The Vision Scenario for the European Union

2017 Update for the EU-28

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Executive Summary

The global framework and a CO_2 emission budget for the EU as starting points

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.

An analysis of the global CO_2 emissions budget and different approaches to derive a fair share for the EU leads to a CO_2 emissions budget of 61.5 billion metric tons from 2015 onwards that is consistent with the global effort to keep the increase of the global average temperature to below 2°C, compared to pre-industrial levels.

The Vision Scenario represents a pathway which consistently combines short- and medium-term objectives with long-term objectives. Furthermore it is in line with an EU greenhouse gas emission budget that is consistent with a 2°C limit on the increase in global temperature. It is the first comprehensive scenario analysis for the European Union that addresses both the (top-down) perspective of a 2°C-compatible CO_2 emission budget and how the related emission trajectories could be achieved from a bottom-up perspective.

Two scenarios that mark the policy-as-usual trend and a 2°C-compatible pathway

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 and climate policies as reflected in the European Commission's Baseline Scenario 2016, an emission reduction of 32% (compared to 1990 levels) by 2030 and 42% by 2050 is achieved. Renewable energies contribute 19% of the primary energy supply in 2030 and 24% in 2050. The share of power generation from renewable energies in total electricity generation is 43% in 2030, and 53% in 2050. The level of nuclear power production decreases slightly in the coming decades.
- The Vision Scenario is based on a greenhouse gas emission reduction target in accordance with the long-term 2°C goal. The total greenhouse gas emission reduction amounts to 54% in 2030 and 93% in 2050. Additional measures in land use, land-use change and forestry could enable a 95% emissions reduction. Renewable energies represent a share of 35% in the total primary energy supply in 2030 (up to 40% if ambient heat is also included) and 97% in 2050. The power sector undergoes a process of early decarbonisation; the share of renewable energies in total net power generation is 70% in 2030 and 100% in 2050. Nuclear power in the EU is phased out in this scenario by 2045. The use of biomass is restricted in order to comply with tight sustainability criteria; CCS

may only be used to avoid CO_2 emissions from industrial processes. The Vision Scenario does not, however, consider major lifestyle changes or structural economic changes which could accompany the transition towards a circular economy; it also does not take into account extensive efforts to create more net sinks for carbon.

Key strategies underlying the Vision Scenario

To achieve the transition to an almost 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 coming 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. A very ambitious level of energy efficiency is essential to achieving a full energy supply from renewable energy sources due to the existing restrictions for the deployment of renewable energies (availability of land for wind and solar power production, sustainable biomass etc.) and the foreseeable high costs of some secondary energies like hydrogen and/or synthetic fuels or gases.

Secondly, the transition to carbon-free energy sources is necessary in all sectors. In the end-use sectors (industry, commercial and residential sectors, transport) 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. In the Vision Scenario all coal-fired capacities in the EU are phased out by 2040.

Furthermore, the electrification of transport and possibly the use of electricity in the heat market are only a robust and 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 early decarbonisation of the power sector is a key enabling factor for all ambitious economy-wide greenhouse gas emission reduction strategies. The Vision Scenario outlines a transition pathway whereby renewables have a 70% share and natural gas nearly a 20% share in total power generation in 2030. In combination with a modernised electricity infrastructure, storage technologies, a broad use of demand response options and some hydrogen-fuelled backup capacities, this power generation mix can ensure the necessary flexibility for a huge 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.

A key prerequisite for the decarbonisation of the transport sectors are the early uptake of electric mobility in the coming decade and major efficiency improvements for all vehicle fleets. Novel fuels can play a role after 2030 for some segments of the transport sector (long distance freight transportation, aviation etc.). Most of these novel fuels will be imported to the European Union and foreseeably at significant costs; they will only be suitable for use in extremely energy-efficient vehicles. Even if it is not entirely clear whether these novel fuels will be electricity-based synthetic fuels or other new sources of motor fuels, the full range of environmental and social safeguards need to be implemented to ensure the sustainability of these energy supplies.

For the heat sector the transition of district heating systems towards green heat is a key opportunity because district heating systems can combine a broad range of renewable energy sources and achieve major benefits from such broader portfolios.

Thirdly, a wide range of other measures is necessary to achieve greenhouse gas emission reductions of 90% and above. 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). The major innovation efforts are needed with regard to high-emitting industries such as iron and steel, cement and the chemical industry which have significant non-energy CO_2 emissions, long-living capital stocks and significant inertia. Developing clear roadmaps and driving forward early demonstration plants for zero-emission technologies for these industries that are based to a significant extent on hydrogen technologies and/or CCS belongs to the enabling strategies needed on the way to a fully decarbonized economy.

The international dimension

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 lie well below recent levels in 2020 and 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, 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.

The changing patterns of imports, e.g. the phase-out of fossil and nuclear fuel imports, phase-in of imports for novel fuels etc. as well as the EU's role in supplying transformative technologies for decarbonisation to the global markets, will also require a new EU policy approach to its external relations on mainly two tracks. Firstly, the economic ties to traditional energy exporters will loosen in a comparatively short period of time. Clean technology innovation will open new markets abroad but may create the need for technology imports from new sources. These changing relations need to be actively managed. Secondly, major imports of, for example, novel fuels to the EU will necessitate new relations with the exporting countries (including early engagement with development aid etc. where poorer countries are concerned). The creation of a new governance scheme that ensures the sustainability and integrity of the imported novel fuels will be crucial. Furthermore, efforts to diversify these new supplies in order to avoid new dependencies from (new) monopolies or oligopolies should be clearly identified as a field of action to be taken.

Targets, strategies and a smart policy mix

Meeting a 2°C long-term target (i.e. keeping the increase of global mean temperature below 2°C and highly industrialised regions like the EU achieving a corresponding 95% greenhouse gas emission reduction) 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 for limiting the EU's tapping of the global greenhouse gas emission budget determined for staying within a 2°C limit. Only a reduction target of 55% or more by 2030 can be seen as in line with a global 2°C limit.

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 for putting a robust price on greenhouse gas emissions by consistently tightening the EU ETS cap to full and early decarbonisation, ensuring the integrity of the scheme, introducing a carbon floor price to bridge the carbon pricing gap for the next decade and introducing significant energy or CO_2 taxes in non-ETS-regulated sectors;
- ambitious policies to achieve huge increases in energy efficiency in its different dimensions (new and existing buildings, vehicles, electrical appliances, etc.);
- robust and accountable remuneration schemes for renewable energies that provide incentives for innovation and provide certainty; they should also reflect

the national and regional dimension of infrastructure upgrades and roll-outs with long lead times;

- ambitious approaches for upgrading, the roll-out and potentially the conversion of the necessary infrastructure for electricity, district heat and gas (at transmission, distribution and local levels and 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 in sectors where fewer alternatives exist; 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.).

The transformation of the European Union to a fully decarbonised economy will need clear targets, robust strategies but also significant flexibility in an ongoing learning-by-doing process. This process of policy learning requires holistic approaches, appropriate evaluation, revision and upgrading cycles (of, for example, 5 years).

Finally, 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 is policy-oriented modelling with relatively frequent cycles that is able to build analytical capital on the necessary scale and at the right times. 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 well below 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 (IPCC 2014a) indicate that for the period from 2015 onwards, the remaining global budget is approx. 890 billion metric tons in the case of CO_2 emissions, if there is to be a sufficient probability (66%) 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.

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 2011; EP 2011). 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 favourable 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. The storage capacity for CO_2 is, however, a finite resource that needs to be actively managed. CO_2 storage should consequently not be used for sectors in which sufficient emission abatement alternatives exist to the use of CCS (as is the case in the power sector). Carbon capture and use (CCU) tends to be more of a niche option due to the need to ensure that the embedded carbon in CCU products will not be released to the atmosphere at a later date.

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, the manifold problems related to the handling of nuclear materials (from mining to the processing of nuclear materials and the management of nuclear waste) and, last but not least, the increasing costs of nuclear options compared to renewable energies etc.

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 & ICE 2006) and 2011 (Öko-Institut 2011). 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 28 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. 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 2050 compared to 1990 levels and a level of cumulative CO_2 emissions should not be exceeded that is compatible with the overarching goals of the Paris Agreement, i.e. “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels” (UNFCCC 2015, art. 2, no. 1 (a)).
  - 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-28 and biomass imports at a level which is acceptable from an equal access rights perspective. 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-28 (domestic production plus imports) should not exceed the level of about 15 GJ per capita. For the domestic bio-energy potential the underlying assumption for the modelling is approx. 7,000 PJ for the EU-28 (Kluts et al. 2017).

