20 Mt CO_2e from changes in agriculture.
- The total emission reduction from HFC, PFC and SF_6 is relatively small in the period 2008 to 2050 (about 10 Mt CO_2e).

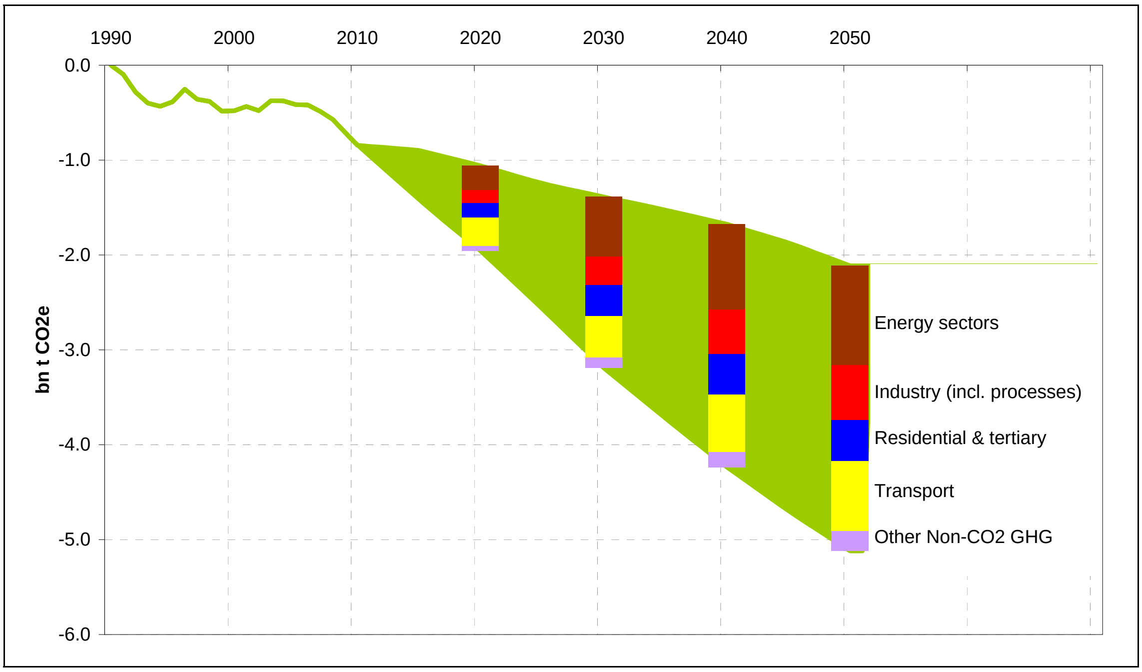
The corresponding emission reduction from the installations regulated by the European Union Emissions Trading Scheme (EU ETS) is about 15% for 2020, compared to 2005 levels (Table 1). The installations covered by the EU ETS would have to purchase significant amounts of offsets to meet their obligation of a 21% emissions reduction under the EU-wide cap for 2020.

Table 1 EU-27 greenhouse gas emission trends the Reference Scenario and the Vision Scenario by gases, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO2e								
CO2 from energy	4.00	3.67	3.40	3.14	2.73	2.83	1.77	0.87	0.12
CO2 from non-energy	0.21	0.20	0.20	0.19	0.19	0.20	0.15	0.09	0.03
CH4	0.41	0.31	0.26	0.24	0.22	0.29	0.22	0.17	0.14
N2O	0.36	0.32	0.31	0.31	0.30	0.27	0.23	0.21	0.19
F-Gases	0.08	0.08	0.07	0.07	0.07	0.08	0.06	0.04	0.02
Total	5.05	4.57	4.24	3.95	3.51	3.67	2.43	1.39	0.50
Change of emissions									
Total from 1990	-10%	-19%	-25%	-30%	-38%	-35%	-57%	-75%	-91%
Total from 2005	-3%	-12%	-19%	-24%	-33%	-30%	-53%	-73%	-90%
ETS from 2005	*-4%*	*-15%*	*-18%*	*-22%*	*-31%*	*-37%*	*-60%*	*-80%*	*-99%*

Source: UNFCCC, Öko-Institut.

Figure 17 Sectoral contributions to the EU-27 greenhouse gas emission trends in the Vision Scenario, 1990-2050



Source: UNFCCC, Öko-Institut.

In the Vision Scenario the emission pathway exceeds the -30% target (compared to 1990 levels) for 2020 and results in a reduction of -57% in 2030 and -91% in 2050.