The starting point for the development of the Reference Scenario is the results from the EU Reference Scenario 2016 (EC 2016) which were slightly modified to the most recent information. 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 own modelling and the review of a broad range of other studies on EU projections (EC 2011b; EC 2011c; EC 2011a; Jacobson et al. 2017; Greenpeace 2014; Öko-Institut & Fraunhofer ISI 2015):

- The analysis for the 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 of various deep decarbonisation projections for the EU or single Member States, which were adjusted to the EU-28 on the basis of existing literature and supplementary expert estimations.
- The analysis for the power sector is chiefly based on an hourly modelling exercise for the EU-28.

The different sector projections were integrated and made consistent with an integration model which was originally developed for the Vision Scenario project (Öko-Institut & ICE 2006; Öko-Institut 2011) and was significantly extended for the analysis presented in this report.

All historic time series (for the years from 1990 to 2015) 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 28 Member States (EU-28). The greenhouse gases regulated by the Kyoto Protocol (carbon dioxide – CO_2, methane – CH_4, nitrous oxide – N_2O, hydrofluorocarbons – HFCs, perfluorocarbons – PFCs, and sulphur 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.

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. The only difference is the accounting approach for the use of ambient heat in heat pump application. This contribution is not accounted for in the model used for developing the Vision Scenario; as a result, the share of renewables in the energy mix will be slightly underestimated.

3 Recent trends in energy supply and greenhouse gas emissions in the EU-28

The development of the total primary energy supply (TPES) of the EU-28 in the period between 1990 and 2015 is characterised by two main trends (Figure 3-1).

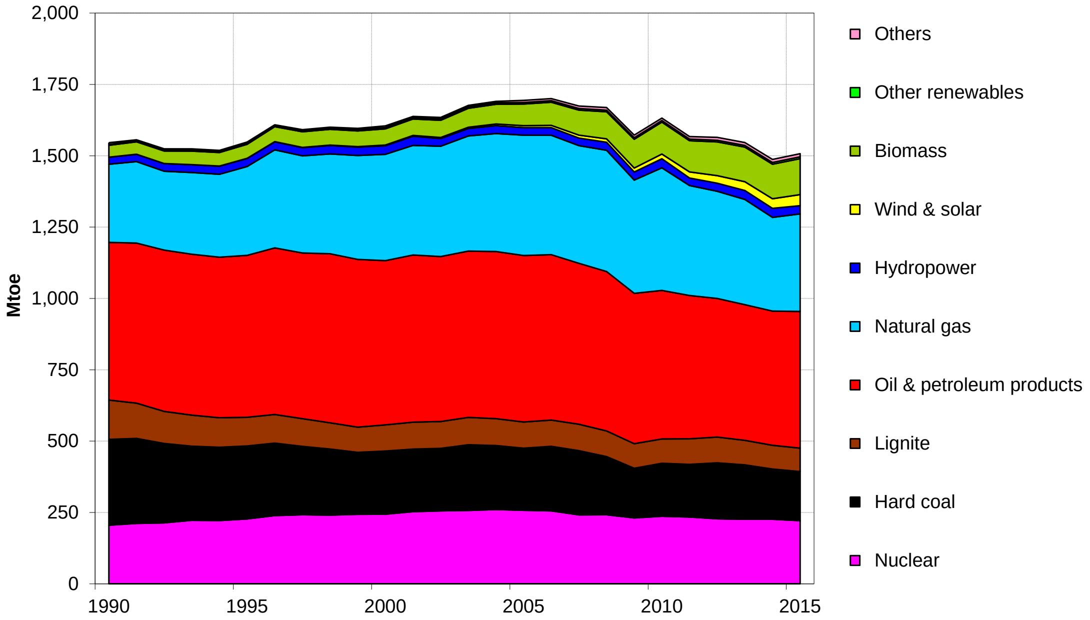
Firstly, the years directly after 1990 show that the economic crisis had a significant impact on the new Member States and the eastern part of Germany, which led to a slight decrease in primary energy consumption for the EU-28. However, apart from this special trend in the eastern economies in transition, the TPES rose steadily. The TPES peaked in 2006 and then subsequently decreased slightly in recent years. In 2015 the TPES amounted to 39 million tons of oil equivalent (Mtoe) below the 1990 level, which is equivalent to a decrease of about 9%. This trend is, however, slightly distorted by the methodological approach for accounting power generation from hydro, wind and solar.[1] If the total primary energy supply in the EU is adjusted for this, the level would be approx. 60 Mtoe (4%) in 2015 above the levels of 1990.

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 19.5% and the share of lignite amounted to 9%. By 2015, these shares decreased to 11% and 5%, respectively. The consumption of coal has however, remained almost unchanged after 2010, essentially due to the low CO_2 prices that were created by the European Union Emissions Trading System (EU ETS).

The contribution of natural gas to the TPES increased from 18% to 35%. The highest growth rates occur in renewable energies, which supplied 188% more primary energy in 2015 than in 1990. However, because of the low base level, the share of the TPES only increased from 4.5% in 1990 to 13% in 2015. Only small changes can be observed for the contribution of oil and nuclear energy. The share of oil in the TPES decreased slightly from 36% in 1990 to 32% in 2015 and the contribution of nuclear energy increased from 13 to 15%. In absolute terms the level of oil consumption was 13% below the 1990 level in 2015 and the supply of nuclear energy increased by about 8% from 1990 to 2015 in the EU-28. However, the level of oil and nuclear consumption has significantly declined since peaking for both in 2004.

[1] According the current methodological approach, power generation from wind, solar and hydro energy is accounted in primary energy terms with a transformation efficiency of 100%. If electricity from solar, wind or hydro substitutes conventional power this will lead to a reduction of up to two thirds in primary energy terms although the same amount of electricity has been produced and used.

Figure 3-1: Total primary energy supply by fuel in the EU-28, 1990-2015



Source: Eurostat, Öko-Institut

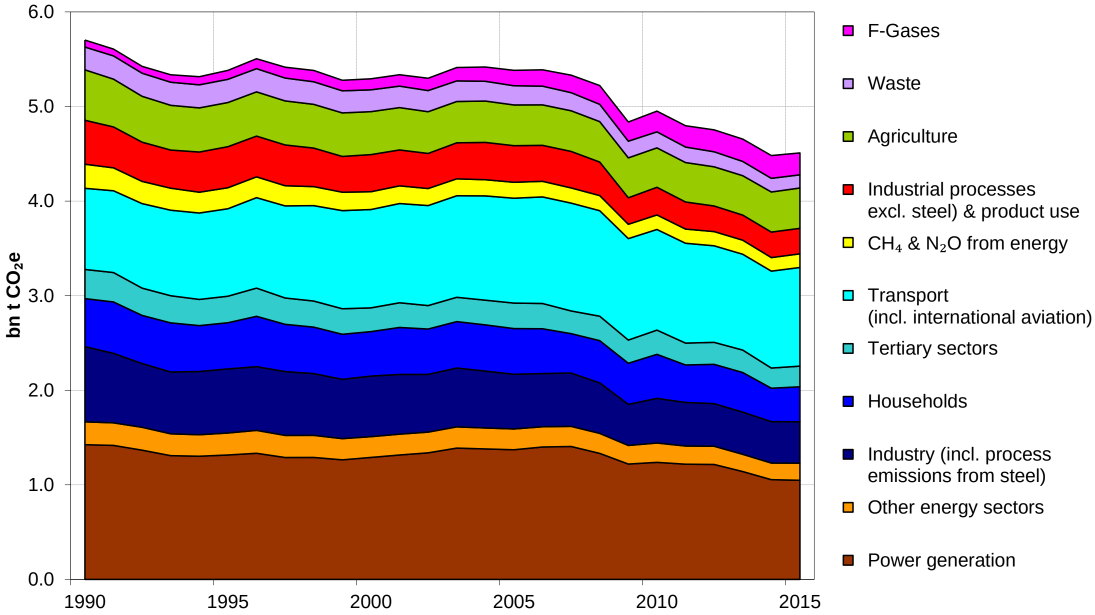
Last but not least, the share of fuel imports increased significantly. The import dependency of the EU-28's energy system grew significantly. The total share of imported fuels in the TPES for energy rose from 56% in 1990 to 67% by the year 2015.[2]

In total, the slight decrease in TPES was complemented by the trend towards fuels with lower carbon emissions, which results in a 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 and after 2008. From 1990 to 1994 the CO_2 emissions decreased by 6% and remained almost stable at this level of 6% up to 2008. Thereafter the CO_2 emissions decreased by an additional 15 percentage points and reached a level of 20% below 1990 in 2015.[3]

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. In addition to this, the primary energy use for non-energy uses is not included in the analysis of this study.

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

Figure 3-2: Greenhouse gas emissions in the EU-28, 1990-2015



Source: UNFCCC, Eurostat, Öko-Institut

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. From 2008 onwards the emissions decreased again and reached a level of 26% below 1990 in 2015.
- Energy-related CO_2 emissions from industry declined steadily in the period from 1990 to 2008, decreased sharply in 2009, grew slightly in 2010 and decreased thereafter, reaching to 45% below the 1990 levels by 2015.
- A general declining trend also can be observed for the CO_2 emissions from households and the tertiary sectors. In 2015 the respective levels were 27% (households) and 29% (tertiary sectors) below the 1990 level.

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.

- The only sector with a significant increase of energy-related CO_2 emissions is the transport sector. From 1990 to 2007 the total emissions increased by about 33%. During recent years the growth trend stopped and the CO_2 emissions returned to 22% above the 1990 level in 2015.

The total decrease of GHG emissions in the period from 1990 to 2015 amounts to 21%. This is because non-energy and non-CO_2 emissions decreased 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 42% from 1990 to 2015.
- 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 42% below 1990 in 2015.

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 2015 these emissions were about 214% 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 The carbon budget: a novel approach for assessing emission trajectories

4.1 Global carbon budget

National and sectoral climate protection strategies and policies are - especially since the Paris Agreement was adopted and came into force - judged by whether they are compatible with the overarching goals laid down in the agreement, i.e. above all with the limit on the increase in global average temperature to (well) below 2°C compared to pre-industrial levels. In the diverse analyses conducted within the scope of climate modelling, emission budgets have proved to be a pragmatic approach that can be used to establish a link between global warming and the development paths for greenhouse gas emissions and provide a guiding basis for action. These analyses focus above all on the cumulative emissions of the most important greenhouse gas carbon dioxide (CO_2) over specific periods of time; this constitutes a robust indicator for different emission developments.[4]

Table 4-1: Global CO_2 emissions and global carbon budget

	CO_2 emissions 1870 to 2010	Global CO_2 budget		
		from 2011	2011 to 2014	Remaining budget
	Gt CO_2			
1.5°C for 66% of model runs	1,914	400	160	240
1.5°C for 50% of model runs	1,914	550	160	390
1.5°C for 33% of model runs	1,914	850	160	690
2°C at 66% probability	1,914	1,049	160	890
2°C at 50% probability	1,914	1,159	160	1,000
2°C at 33% probability	1,914	1,449	160	1,290
3°C for 66% of model runs	1,914	2,400	160	2,240
3°C for 50% of model runs	1,914	2,800	160	2,640
3°C for 33% of model runs	1,914	3,250	160	3,090

Source: Intergovernmental Panel on Climate Change (IPCC), PRIMAP, calculations by Öko-Institut

Table 4-1 provides a summary of some basic data relevant to the analyses on determination of the emission budgets[5]:

[4] In order to ensure consistency with the work of the IPCC on which the following is based, the present study considers only CO_2 emissions and not the other greenhouse gas emissions. Given the clearly dominant role of CO_2 emissions in the context of the total (energy-related) emissions of Germany, this is a helpful and robust approach.

[5] In IPCC terminology, “likely” means a probability of 66% to 100%; “about as likely as not” means a probability of 33% to 66%; and “unlikely” means a probability of 0% to 33%.

- In the 5th IPCC Assessment report, a large number of models were evaluated. These enable the probabilities of carbon budgets staying below the 2°C increase limit on the global mean temperature compared to pre-industrial levels to be calculated for the time frame from 2011 to 2050 (IPCC 2013, p. 27).
- A probability assessment of this kind cannot be conducted for other temperature limits. However, the information presented in the 5th IPCC report on the number of model runs in which the temperature levels remain below the limits, enables at least an approximate classification of the different emission budgets (IPCC 2014b, p. 64).
- The long series for the development of CO_2 emissions (including those from land use and land use change) were taken from the database of the PRIMAP project and evaluated (Gütschow et al. 2017). Global emissions of 2,074 billion tonnes of CO_2 were determined for 1870 to 2014, of which over a quarter (25.9%) stems from 2000 to 2014 and almost 40% (39.6%) from 1990 to 2014. This demonstrates the great impact that the emissions development of the last 25 years has had on cumulative greenhouse gas emissions and the central importance of avoiding further delays in implementing emission reductions in order to enable an effective climate protection. Although the CO_2 emissions from land use and land use change have only a 6.3% share in the cumulative CO_2 emissions from 1870 to 2014, they currently account for about 13.3% of annual CO_2 emissions. The most substantial share of CO_2 emissions is attributable to energy-related emissions.
- It can only be expected with a probability of 66% that the increase in global temperature stays below 2°C if the CO_2 emissions arising from 2015 onwards do not exceed a total of 890 billion t CO_2. For lower probabilities of 50% and 33% respectively, the carbon budgets are correspondingly higher, at 1,000 and 1,290 billion t CO_2. For temperature increase limits of 1.5°C and 3°C, approximate reference levels are derived from the available model analyses and shown in Table 4-1. Limiting the global temperature increase to below 1.5°C with a relatively high probability leads to a global carbon budget of approx. 240 billion t CO_2 from 2015 onwards; the carbon budget for the 3°C limit amounts to 2,240 billion t CO_2.
- A comparison with the current annual emissions of approx. 40.6 billion t CO_2 worldwide shows that huge emission reductions will be necessary within a relatively short time frame to keep the increase in global temperature below the 2°C and 1.5°C limits.
- If the global temperature increase is kept below 2°C there is a relatively high probability (66%) that the current emission levels could be maintained for 22 years. If a linear emissions trend is assumed, global CO_2 emissions would have to be reduced to net zero within 44 years. Otherwise, in the subsequent years, substantial quantities of CO_2 would have to be removed from the atmosphere with technologies that have currently been scarcely tested (carbon

capture from biomass production or direct air capture, combined with safe carbon storage, e.g. in geological formations).

- Adherence to the limit in global temperature of 1.5°C could be achieved with a relatively high probability, based on the available data, only if emissions continue unchanged from today's levels for 6 years. If a linear reduction of global emissions is assumed, global decarbonisation would be necessary within 12 years or huge volumes of CO_2 would need to be removed from the atmosphere in the subsequent years.

The following analyses are based on the working hypothesis that cumulative global CO_2 emissions should not exceed 890 billion t CO_2 from 2015 onwards.[6] On this basis, the increase in global temperature could, with a high probability (in IPCC terms: likely), remain safely below 2°C compared to preindustrial levels.

4.2 A climate-fair carbon budget for the EU-28

Based on a global carbon budget of 890 million t CO_2 from 2015 onwards, a corresponding emissions budget can be derived for the EU. Transparent derivation of national emission budgets based on clear criteria is a useful and reasonable approach to determining the EU's fair share of use of the global resource, the atmosphere. Such an approach can be used to prevent emission reduction measures in legislation areas that have only relatively small shares of global emissions at national or regional level, meaning that they can make only correspondingly small contributions to global emission reductions. These evaluation metrics are not only in the interests of a legally binding concept, but also in terms of ensuring the consistency of national and regional activities.

The key question in the derivation of national carbon budgets is what the principles and criteria are for breaking down the global emission budget to reference areas such as a country or region. Among the many conceivable and discussed perspectives, four approaches are especially significant:

1. The global carbon budget can be divided according to current emission levels (also as an approximation for prosperity levels, etc.). This approach ultimately represents the principle of the protection of vested rights.
2. An alternative option is to divide the global budget on an equality basis, i.e. based on population numbers, although different emphases can be achieved depending on whether current population numbers are used or projections of

[6] This is in line with another recently conducted analysis: IEA & IRENA (2017, pp. 46–48) base their analysis on a global carbon budget of 880 billion t CO_2 (from energy only) from 2015, the Emissions Gap Report by UNEP (2017, pp. 16–18) is based on a budget of 1,000 billion t CO_2 from 2011 onwards.

future populations should be considered. In essence, such an approach follows the principle of equality of opportunity.