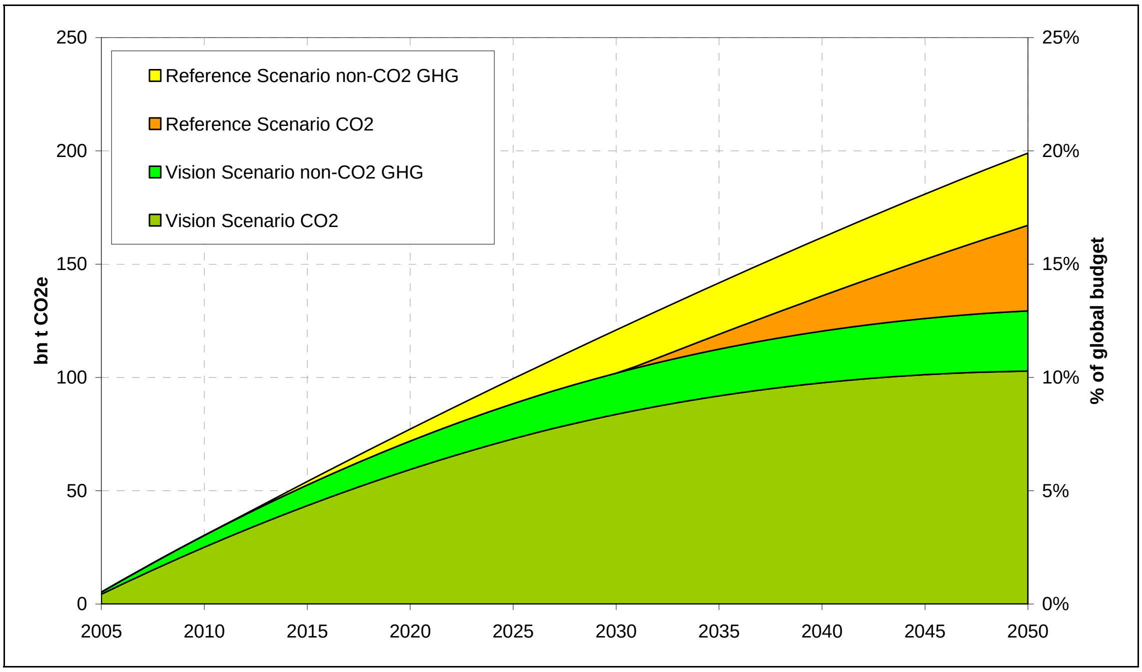
- Energy-related CO_2 emissions are again the main driver for the emission reduction. The respective sectors bring about 3,870 Mt CO_2 of the total emission reduction of about 4,550 Mt CO_2e in the Vision Scenario from 2008 to 2050. The key sector is the power sector which contributes about 1,325 Mt CO_2 over the scenario period. The emission reduction from the transport sector reaches nearly the same magnitude (1,025 Mt CO_2). However, the emission reductions from the other sectors (industry 520 Mt CO_2, households 450 Mt CO_2 and tertiary sectors 220 Mt CO_2) are also significant. With a view to the building sector it should be highlighted that these emission reduction potentials can only be achieved by a steady integration of the highest efficiency standards into the ongoing modernisation process.
- CH_4 emission reductions constitute the second largest contribution to the total decrease of emissions. The total reduction is about 270 Mt CO2e, and mainly from waste management (100 Mt CO_2e), agriculture (90 Mt CO_2e) and fugitive emissions from the energy sector (about 50 Mt CO_2e).
- CO_2 emissions from non-energy sources drop significantly, by about 170 Mt CO_2 from 2008 to 2050. This is mainly due to the increase of resource efficiency (regarding steel, cement, etc.) and the introduction of CCS for process-related emissions in the steel and cement industry.

- The same level of emission reductions (170 Mt CO_2e from 2008 to 2050) stems from N_2O emissions, coming mainly from agriculture (100 Mt CO_2e) and industrial processes (35 Mt CO_2e).
- Significant emission reductions (35 Mt CO_2e) result from HFC use; the contribution of PFC and SF_6 amounts to 10 Mt CO_2e.
- The total contribution of CCS (process emissions in the steel and cement industry and net sinks from biomass-CCS) amounts to about 300 Mt CO_2 by 2050; process emissions account for 180 Mt CO_2 of this emission reduction and the use of bio-energy with CCS (BECCS) accounts for the remaining 120 Mt CO_2. However, the key contributions from CCS occur after 2030 in the Vision Scenario.

The emission trajectories for the Reference Scenario, the Vision Scenario, and the sectoral contributions to the additional GHG emission reductions in the Vision Scenario (Figure 17) highlight some strategic results of the modelling exercise:

- If a long-term emissions reduction target of at least 90% compared to 1990 levels is set, interim targets other than about 30% or more for 2020 and 55 to 60% in 2030 are inconsistent with the long-term trajectory.
- The power and the transport sector are key sectors with a view to their emission reductions and their interactions (electric mobility, etc.). The residential sector is of special importance because of the durable capital stock.

Figure 18 Cumulative greenhouse gas emissions in the Reference Scenario and the Vision Scenario, 2005-2050



Source: Öko-Institut.

The level of cumulative GHG emissions is a complementary and more useful indicator for the impact of certain greenhouse gas emissions trajectories on global warming (Figure 18). The diagram highlights that only ambitious and at the same time early emission reductions have a major impact on the level of cumulative emissions and as such on the process of global warming. The data indicates that the EU exhausts a significant share of the global emission budget that is available to meet the 2°C target with an acceptable probability (see chapter 1).