3. A third option is to allocate the global budget based on the performance-related principle. Countries or regions with a higher performance capacity (also in terms of emission reductions) or higher prosperity would be allocated a smaller share of the global budget under this approach, if other countries of the world are to be given the chance to catch up in these respects. This option particularly brings to bear the challenges of, for example, how to handle the very different methods for measuring economic performance and prosperity (gross domestic product as, in some cases, a controversial indicator, adjusting values based on exchange rates or purchasing power parities, etc.), future growth dynamics and also the corresponding uncertainties.

Another issue of great importance is how to consider past utilization of the atmosphere. There needs to be a discussion about whether historical emissions should be taken into account in determining national emission budgets and, if so, what time scale is appropriate. Here, too, different approaches are conceivable:

- An extreme approach would be to consider all historical emissions, e.g. since the beginning of industrialisation. In the case of the EU, historical emissions totalling 345 billion tonnes CO_2 from 1870 to 2014 would have to be taken into account as prior utilisation of the total emission budget. To keep within the 2°C limit with a probability of 66%, the global emission budget, taking into account historical emissions, amounts to a total of 2,963 billion t CO_2 (890 plus 2,074 billion t CO_2) up to 2050: on this basis the EU would already have used 12% of the global emission budget available up to the middle of this century.
- An alternative approach would be to take into account historical emissions from the point in time when the dangers of man-made (anthropogenic) climate change were widely addressed as a challenge, regardless of whether measures were immediately adopted or not. The year 1990 could be chosen as a useful reference point. For the EU, historical emissions of approx. 103 billion t CO_2 would have to be considered, corresponding to 6% of the total global emission budget available for 1990 to 2050 (890 plus 821 billion t CO_2 for the emissions in the period from 1990 to 2014).
- Another option would be to consider emissions from the time at which the international community as a whole committed to binding climate protection targets. The point of reference here would be, for example, the adoption of the Paris Agreement in 2015. In effect, only the future release of CO_2 into the atmosphere (i.e. that which can still be influenced) would count towards the emissions budget remaining for 2015 to 2050.

As these options show, there are a large range of approaches to determining national or regional emission budgets. It should be pointed out, however, that not all combinations of reference period and distribution key are useful.[7]

Table 4-2 shows the results of using different distribution keys on carbon budgets for different temperature limits and the corresponding probability of keeping within these limits, without considering historical emissions. In terms of the global emission budget, the EU's "rights of use" calculated on this basis range between 5.4% and 9%.

Table 4-2: Global CO_2 emissions and the EU-28 carbon budget (without considering historical emissions)

	CO_2 budget global from 2015	CO_2 budget EU-28		
		Emissions share 2015	Share in population	
			2015	2050
	Gt CO_2			
1.5°C for 66% of model runs	240	21.7	16.6	12.9
1.5°C for 50% of model runs	390	35.2	27.0	20.9
1.5°C for 33% of model runs	690	62.2	47.7	37.1
2°C at 66% probability	890	80.2	61.5	47.7
2°C at 50% probability	1,000	90.1	69.1	53.6
2°C at 33% probability	1,290	116.2	89.2	69.2
3°C for 66% of model runs	2,240	202.0	154.9	120.2
3°C for 50% of model runs	2,640	238.0	182.6	141.7
3°C for 33% of model runs	3,090	278.6	213.7	165.9
Reference levels for calculation of EU-28 share		CO_2 emissions	Population	
		2015	2015	2050
		Gt CO_2	Million	
World		40.644	7,347	9,725
EU-28		3.664	508	522
EU-28's share		9.0%	6.9%	5.4%

Source: Intergovernmental Panel on Climate Change (IPCC), PRIMAP, World Bank, UN WPP, Eurostat, calculations by Öko-Institut

Additional model calculations that consider historical emissions and the 2°C limit on the global temperature increase show that the EU's available emission budget would already have been exhausted if historical emissions covering very long periods (e.g. 1870 to 2014) are considered. If historical emissions over shorter periods (e.g. from 1990 to 2014) are taken into account and the increase in global temperature is assumed to be safely below 2°C, only distribution approaches that are considerably above the EU's population share in the global population would mean that it would be

[7] For example, it is not very consistent with combining emission budgets for future emissions with distribution keys based on the preservation of vested interests. It would be essential to consider historical emissions, at least in part, in order to achieve an acceptable distribution of the global emission budget.

possible to count future emissions against the carbon budget, i.e. the carbon budget would not have been completely or very extensively tapped by historical emissions.

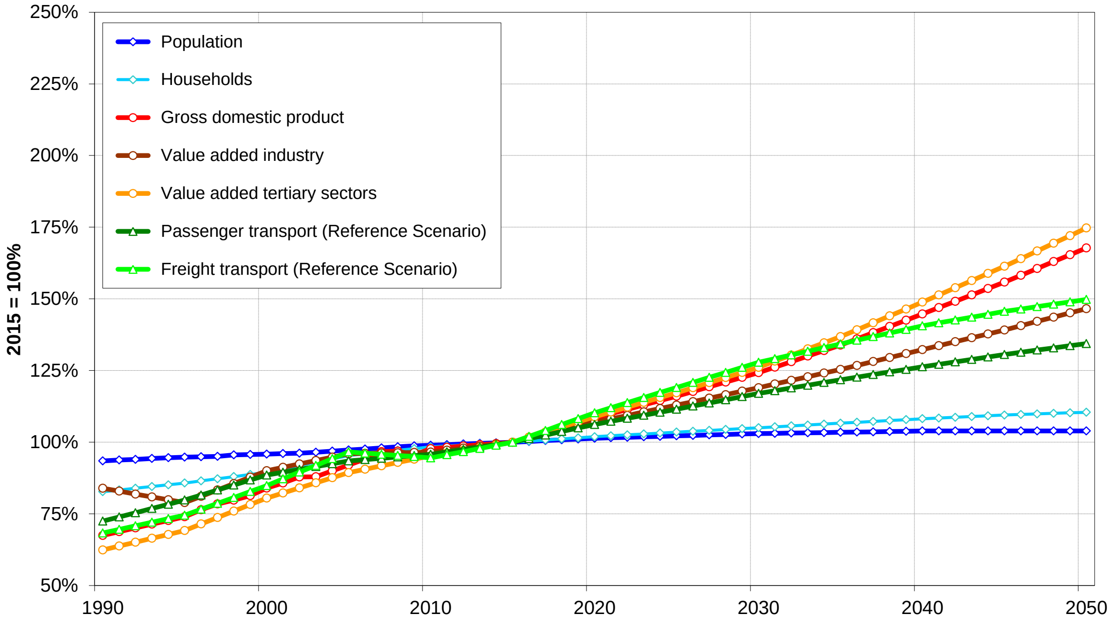
In the overarching ranking of all aspects, for a fair contribution to global climate protection that the EU-28 should make by reducing its future CO_2 emissions, it would not be meaningful to consider historical emissions but the remaining global emission budget should be divided on a global per capita basis, i.e. based on the equity principle. The EU's current population (as of 2015) serves as a robust reference value for this per capita distribution. The EU's contribution to achieving global climate protection goals above this distribution would have to be met via financial transfers, i.e. by financially enabling additional emission reductions in regions in which the quantity of historical emissions is lower or the development of CO_2-intensive capital stocks is less highly advanced or can still be effectively avoided.

Based on a global emissions budget of 890 billion t CO_2 from the year 2015 onwards and the EU's population share in the world population in 2015 (6.9%), the maximum emission budget for the EU is calculated as approx. 61.5 billion t CO_2 up to 2050. It should also be noted that the determination of this budget is also relatively balanced in view of the fact that the calculation approaches are advantageous for the EU (no consideration of historical emissions, using the current population level as a reference) on the one hand and acceptable from a global equity perspective (per capita distribution) on the other hand.

5 Main economic and demographic drivers

Figure 5-1 indicates some of the key drivers for the economic and demographic development considered for the scenarios. These assumptions were taken from the recent EU Reference Scenario (EC 2016).

Figure 5-1: 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 2015 to 2030 the population in the EU-27 grows by about 3%. This slight population growth slows down thereafter; in 2040 and 2050 the populations is 3.9% higher than in 2015. The EU-28 population amounts to approx. 524 million inhabitants in 2030, approx. 528 million in 2040, and approx. 529 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 2015 to 2030 the number of households increases by about 5%; and by another 5 percentage points up to 2050.

- The growth of GDP in the period from 2015 to 2030 is significant; the level of GDP, in constant terms, will be 24% higher compared to the 2015 levels. In 2050 the total level of GDP will exceed the 2015 levels by 68%. The economic growth for the next three and a half 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-28 will result from growth in the tertiary sectors. The assumption on the growth of value added in the tertiary sectors is 26% from 2015 to 2030 and further 49 percentage points from 2030 to 2050.
- A significant growth is projected in transport activities. In 2030 the level of passenger transport activities in the Reference Scenario is projected to exceed the levels from the year 2015 by 17%; from 2030 to 2050 the passenger transport activities are projected to increase by additional 17 percentage points. Freight transport activities increase from 2015 to 2030 by 28% and another 22% for the period from 2030 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.

6 Reference Scenario and Vision Scenario

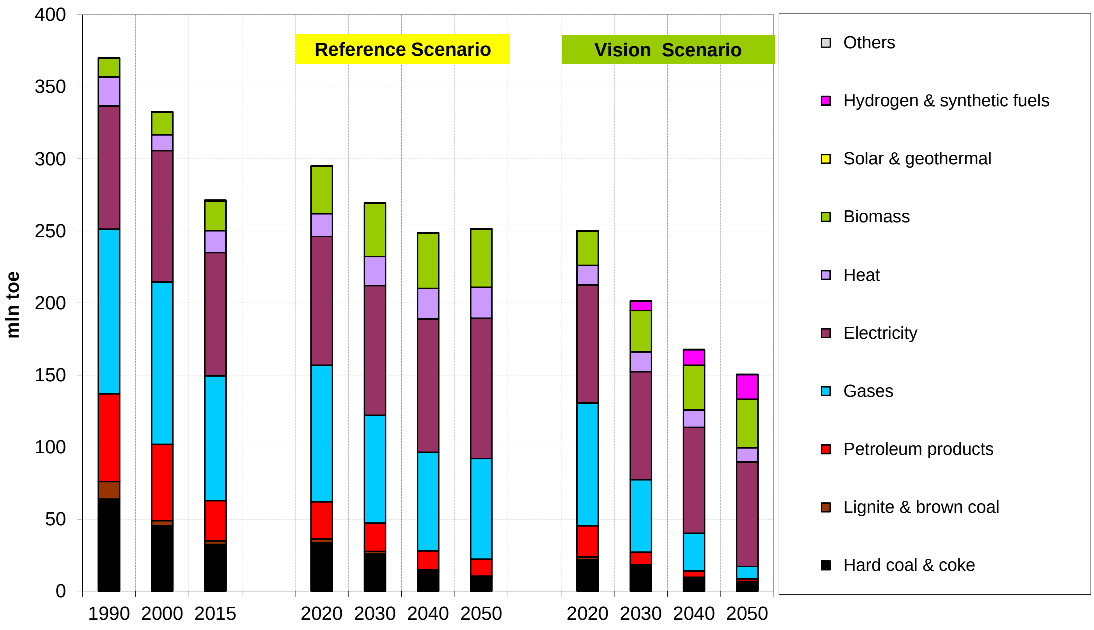
6.1 End-use sectors

6.1.1 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 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. In 2015 not only the share of final energy consumption in the transport sectors (33%) but also of households (25.5%) exceeded industrial energy consumption (25%) This is mainly because the energy consumption in industry decreased from 370 Mtoe in 1990 to 272 Mtoe in 2015 and the energy consumption in all other sectors rose significantly.

Figure 6-1: Final energy consumption by fuel in EU-28 industry, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

However, industry is still the largest consumer of electricity among the final energy sectors. More than 36% of the total electricity consumed in the final energy sectors came from industrial consumers in 2015. Industry also makes up the largest share of fuel consumption in terms of final energy for solid fuels. For natural gas the consumption of households has exceeded industrial consumption since 1996.

In the Reference Scenario, the final energy demand is projected to rise slightly by 2020 and to decrease thereafter (Figure 6-1). The total final energy consumption increases by 4% by the year 2025 compared to 2015 levels. In the period from 2025 to 2050 the final energy consumption returns to the 2015 consumption levels by 2030 and reaches a level of 7% below 2015 by 2050. The consumption of solid fuels and petroleum products is projected to stagnate by 2020 and decrease significantly afterwards; the consumption of natural gas is projected to increase from 2015 to 2020 by 9% and then to decrease to 2015 levels by 2025. In 2030 the industrial consumption of natural gas is projected to be 14% and in 2050 approx. 19% below 2015 levels. It is expected that the electricity consumption will rise steadily by 5% in the period from 2015 to 2030 and by another 9 percentage points from 2030 to 2050. The share of renewable energies (mainly wood and wood waste) in the total industrial energy consumption grows from 8% in 2015 to 14% in 2030 and 16% in 2050. In absolute terms the use of renewables in industry increases by 76% from 2015 to 2030 and by another 16 percentage points by 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 the industrial sectors is seen to lie between 17% by 2030 and 37% by 2050 in the Reference Scenario, additional measures for improving the energy efficiency could provide additional efficiency gains of 21 (2030) to 25 percentage points (2050).
- The use of renewable energies (mostly biomass) will increase, reaching a level of 14% by 2030 and 23% by 2050.
- Hydrogen as an electricity-based fuel will start to play a role after 2030 and reaches a share in total industrial energy consumption of 6% by 2040 and 11% by 2050.
- Taking into account the contributions of renewable energies to the power, district heating and hydrogen production the (direct and indirect) use of renewable energies reaches a level of 47% in 2030 and 88% 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 93% 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:

- Broad optimisation of production processes in terms of energy and resource efficiency, e.g. based on mass data processing;
- Increasing electrification of industrial processes;
- Broad modularisation of high electricity-consuming processes to increase the flexibility of power consumption.
- 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;
- Switch to hydrogen-based processes.

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 phased out by 2050 in the Vision Scenario. In 2030 the consumption of oil is 70% less in the Vision Scenario compared to the Reference Scenario.

3. Compared to the levels of the Reference Scenario, the consumption of gas is 33% lower in the Vision Scenario in 2030 and about 87% lower in 2050.
4. The demand for electricity in the Vision Scenario is 17% less in 2030 and 25% less in 2050 than in the Reference Scenario although the share of electricity in total industrial energy consumptions is 4 percentage points higher in 2030 and 10 percentage points higher in 2050 in the Reference Scenario.
5. The use of biomass in the Vision Scenario is projected to fall below the Reference Scenario levels. In 2030 the biomass use in industry for energy is 23% lower in 2030 and 17% lower in 2050 than in the Reference Scenarios. The decreasing level of biomass use is, however, complemented by the increasing use of hydrogen in industry for the period after 2030.

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 2030 in the Vision Scenario compared to the Reference Scenario and decreases in absolute terms by 24% from 2015 to 2030 and by another 21 percentage points by 2050.

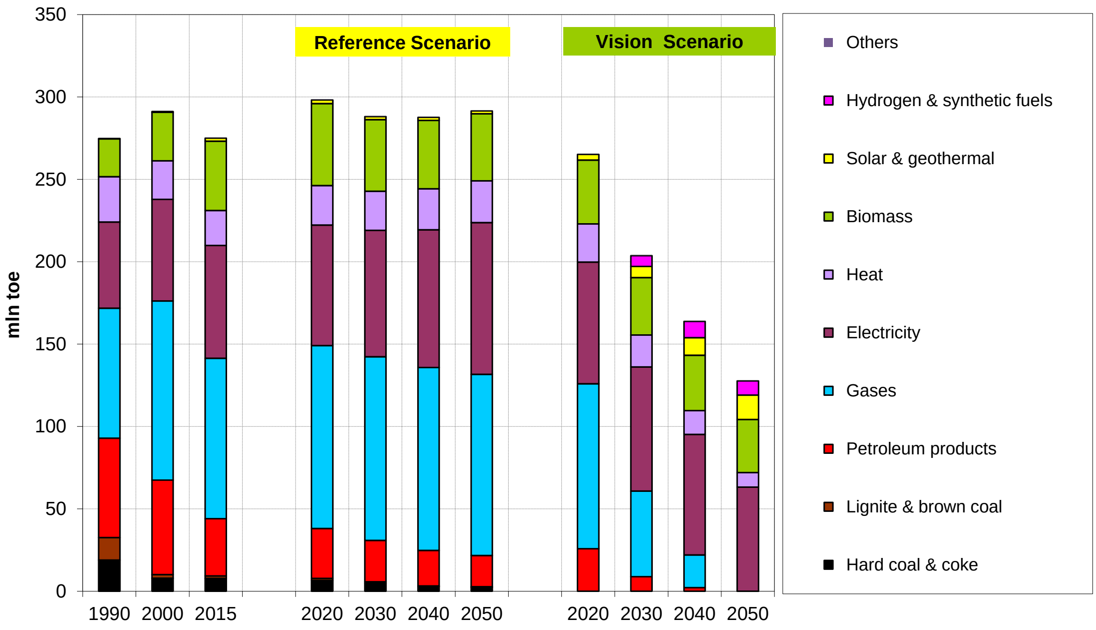
The effects of the significantly increasing role of electric and hydrogen technologies (which shift transformation losses from the final energy sectors to the power sector) should, however, be taken into account when classifying this progress in end-use energy efficiency. If the share of renewables in electricity, district heating and hydrogen production is considered, the share of non-fossil energy sources (renewable energies, electricity and heat) expands from 30% in the Reference Scenario in 2030 to 47% in the Vision Scenario and from 38% to 88% in 2050.