In the Reference Scenario the EU’s cumulative GHG emissions correspond to 16% of the global budget of 1,230 bn t CO_2e for 2005 to 2050. Even in the ambitious Vision Scenario the level of the EU’s cumulative GHG emissions is equivalent to a share of 16% of the global budget for all GHG emissions. With a view to CO_2 emissions the cumulative emissions represent a share of 17% (Reference Scenario) and 10% (Vision Scenario) in the global CO_2 emission budget of 1,000 bn t CO_2 for the period 2005 to 2050.

In terms of the projected 5.7% share of the EU in global population in 2050 (UN 2008) even the ambitious Vision Scenario is far from achieving an equity approach for the allocation of the global emissions budget within the 2°C target.

7 Indicators and targets

A series of indicators can be derived from the modelling results. In the context of this analysis, indicators for the share of renewable energies in different sectors, energy efficiency indicators, and emission reduction indicators could serve as appropriate indicators for the development of respective political strategies.

Table 2 Energy indicators for the Reference Scenario and the Vision Scenario, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
Share of renewables									
Power generation	17%	24%	29%	37%	46%	39%	60%	79%	94%
District heat	16%	16%	17%	20%	24%	22%	32%	60%	85%
Final energy	10%	13%	16%	19%	23%	20%	34%	57%	82%
Industry	*12%*	*14%*	*16%*	*20%*	*24%*	*21%*	*35%*	*54%*	*74%*
Tertiary	*9%*	*14%*	*17%*	*23%*	*30%*	*21%*	*37%*	*58%*	*81%*
Households	*16%*	*19%*	*21%*	*25%*	*30%*	*28%*	*49%*	*73%*	*93%*
Transport	*3%*	*7%*	*9%*	*11%*	*12%*	*10%*	*17%*	*44%*	*82%*
Primary energy	9%	13%	16%	20%	24%	20%	37%	64%	88%
Energy Efficiency	Change from 2005								
Final energy	-1%	2%	0%	-3%	-10%	-18%	-34%	-45%	-55%
Households	-3%	4%	1%	-2%	-6%	-10%	-30%	-47%	-58%
Transport	3%	5%	-3%	-9%	-16%	-22%	-42%	-52%	-62%
Primary energy	-1%	-1%	-2%	-7%	-15%	-22%	-38%	-42%	-46%
Primary energy imports	75%	75%	76%	76%	76%	65%	53%	37%	29%
Notes: The share of renewables in the end-use sectors (final energy) includes indirect contributions from electricity, heat and hydrogen. Nuclear fuel was fully considered as imported primary energy.									

Source: Öko-Institut.

The set of indicators for energy efficiency improvements (Table 2) highlights some of the key issues for robust energy and climate strategies backed by the Vision Scenario:

- Achieving primary energy savings of 20% by 2020 and 40% by 2030 form a key objective of the Vision Scenario.
- The slow but steady efficiency improvement in the residential sector is basically an issue of modernisation of buildings and constitutes an important sub-sectoral indicator.
- The energy efficiency improvement in the transport sector is also a long-term, innovation-based objective.
- For the industrial and tertiary sectors the energy efficiency indicator is of less significance because of the statistical artefacts caused by the increasing importance of electricity in these sectors. The same reservation applies for primary energy demand reductions after 2020 because of the statistical artefacts caused by the statistical conventions for calculating primary energy equivalents for power production from renewable energy sources.

The indicators for renewable energy, which were used for different sectors and aggregation levels (Table 2), outline the key objectives that need to be fulfilled if the emission trajectory of the Vision Scenario shall be achieved:

- Renewable energies represent a share of total primary energy supply of 20% in 2020, nearly 40% in 2030 and about 90% in 2050.
- The share of renewables in the final energy consumption of the end-use sectors and the total final energy consumption oscillate around this level for the years 2020, 2030 and 2050.
- The power sector undergoes an early transition towards renewable energies; the share of renewables in net power generation is about 40% in 2020, 60% in 2030 and about 95% in 2050.

Table 3 Greenhouse gas emission reduction indicators for the Reference Scenario and the Vision Scenario, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
Total emissions									
from 1990	-10%	-19%	-25%	-30%	-38%	-35%	-57%	-75%	-91%
from 2005	-3%	-12%	-19%	-24%	-33%	-30%	-53%	-73%	-90%
ETS emissions									
from 2005	-4%	-15%	-18%	-22%	-31%	-37%	-60%	-80%	-99%

Source: Öko-Institut

Key base years for the assessment of GHG emission reductions are 1990 (base year for the overall emission reduction target) and 2005 (base year for the cap under the EU ETS as well as the effort sharing for the non-ETS emissions).

From the modelling results for the Vision Scenario, the following emission targets can be derived:

- Total GHG emission reductions of at least 30% for 2020 and about 55 to 60% in 2030 are consistent with a long-term target of at least 90% by 2050, based on 1990 levels. Furthermore, such interim targets are appropriate, also within the concept of cumulative emissions. If land use, land-use change and forestry are also considered, a 95% reduction target for 2050 could also be achieved.
- From the modelling database, targets for the cap under the EU ETS can also be derived. The cap should be 35 to 40% below 2005 levels for 2020 and 60% below 2005 levels for 2030. In 2050 all ETS-regulated installations should be nearly decarbonised.
- If high quality international offsets shall be used, the offsetting should be additional to the targets mentioned above. This could also be a way to shift the exploitation of the global GHG emissions budget by the EU more towards an equity approach.