6.1.2 Households

In contradistinction to the projected trend in industry, the final energy consumption rises substantially in the Reference Scenario for the period from 2015 to 2020 due to the increasing size of living space, increasing penetration of new appliances etc. which cannot be offset by the recent level of energy efficiency improvements. However, for the period after 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 298 Mtoe which is 8% above the 2015 levels. The total final energy consumption then falls slightly; it is 5% above the 2015 levels in 2030 and then stagnates by 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 12% above 2015 levels in 2030 and 25% above 2015 levels by 2050. The consumption of natural gas is projected to rise in the period from 2015 to 2020, by 14%. However, after the peak of gas consumption in households in 2020 the gas demand remains almost constant by 2050 and represents the biggest share of final energy consumption of households throughout the period from 2015 to 2050 (35% in 2015, 39% in 2030, and 38% in 2050). 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 72% of the 2015 levels; in 2050 the oil consumption reaches 55% of the 2015 levels. Solid fuels will only play a minor role in 2020, 2030 and 2050. The share of directly used renewable energies in the residential sector is comparatively stable at a level of 15 to 17% (Figure 6-2).

The consumption pattern of the residential sector in the EU-28 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 households. It is worth mentioning that about half of electricity consumption in the EU-28 is used for different heating purposes and cooling at present.

Figure 6-2: Final energy consumption by fuel in EU-28 households, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

The following 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 directly used renewable energies in the residential heat market (mainly biomass and solar heating) is 22% and is increased to approx. 37% in 2050.
- Electrical systems, including highly efficient heat pumps play an increased role for heating purposes in highly efficient buildings after 2025;
- For the period after 2030 hydrogen gains a market share, essentially in combination with biogas.

As a result, the total final energy consumption in the Vision Scenario decreases by 2020 to a level that is 4% lower than the consumption in 2015. In 2030 the remaining energy consumption of households is only 74% of the 2015 levels, or 29% below the level in the Reference Scenario. From 2030 to 2050 the final energy consumption falls to 46% of the 2015 levels, this 44% lower than in in the Reference 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 after 2030, is limited to 10% above the 2015 levels or 2% below the consumption projected for the Reference Scenario in 2030. The electricity consumption then decreases to 8% below the 2015 levels by 2050 which is one third lower than in the Reference Scenario.

The use of solar energy for hot water and heating increases by a factor of almost 4 from 2015 to 2030 and about 8 by 2050. It reaches a share of 3% of total residential final energy consumption in 2030 and 11% in 2050. However, the use of biomass forms the largest share of renewable energies in the residential sector with a share of 18% of the total final energy consumption in 2030 and 26% in 2050. The total direct contribution of renewable energies amounts to 20% of the total final energy consumption in the year 2030 and 37% in 2050. For the period after 2030 hydrogen, complementing the biogas supply, gains a share in total final consumption that amounts to 7% in 2050 but represents a comparatively low contribution in absolute terms. District heating systems will play a significant role in the integration of heat supply from solar, heat pumps, waste heat, waste biomass, etc.

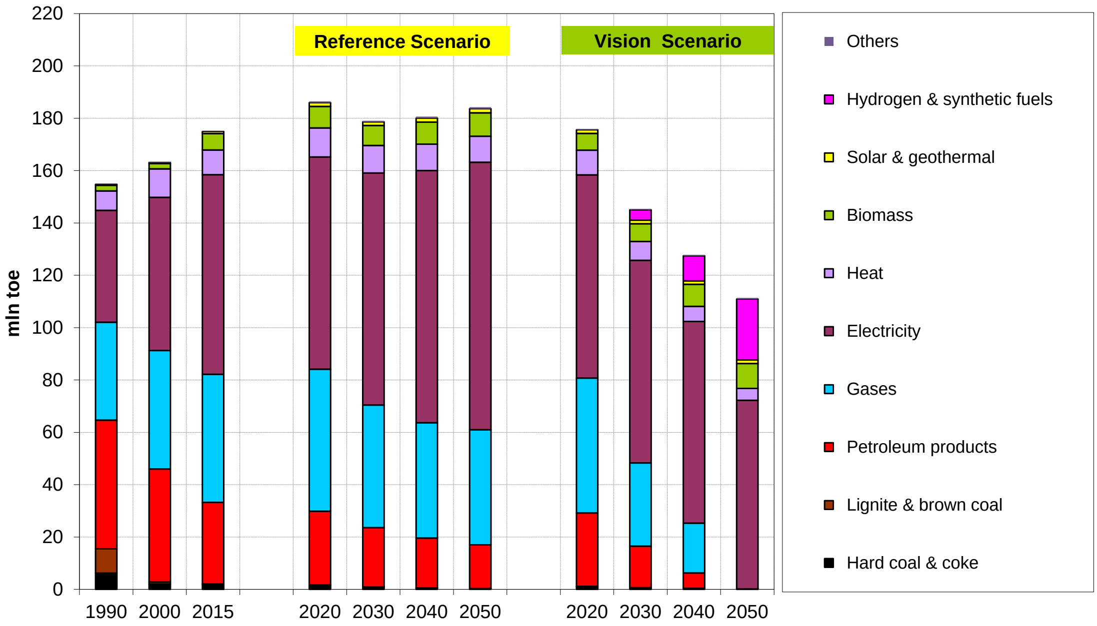
Taking into account the contributions of renewable energies to the power, district heating and hydrogen production, the (direct and indirect) use of renewable energies in the Vision Scenario reaches a level of 55% in 2030 and 100% in 2050.

6.1.3 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 increases only slightly from 2015 to 2030 by 2% and by an additional 3 percentage points by 2050 (Figure 6-3). The total final energy consumption in 2050 is 5% above the 2015 levels. The only energy source with a steady growth trend in the next three and a half decades in the Reference Scenario is electricity, the demand for which is projected to grow by 16% from 2015 to 2030 and for another 18 percentage points from 2030 to 2050. For all other conventional fuels the future consumption will be below the recent levels from 2030 onwards. However, the demand for natural gas will only slightly decrease 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 2030 and 2050.

Figure 6-3: Final energy consumption by fuel in EU-28 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 19% in the Vision Scenario by 2030 and 40% by 2050, compared to the Reference Scenario. In 2030 the final energy demand is 17% below the 2015 levels; in 2050 the final energy consumption decreases by an additional 19 percentage points. Due to the significant potentials of electricity savings in the tertiary sectors, the electricity consumption can be stabilised in the Vision Scenario for the next three decades and falls 5% below the 2015 levels by 2050. Fossil fuels will be gradually phased out by 2050. For the period after 2030 hydrogen, mainly in combination with biogas, starts to play a role in the energy mix for the tertiary sectors. In 2050 the share of hydrogen in the total final energy consumption (21%) could be the second largest after electricity (65%).