8 Conclusions and policy recommendations

The scenario analysis presented in the previous chapters indicate that it is possible to draft a strategy which combines ambitious greenhouse gas reductions for the short-, medium- and long-term, a phase-out of nuclear energy, less energy imports and the increasing use of renewable energies. The potentials for such transformation are available and can be combined in robust strategies to make these targets achievable. The total GHG emissions can be reduced by more than 90% compared with 1990 levels in the next four decades by a wide range of measures in all sectors. However, the scenario analysis did not address emission reductions from land use, land use change and forestry (LULUCF). The existing literature on de-carbonisation strategies (e.g. Prognos/Öko-Institut 2009) indicates additional emission mitigation potentials from LULUCF which could probably enable a 95% emissions reduction for the European Union by 2050.

For the long-term greenhouse gas reduction targets all sectors must contribute to significant emission reductions and will have to undertake a fundamental transition. With a view on the modernisation cycles in key sectors with long-living capital stocks (e.g. power plants, buildings, infrastructure) it is essential to set a consistent set of targets for GHG emissions, energy efficiency and renewable energies to safeguard the short-, medium- and long-term transition of economy towards a nearly zero-carbon economy, based on high levels of energy efficiency and a fully renewable energy system:

1. The analysis has shown that short- and medium-term greenhouse gas emission reduction targets must be consistent with the long-term objectives.

    a) If the long-term greenhouse gas emission reduction target is at least -90% (compared to the 1990 levels) for the EU-27 or even more ambitious (e.g. -95%), the emission reduction target must be set at least at -30% for 2020 (probably even higher, e.g. at a level of -35%) and 55 to 60% in 2030. This is to ensure the consistency of the emission trajectory on the one hand and to limit the cumulative emissions (in other words: the EU's share in the exploitation of the global emission budget which is available if the 2°C target shall be achieved). Less ambitious targets for domestic emission reductions in 2020 and 2030 would significantly lower the probability that a long-term target of at least 90% could be achieved and would significantly increase the EU's share in exhausting the global GHG emissions budget and thus ignore completely an equity-based approach to GHG mitigation.

    b) A coherent target for the installations in the EU-27 which are regulated by the European Union Emissions Trading Scheme (EU ETS) would be -37% in 2020 (compared to the 2005 emission levels) and 60% in 2030.

2. To ensure comprehensive and robust emission reductions, targets for energy efficiency are imperative to set:

    a) A target of 20% in absolute primary energy reduction for the period from 2005 to 2020 is in line with the greenhouse gas reduction target mentioned above. For 2030 primary energy consumption should be reduced by 35 to 40%.

    b) A first sectoral energy efficiency target should be set for the private household to ensure timely policies and measures with regard to the buildings stock, which is characterized by an extremely long-living capital stock. A reduction of the final energy consumption of 10% by 2020 (compared with 2005 levels), 30% by 2030 and 60% by 2050 is appropriate and consistent to the emission reduction targets.

    c) A second sectoral efficiency target should be set for the transport sector, e.g. to safeguard the restrictions on the use of sustainable biofuels. With energy savings of about 20% by 2020, 40% by 2030 and 60% by 2050 (based on 2005 levels) the transport sector could undergo the necessary transition without exceeding the acceptable level of biomass consumption.

3. Renewable energies will be the second key pillar for the necessary emission reductions:

    a) A contribution of at least 20% to the total primary energy supply for 2020 is consistent to the medium- and long-term emission reduction target. For 2030 this target should be set at 40% and 90% for 2050.

    b) Taking into account the key role of early and fast transformation of the power sector towards renewable energies a sub-target should be set for the share of renewable energies in electricity generation, which should be set at a level of 40% in 2020, at least 60% in 2030 and 95% in 2050.

However, the transition of the energy system to a nearly zero-carbon system should not only be assessed against the effects of climate change. In a world of growing prices for fossil and nuclear fuels and increasingly volatile primary energy prices in the world market the issue of energy imports, vulnerability of economies and consumers to prices as well as the wealth transfer to the primary energy producers, the issue of energy imports must be seen as an emerging challenge. Although the structure of energy consumption between the different sectors changes significantly in the Vision Scenario, some effects on the necessary energy imports are notable:

- Although the gas consumption in the power sector will increase slightly for the next two decades in the Vision Scenario, the additional increase in gas consumption can be compensated for by increased efficiency in other sectors (notably in the heat market) in a way that the consumption levels of 2008 will not be exceeded in the upcoming years and the natural gas imports will by reduced steadily. In contrast, the gas consumption rises in the Reference Scenario for the next two decades, peaking in 2020 and falling to 2008 levels only in 2030. However, the imports of natural gas are projected to grow steadily in the Reference Scenario by 2040.

- The diversification in the transport sectors is improved significantly in the Vision Scenario. For this most vulnerable sector, the dependency on oil can be reduced from about 94% in 2008 to about 87% by the year 2020 and 79% by 2030 in the Vision Scenario. Avoided transport, modal shift, the massive improvement of energy efficiency, the phase-in of electric cars as well as the phase-in of biofuels will play a key role in this context. Although the import of crude oil and petroleum products is projected to fall in both Scenarios the decrease of oil imports is much more significant in the Vision Scenario.
- The availability of sustainable biofuels is one of the major challenges within the issue of energy imports. If it is assumed that international markets for biofuels will develop rapidly, the certification of biofuels will be crucial to ensure the sustainability of the biofuels strategy. An acccountable system of certification of sustainability of biomass import will be of key importance if significant imports must be considered beyond 2020 as projected in the Vision Scenario.
- The total dependency on energy imports decreases significantly in the Vision Scenario from 75% in 2008 to 65% in 2020, 53% in 2030 and 29% in 2050. Even if one assumes that the rate of energy imports is not the most appropriate indicator for addressing the issue of the security of supply, it should not be ignored that a high share of domestic energy production ensures added domestic value and jobs. The difference of primary energy imports between the Vision Scenario and the Reference Scenario represents an economic value of € 130 bn in 2020, about € 260 bn in 2030 and approx. € 455 bn in 2050, based on the most recent oil price forecast by the International Energy Agency.

The implementation of an energy and climate policy framework, which is outlined by the Vision Scenario, requires a broad range of interventions. Key strategic goals for a transformation as outlined in the Vision Scenario are:

1. A strong focus on energy efficiency measures
    - for improvement of buildings (heating and cooling) for both new buildings and the renovation of the existing building stock so as to reach near-zero energy house standards for the whole building stock in the period up to 2050;
    - for conventional appliances and installations consuming electricity in all sectors (household equipment, electronics, motors, pumps, etc.);
    - implementing ambitious performance standards for cars, trucks and airplanes.

2. A strong focus on changing the modal split targeting public and rail freight transport
   - with comprehensive efforts to decrease transport demand;
   - with strong efforts to increase the capacity of the railway system and major system investments to strengthen the competitiveness and the infrastructure of rail transport and sustainable modes of transports in cities;
   - with measures to establish a level playing field between the different modes of transport, e.g. by removing the tax advantages for kerosene and jet fuels for air transport.
3. Ambitious efforts to increase the share of renewable energies in both, the energy and the end use sectors
   - by incentivising power production from renewable energies with robust and accountable policies and measures;
   - by setting an analytical, political and regulatory framework to upgrade and develop the necessary infrastructure in a timely manner;
   - by changing market designs and regulatory approaches to enable the large-scale use of renewable energies, including those with variable production characteristics.
4. Strong efforts to increase the efficiency of power generation and to phase-out high-emitting power production assets.
5. Focused efforts to safeguard the sustainability of the necessary biomass supply, which does not exceed the equity-based usage rights of the EU-27 in the global sustainable biomass potential
   - by setting an analytical, political and regulatory framework to assess and safeguard the environmental effects of biomass use properly (including the effects from direct and indirect land use change) for the domestic supply of biomass as well as biomass imports from other regions of the world;
   - by establishing a careful monitoring and management system to make the best use of the limited potential of sustainable biomass, bearing in mind the short- and medium-term as well as the long-term time horizon and appropriate cascades of biomass use (food, raw materials, energy);
6. Carefully planned strategies to reduce emissions from capital-intensive installations with long lifetimes (e.g. capital stocks of power plants, buildings, infrastructures, etc.) to use consequently the respective windows of opportunities to minimize the costs of the transformation and to ensure that the ambitious emission reduction targets can be achieved.

7. Trigger appropriate and effective innovation strategies for
    - radical innovations in energy efficiency technologies (insulation, industrial processes, vehicles etc.) and services (improved and more efficient logistics, renovation of building, third-party financing, etc.);
    - renewable energies, including sustainable biofuels;
    - transmission and distributions infrastructures and energy storage;
    - logistics and more efficient use of transport infrastructures;
    - more efficient use of non-energy resources (e.g. for steel, cement, etc.);
    - carbon capture and storage (with a special focus on industrial processes and bio-energy CCS).

A central bottleneck of the transition towards a near zero-carbon energy system will be the necessary upgrade and roll-out of energy and transport infrastructures. Some of the implications from the transition pathway described in the Vision Scenario are:

- The development drafted for the power sector requires the integration of large quantities of power generation from variable, decentral and remote sources. The network infrastructure and the necessary system services must be strengthened and extended in this framework. This upgrade is necessary for transmission grids to integrate offshore wind or utility-scale solar power plants as well as for distribution networks. Smart distribution networks are a key prerequisite for electric mobility or significant shares of decentralised power generation.
- The use of natural gas will change significantly. If natural gas shall play a more significant role in power generation, the strengthening of the intra-EU gas networks, storage facilities with fast-release profiles and other infrastructure will prove to be a main priority in the EU-27 especially for the next two decades, which is crucial especially for Central and Eastern Europe.
- If biofuels shall play a significant role, the investment in production facilities that can deliver high quality sustainable biofuels will be necessary.
- Carbon dioxide capture and sequestration systems have to play a role in the future, e.g. for industrial process emissions and to create net sinks in combination with bio-energy with carbon capture and storage (BECCS). Therefore the preparation of an appropriate and risk-minimized infrastructure for CO_2 transport and storage sites must start in the near future.
- Railway infrastructures must also be upgraded significantly to achieve the necessary modal shifts from road and air transport for passenger as well as freight transport.