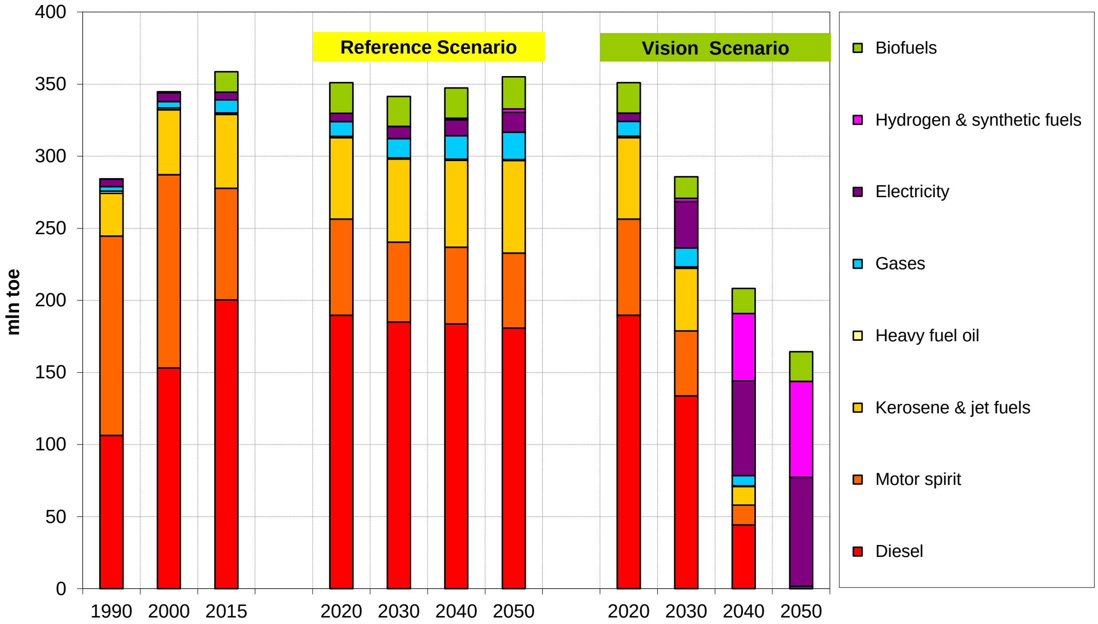
The share of directly used renewable energies (mainly solar and ambient heat as well as some biomass) increases to 6% in 2030 and to 10% in 2050. Taking into account the contributions of renewable energies to the power, district heating and hydrogen production, the (direct and indirect) use of renewable energies in the Vision Scenario reaches a level of 48% in 2030 and 99% in 2050.

6.1.4 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 slowly decrease as a result of enhanced efficiency until 2030. In 2030 the energy use of the transport sector is around 5% lower than in 2015. This reduction is mainly driven by an increased energy efficiency of the passenger car stock due to the EU regulation on CO_2 emissions of new cars and vans. Thus, the energy efficiency of the passenger car stock compensates for the rising transport demand (+13% for motorised individual transport between 2005 and 2030). After 2030, the efficiency increase of passenger cars in the Reference scenario is slower than in the 2015-2030 timeframe and energy demand increases again slightly, until it reaches nearly 2015 levels again in 2050. A strong increase is assumed in the use of kerosene and jet fuels, which is estimated at 12% in 2030 and 25% in 2050 above the 2015 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. 6.2% in 2030 and 6.6% in 2050 for the Reference Scenario (Figure 6-4).

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 transport and the switch to renewable energy sources.

Figure 6-4: Final energy consumption by fuel in EU-28 transport sectors, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

The overall energy use in the Vision Scenario is reduced by 16% in 2030 compared to the Reference Scenario. The contribution of electricity to the total final energy consumption in the transport sector increases from 1.5% in 2015 to 11% in 2030 and 46% in 2050. In absolute terms the electricity demand in the transport sector increases by a factor of 14 from 2015 to 2050. The total increase of about 825 TWh for electric powertrains in the transport sector until 2050 corresponds to a share of 27% in the total electricity consumption by end-use sectors in 2050.

In the Vision Scenario the share of renewable energies in the total final energy demand of the transport sector rises significantly to 14% in 2030 and 100% in 2050 (taking into account the contributions of renewable energies to power production).

The Vision Scenario represents a major transformation of the whole transport sector. Main strategies for decarbonising transport are often summarised in the so-called “A-S-I” approach: Avoid transport, shift to energy-efficient modes and improve energy efficiency and use of renewable fuels.

The following paragraphs detail the main underlying assumptions, strategies and policies to achieve a full decarbonisation of the transport sector by 2050.

Avoid

Projections relating to transport demand reduction in the Vision Scenario were calculated using results from the Renewbility III project[8] (Zimmer et al. 2016).

Transport demand in passenger transport in the Renewbility "Efficiency plus" scenario decreases by 15% in 2050 compared to the reference scenario. The Renewbility scenario "Efficiency plus" assumes the following:

- investments in cycling and walking infrastructure and in public transport,
- an increase in "out-of-pocket" costs for private motorised transport (e.g. by fuel taxes or road pricing),
- a set of measures which aim to promote a modal shift and to improve quality of life in (inner) cities.

Measures for urban transport include an improved local area supply and a stronger land-use mix in the spirit of the "city of short distances" planning concept, a country-wide introduction of car sharing in cities with over 50,000 inhabitants and inner-city access restrictions for polluting vehicles in cities with over 200,000 inhabitants. Furthermore, a large-scale expansion of parking space management with a substantial increase in prices, a 30 km/h speed limit for all urban secondary roads and an increase in the attractiveness of cycling and public transport were assumed. The motorisation rate in cities with more than 100,000 inhabitants is lower by a third compared with the baseline development in 2050.

Other scenarios achieve even higher reductions in transport demand. The Renewbility scenario "Efficiency plus road pricing" in which out-of-pocket costs for private motorised transport increase by 50% compared to the reference scenario results in a demand reduction of 25%. The most ambitious scenario provided in the SULTAN tool (Hill 2016) also achieves a 25% reduction of passenger transport demand.

For freight transport, a reduction by 6% in transport demand compared to the reference scenario is assumed based on the Renewbility III. Reduction of freight transport demand stems from the decarbonisation of the whole economy resulting in reduced transport of fossil energies like coal, etc. Furthermore, a circular economy with reduced trip distances in freight transport contributes to a reduction in transport demand.

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[8] The "Renewbility" project develops and analyses scenarios for the German transport sector based on complex models estimating future vehicle stock, transport demand, material requirements, energy demand, CO_2 emissions and economic effects (Zimmer et al. 2016). These models also capture interactions between the energy and transport sectors. The project was conducted by Öko-Institut, Institute of Transport Research at DLR, INFRAS and ifeu-Institut on behalf of the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

Shift

Assumptions on modal shift to rail transport are based on (CE Delft 2011) and correspond to goals in the EU White Paper for Transport (EC 2011d): Modal share of passenger rail transport in the Vision Scenario increases from 8% (2015) to 27% in 2050. Around 1/3 of the modal shift comes from aviation as 50% of intra-EU-flights are shifted to rail transport. The remaining increase is due to a shift from private motorised transport. This means that the modal share of car transport decreases from around 72% (2015) to 56% (2050).

Not only in passenger transport, but also in freight transport a major shift to rail is assumed in the Vision Scenario. Based on (CE Delft 2011), the modal share of freight rail doubles from 16% (2015) to 38% (2050), and the modal share of road freight transport decreases accordingly. The main goal of making freight transport more environmentally friendly is to attract as much of the freight traffic demand to railways since the latter are already to a large extent decarbonised and energy efficient. The capacity of the railway network has to be adjusted to this demand by means of operational measures and infrastructure extensions. As road freight transport will always be needed to fill the gaps (especially in collection and distribution) left by railway transport, efforts to make road transport more efficient need to be increased. The consequence is significantly to improve intermodal transport by efficient terminal handling and fast and reliable transport by rail, thus combining the advantages of both modes.

Rail transport in the Vision Scenario quadruples by 2050. In order to make a major shift to rail transport possible, both supply and demand measures are necessary. Increasing network capacity is a prerequisite for modal shift (CE Delft 2011), but needs to be combined with economic incentives (e.g. via internalisation of external costs of road transport). Furthermore, the reliability and punctuality of rail transport is crucial to inducing modal shift.

Pricing instruments such as road user charges are already used to some extent in the EU, but there is still a large potential for supporting modal shift and mitigating the environmental impacts of transport (EEA 2016). Fuel tax revenues decreased between 2000 and 2014 in real terms from € 200 billion to € 167 billion (T&E 2015). The low diesel taxes in Europe are unique, and differing fuel taxation in Europe leads to fuel tourism. To prevent this, the minimum fuel tax level for diesel should be raised and both diesel and petrol minimum fuel taxes should be periodically corrected for inflation.