For all these measures on infrastructure, significant investments will be necessary. To create an enabling framework for these infrastructures the following issues must be reflected in the respective energy and climate policies:

- The adjustment and the development of the necessary regulatory framework for major upgrades and roll-out of infrastructures under uncertainty constitute a crucial basis for many of the new measures related to infrastructures.
- For many infrastructure upgrades and roll-outs long lead-times must be considered. Consistent and coordinated longer-term planning processes on these infrastructures are necessary at the EU as well as at the Member States level.
- If infrastructures shall be implemented in a timely manner, the consistency between infrastructure planning and implementation and support schemes must be ensured. Especially the support schemes for renewable energies must not only provide certainty for investors but also create the necessary certainty for infrastructure adjustments with the related long-lead times. Technology and regional differentiation will be key elements for any sustainable support mechanism, as long as such mechanisms will be necessary.

The establishment of sufficient policies and measures to create incentives and the framework for the necessary transition of the energy system is the most crucial issue. On the one hand, clear priorities must be set up with regards to the necessary comprehensive policy mix (Matthes 2010). On the other hand, many experiences on how different political instruments interact and what clusters of instruments fit best still have to be gathered. A clear structure and the necessary flexibility to adjust the policy mix is probably the biggest challenge for future energy, transport and climate policy. From the broad range of necessary and suitable policies and measures the following shall be highlighted:

- The EU ETS is the central element of the policy mix. If carbon pricing is the necessary (but not necessarily sufficient) precondition for the transformation at the lowest costs, the EU ETS must be adjusted in a way that in all investments and for all operational decisions the full price of carbon is reflected. A tightened cap as well as provisions to safeguard the integrity of the scheme (e.g. with a view on offsets) will be of key importance. With the introduction of an emissions trading scheme for aviation, another crucial sector could be subject to market-based carbon pricing. However, the future design of the EU ETS should focus primarily on ambitious domestic emission reductions to foster the transition to a nearly zero-carbon energy system. More ambitious energy or CO_2 taxes for the non-ETS-regulated sectors are a second important track on carbon pricing.
- In the framework of the EU internal market, ambitious performance standards for the energy consumption of electric appliances and installations, buildings as well as vehicles should be immediately established and updated on a regular and transparent basis.
- Given the necessarily fast and strong penetration of electricity, heating & cooling and transport markets by renewable energies, a combination of carbon pricing, market design changes and innovation approaches is required. Clear and differentiated targets should also be strengthened for renewable energies. Against the background of the necessary learning investments for many renew-

able energies and the long lead-times for the upgrade of infrastructure, the establishment of, to the necessary extent, technology-specific and regionally differentiated policies and measures will be appropriate, at least for the next two decades.

- The strengthening of the EU energy market liberalisation and enforcing competition for the electricity market and, especially, the gas market will play a crucial role in the transformation of the energy system. Stronger action against market power and more transparency and integrity of energy markets will be needed.
- The fair access to grids is being increasingly seen as a key measure and some progress will be made on this if a more strict ownership unbundling approach can be implemented. However, the extension of network services and the necessary regulatory framework as well as the reduction of market dominance especially in the power generation sector represent major challenges for the future. The mandate of energy infrastructure regulation should be extended to promote, enable and enhance the emerging transition process.
- In the framework of energy market liberalisation and the different dimensions of energy security, the development of a coherent EU gas strategy is crucial, which takes into account the limited need for gas imports, the decreasing share of natural gas in the heat market and the slightly increasing demand from power generation for the next one or two decades.
- The manifold options for reducing greenhouse gas emissions in the non-energy sectors require a series of polices with regard to agriculture, waste management and a variety of industrial processes.
- Innovation plays a key role in extending the portfolio for the transformation of the energy system. Key issues to be addressed in the framework of an innovation program are the emerging technologies in the field of efficient use of energy in industry, in buildings and in the transport sector, the full range of renewable energies including sustainable biofuels, energy storage and carbon dioxide capture and sequestration.

The fundamental transformation of the energy sector drafted in the Vision Scenario indicates a very ambitious pathway towards a sustainable energy system. However, compared to the different dimensions of the Reference Scenario in terms of greenhouse gas emissions, consumption of fossil fuels and the different aspects of energy security the Vision Scenario shows that a multitude of benefits can be raised if such a pathway forms the framework for the design of future energy and climate policies.

Last but not least, the development of comprehensive, consistent, flexible and learning policies and measures within the framework of the European Union, which is characterised by many distributed responsibilities, requires a lot of transparency with regard to the interactions and gaps between the different policies and instruments on the one hand and the gaps with regard to the compliance with targets on the other. A suitable approach to dealing with this challenge is policy-oriented modeling. Significantly increased efforts should be undertaken in order to develop a transparent bottom-up modeling framework for the EU which enables the assessment and the development of policies and measures on a consistent and transparent basis.

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Annex

Table A- 1 Final energy consumption industry, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	40	35	34	33	30	29	23	22	20
Lignite & brown coal	3	2	2	2	2	2	2	2	1
Petroleum products	42	31	29	28	25	20	12	6	3
Gases	97	107	109	105	96	78	58	32	12
Electricity	98	106	116	122	124	84	88	98	109
Heat	15	23	25	24	22	15	13	11	10
Biomass	19	16	17	17	15	14	17	20	23
Solar & geothermal	0	0	0	0	0	0	0	0	0
Others	2	2	2	2	2	2	2	2	2
Total	318	324	335	334	317	244	215	194	180
Share of renewables									
direct	*6%*	*5%*	*5%*	*5%*	*5%*	*6%*	*8%*	*11%*	*13%*
direct & indirect	*12%*	*14%*	*16%*	*20%*	*24%*	*21%*	*35%*	*54%*	*74%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 2 Final energy consumption commercial sector, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	2	1	1	1	1	1	1	1	1
Lignite & brown coal	0	0	0	0	0	0	0	0	0
Petroleum products	38	32	29	26	19	31	20	11	5
Gases	54	55	52	46	35	46	32	19	6
Electricity	71	78	85	87	82	69	70	71	64
Heat	10	10	9	8	6	6	5	4	3
Biomass	3	4	5	5	4	4	5	6	7
Solar & geothermal	1	1	1	1	1	1	2	2	3
Others	1	1	1	1	1	1	1	1	1
Total	180	182	182	176	149	159	136	115	88
Share of renewables									
direct	*2%*	*3%*	*3%*	*4%*	*4%*	*3%*	*5%*	*7%*	*11%*
direct & indirect	*9%*	*14%*	*17%*	*23%*	*30%*	*21%*	*37%*	*58%*	*81%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 3 Final energy consumption households, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	8	5	4	4	3	5	2	1	0
Lignite & brown coal	1	1	1	1	1	1	0	0	0
Petroleum products	47	43	38	34	30	28	11	3	0
Gases	117	129	118	107	95	95	47	16	2
Electricity	70	83	93	102	111	88	97	94	84
Heat	19	21	19	17	15	19	15	10	5
Biomass	32	35	35	34	32	35	35	31	26
Solar & geothermal	1	1	1	1	1	4	6	8	10
Others	0	0	0	0	0	0	0	0	0
Total	297	318	309	301	289	275	213	163	129
Share of renewables									
direct	*11%*	*11%*	*12%*	*12%*	*12%*	*14%*	*19%*	*24%*	*28%*
direct & indirect	*16%*	*19%*	*21%*	*25%*	*30%*	*28%*	*49%*	*73%*	*93%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 4 Final energy consumption transport sector, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Diesel	196	189	164	152	134	142	104	59	15
Motor spirit	101	93	82	68	58	69	39	18	4
Kerosene	54	60	64	68	70	37	26	15	4
Heavy fuel oil	2	1	1	1	1	1	0	0	0
Gases	6	6	5	3	2	4	3	2	1
Electricity	6	7	8	8	8	10	12	17	21
Hydrogen	0	0	0	0	0	0	0	2	2
Biofuels	10	27	31	33	33	24	28	62	93
Others	0	0	0	0	0	0	0	0	0
Total	374	384	355	332	306	286	213	176	140
Share of renewables									
direct	*3%*	*7%*	*9%*	*10%*	*11%*	*9%*	*13%*	*35%*	*67%*
direct & indirect	*3%*	*7%*	*9%*	*11%*	*12%*	*10%*	*17%*	*44%*	*82%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 5 Total final energy consumption, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	51	42	39	38	34	35	26	24	20
Lignite & brown coal	4	3	3	3	3	3	2	2	1
Gas/diesel oil	276	259	226	207	181	196	134	74	21
Motor spirit	101	94	82	68	58	69	39	18	4
Kerosenes - Jet Fuels	59	65	68	71	73	40	27	16	4
Other petroleum products	47	38	34	31	27	25	15	7	3
Gases	269	292	279	259	226	219	138	68	21
Electricity	246	274	302	319	324	251	267	281	278
Heat	45	54	54	50	44	40	33	25	18
Hydrogen	0	0	0	0	0	0	0	2	2
Biomass	64	82	88	89	86	78	85	120	149
Solar & geothermal	2	2	2	2	2	5	7	10	13
Others	3	3	4	4	3	3	3	3	3
Total	1,169	1,208	1,181	1,142	1,061	964	776	647	537
Share of renewables									
direct	*6%*	*7%*	*8%*	*8%*	*8%*	*9%*	*12%*	*20%*	*30%*
direct & indirect	*10%*	*13%*	*16%*	*19%*	*23%*	*20%*	*34%*	*57%*	*82%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 6 Net power generation, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	TWh								
Nuclear	888	906	991	809	627	402	150	21	0
Hard coal	512	484	505	463	372	367	128	43	0
Lignite & brown coal	328	310	324	271	185	208	79	12	0
Oil	99	48	36	30	25	38	19	1	0
Gases	770	900	875	972	987	905	933	623	94
Hydro	327	346	365	415	464	356	366	373	376
Wind	118	320	478	698	918	546	896	1,201	1,398
Photovoltaics	7	45	68	120	171	110	270	417	484
Concentrated solar	0	8	14	20	27	36	180	317	455
Biomass	75	125	173	232	292	187	287	387	463
Geothermal	5	7	9	13	18	23	60	148	197
Others	43	43	43	53	64	46	56	77	130
Total	3,173	3,542	3,881	4,097	4,150	3,225	3,423	3,620	3,599
Share of renewables									
Total	*17%*	*24%*	*29%*	*37%*	*46%*	*39%*	*60%*	*79%*	*94%*
Intermitting	*4%*	*10%*	*14%*	*20%*	*26%*	*20%*	*34%*	*45%*	*52%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 7 Total primary energy supply (excl. non-energy use), 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Nuclear	242	246	270	220	171	110	41	6	0
Hard coal	185	147	140	127	104	118	54	33	20
Lignite	92	73	69	56	37	52	20	4	2
Oil and petroleum products	547	504	452	416	373	366	237	124	35
Gases	447	469	445	433	395	389	297	169	38
Hydropower	28	30	31	36	40	31	31	32	32
Wind	10	27	41	60	79	47	77	103	120
Solar	2	6	8	13	18	16	44	71	91
Biomass	106	151	172	188	195	154	181	291	384
Geothermal	6	7	9	13	17	22	54	132	176
Others	18	17	16	15	14	16	15	14	14
Total	1,684	1,678	1,654	1,578	1,444	1,320	1,052	980	911
Share of renewables	*9%*	*13%*	*16%*	*20%*	*24%*	*20%*	*37%*	*64%*	*88%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 8 Total primary energy imports to the EU-27, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Nuclear	242	246	270	220	171	110	41	6	0
Hard coal	138	120	121	120	108	70	0	0	0
Lignite	0	0	0	0	0	0	0	0	0
Oil and petroleum products	598	550	510	482	446	412	295	189	108
Natural gas	274	344	352	368	358	267	211	114	12
Biomass	3	5	7	9	10	6	7	52	145
Others	1	0	0	0	0	0	0	0	0
Total	1,257	1,266	1,260	1,198	1,092	864	554	361	264
Share of imports	*75%*	*75%*	*76%*	*76%*	*76%*	*65%*	*53%*	*37%*	*29%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 9 Greenhouse gas emissions by sectors, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO2e								
Power generation	1.39	1.14	1.07	0.99	0.82	0.96	0.57	0.30	0.07
Other energy sectors	0.22	0.22	0.20	0.19	0.16	0.16	0.10	0.01	-0.10
Industry	0.56	0.53	0.52	0.50	0.46	0.39	0.27	0.14	0.04
Households	0.45	0.46	0.41	0.37	0.33	0.33	0.15	0.05	0.01
Tertiary	0.25	0.23	0.21	0.19	0.14	0.21	0.14	0.08	0.03
Transport	1.10	1.07	0.97	0.89	0.81	0.77	0.53	0.29	0.07
CH4 & N2O from energy	0.05	0.05	0.05	0.04	0.04	0.04	0.02	0.01	0.00
Fugitive	0.08	0.06	0.04	0.03	0.02	0.06	0.04	0.03	0.02
Process (w/o I&S) & produc	0.24	0.21	0.20	0.20	0.20	0.21	0.16	0.09	0.04
Agriculture	0.47	0.44	0.43	0.43	0.43	0.39	0.34	0.31	0.28
Waste	0.14	0.08	0.05	0.04	0.03	0.08	0.05	0.03	0.03
F-Gases	0.08	0.08	0.07	0.07	0.07	0.08	0.06	0.04	0.02
Total	5.05	4.57	4.24	3.95	3.51	3.67	2.43	1.39	0.50
CO2 mitigation by CCS	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.16	0.30
Change of emissions									
Total from 1990	-10%	-19%	-25%	-30%	-38%	-35%	-57%	-75%	-91%
Total from 2005	-3%	-12%	-19%	-24%	-33%	-30%	-53%	-73%	-90%
ETS from 2005	-4%	-15%	-18%	-22%	-31%	-37%	-60%	-80%	-99%

Source: Öko-Institut.

Table A- 10 Greenhouse gas emissions by gases, 2008-2050

	History	Reference Scenario				Vision Scenario			
	2008	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO2e								
CO2 from energy	4.00	3.67	3.40	3.14	2.73	2.83	1.77	0.87	0.12
CO2 from non-energy	0.21	0.20	0.20	0.19	0.19	0.20	0.15	0.09	0.03
CH4	0.41	0.31	0.26	0.24	0.22	0.29	0.22	0.17	0.14
N2O	0.36	0.32	0.31	0.31	0.30	0.27	0.23	0.21	0.19
F-Gases	0.08	0.08	0.07	0.07	0.07	0.08	0.06	0.04	0.02
Total	5.05	4.57	4.24	3.95	3.51	3.67	2.43	1.39	0.50
Change of emissions									
Total from 1990	-10%	-19%	-25%	-30%	-38%	-35%	-57%	-75%	-91%
Total from 2005	-3%	-12%	-19%	-24%	-33%	-30%	-53%	-73%	-90%
ETS from 2005	*-4%*	*-15%*	*-18%*	*-22%*	*-31%*	*-37%*	*-60%*	*-80%*	*-99%*

Source: Öko-Institut.