Improve

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:

- The EC regulation on emission performance standards for new passenger cars should be further developed and tightened. The introduction of CO_2 emission standards (EC/443/2009 and EU/511/2011) was linked to the aim of ensuring that road transport makes an effective contribution to climate protection. While the specific type approval emissions from passenger cars and light commercial vehicles measured on a chassis dynamometer fall continuously, the vehicle emissions in real-world driving have only decreased to a smaller extent and the "real world gap" between type approval emissions and real world emissions has increased to 42% in 2016 (Tietge & Mock 2017). Consequently, the regulations have so far turned out to be less effective than desired in achieving a contribution to climate protection from road transport. On 8th November 2017, the EU Commission published a proposal for reducing CO_2 emissions from passenger cars and light-commercial vehicles in the 2021-2030 timeframe. New cars, on average, would have to reduce their CO_2 emission level by 30% by 2030, compared to the 2021 level. This proposal means that annual reduction rates in the time period of 2021 to 2030 are below 4% and thus lower than in the 2015 to 2021 timeframe, with an approx. 5% annual reduction (Mock 2017). Much higher reductions by 2030 are possible, especially when considering the possibility of achieving major CO_2 reductions of new cars by introducing electric mobility. The Vision Scenario assumes a reduction of 75% until 2030, combined with a 15% limit for the real world gap.[9] Testing a vehicle's CO_2 emissions on the road, rather than in a laboratory environment, is an important measure to ensure that the gap between laboratory tests and real-world emissions will not increase further. To decarbonise transport by 2050, no conventionally fuelled cars should be sold after 2030 / 2035. An ambitious CO_2 regulation would provide original equipment manufacturers (OEMs) with a clear regulatory framework for investing in electric mobility. Without an ambitious EU regulation for new passenger cars and vans, national GHG reduction efforts of member states may result in uncoordinated national policies leading to a non-harmonised EU market for new cars.
- Like passenger cars, lorries also have technical potential for reducing energy consumption, amounting to at least 40% compared to current levels (Delgado et al. 2017). Lorries, in particular, need to reduce their emissions; although they represent only four percent of the on-road fleet, they are responsible for almost 30 percent of CO_2 emissions from road transport. Furthermore, innovation in the

[9] CO_2 emission standards will gradually be transferred from the NEDC to the Worldwide Harmonised Light Duty Test Procedure (WLTP) from September 2017 to 2021. The procedure for converting the NEDC target value into the WLTP target value for 2021 presents a major incentive for achieving a high ratio between WLTP and NEDC equivalent emission values in 2020 and, thus, for meeting the 95 g target in 2021 with a rather low effectiveness in terms of real world emission reduction (Kasten & Blanck 2017). Assuming a conversion factor of 1.25 between NEDC and WLTP, a 75% reduction will result in a 30 g target (WLTP) in 2030.

trucking industry over the past 15 years has been called into question in light of the stagnant fuel efficiency of heavy-duty vehicles. In response, the European Commission proposed a monitoring and reporting scheme for new lorries in May 2017. As of 1 January 2019, lorry manufacturers will have to calculate the CO_2 emissions and fuel consumption of new vehicles that they produce for the EU market, using the Vehicle Energy Consumption Calculation Tool (VECTO). A regulatory proposal for Heavy-Duty-Vehicle (HDV) CO_2 emission standards is expected in 2018. A type approval test for CO_2 emissions from lorries is also necessary to be able to introduce a CO_2 component into heavy-duty vehicle road-pricing schemes. Road-pricing has already proved quite effective in reducing pollution and should be used to incorporate emission-based price differentiations.

- For both cars and lorries, electrification is the most energy-efficient option for decarbonisation. For short distance and regional transport, battery-electric lorries are increasingly being considered by both manufacturers and transport companies. The driving forces behind electrification are tightening regulations from cities (e.g. restriction of diesel vehicles) and decreasing costs of batteries. For long-haul transport, battery-electric vehicles are less attractive than for regional transport because battery size and battery costs increase significantly when higher driving ranges are required. The main options for decarbonising long-haul transport that are being discussed are lorries powered with liquified natural gas (LNG) and electric road systems (ERS). An example of an electric road system is the Siemens e-highway concept that connects a hybrid electric lorrie with overhead lines through a pantograph (like a tram). This concept is being trialled in Sweden, Germany and California in cooperation with Volvo and Scania. As shown in (Kasten et al. 2016), from a macroeconomic perspective, ERS systems are the cheapest option for decarbonisation of long-haul transport. The main challenge is that ERS require implementation of an e-highway network, e.g. via an overhead catenary infrastructure. Because of the high share of border-crossing freight transport in Europe, such an infrastructure network would need to be interoperable and available at EU-level. Even if ERS are the most cost-efficient option in the long term, they need high up-front investment in an early market stage to finance the catenary infrastructure. According to (T&E 2017), 34% of heavy goods vehicle traffic could be running on e-highways by 2050. Electric vehicles are the key to decarbonising the transport sector. However, a range of non-renewable materials that are only mined in a limited range of countries are required to manufacture batteries (i.e. lithium, cobalt, nickel and graphite). Reducing primary demand for raw materials via recycling would help to ward off temporary production bottlenecks and associated price increases that could impair the adoption of electric vehicles. In order to improve the legal basis for an efficient recycling system, we recommend reforming the EU Battery Directive. A revised directive could establish quotas for the recycling of lithium, cobalt, nickel, and graphite. In order to improve the environmental and working conditions associated with the mining of raw materials necessary for manufacturing electric vehicles, we recommend the establishment of a global industrial alliance for sustainable lithium and that companies adopt a Due Diligence Codex for Cobalt (Buchert et al. 2017).

- 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.
- 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 based on calculations with Öko-Institut's model TEMPS[10].

- efficiency improvements of 40% for private vehicles with conventional power trains and an increase in average load factors of 10%;
- efficiency improvements of 40% for conventional lorries and an increase in average load factors of 10%;
- efficiency improvements of 35% for conventional vehicles in public road transport and an increase in average load factors of 14%;
- efficiency improvements of 55% for air transport and an increase in average load factors of 11%; and
- efficiency improvements of 10% for rail rail transport, combined with an increase in average load factors of 10 (passenger rail) and 12% (freight); respectively.

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

- 25% electric mode for private cars in 2030 and 75% in 2050;
- 6% fuels cell powertrains for private cars in 2050;
- 4% electric mode for lorries (short distance transports) in 2030 and 34.5% in 2050 (short distance transport and electrified road transport)

[10] Transport Emissions and Policy Scenarios.

- 25% LNG-fuelled lorries 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 75% 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, and around one third of freight transport. By avoiding, shifting and improving transport, demand for gaseous and liquid hydrocarbons in the transport can be reduced below 90 million toe in 2050 (which equals approx. 25% of current consumption). However, in order to achieve full decarbonisation the remaining consumption (e.g. in air transport and to some extent in freight transport) renewable liquid and gaseous fuels are needed. This could be achieved by using biofuels of second and third generation and power-generated fuels.

In the Vision Scenario it is envisaged that the second and third generation biofuels in road transport will assume a 20% share in 2050 (from around 5% today), most of which is used in freight transport. International quality standards for the production of biofuels or biomass in general, are an essential means of introducing high shares of such fuels in a way that is compatible with sustainability. Because of the efficiency improvements in the transport sector, overall demand for hydrocarbons decreases and absolute use of biofuels in 2050 will not be much higher than today.

The remaining fuels in the Vision Scenario are provided using novel, from today's perspective power-generated fuels. Deployment of novel fuels starts in air transport (3% in 2030). In road transport, the share of novel fuels amounts to 24% of the remaining liquid motor fuels in 2040 and 80% in 2050. It is important to note that sustainability criteria for these fuels have not yet been established, and there is still a lack of research on how to ensure sustainability of power-generated renewable fuels. Thus, they should only be seen as a strategy in the post-2030 timeframe. Furthermore, novel or power-generated renewable fuels are only the "very last option" for decarbonising transport and should only be used when direct electrification is not an option. When battery-electric cars are with conventional cars using power-generated fuels, the latter result in a much lower environmental performance due to low energy efficiency. With the same amount of electricity, a battery-electric car can drive 5-6 times as far as a conventional car with power-generated fuels.

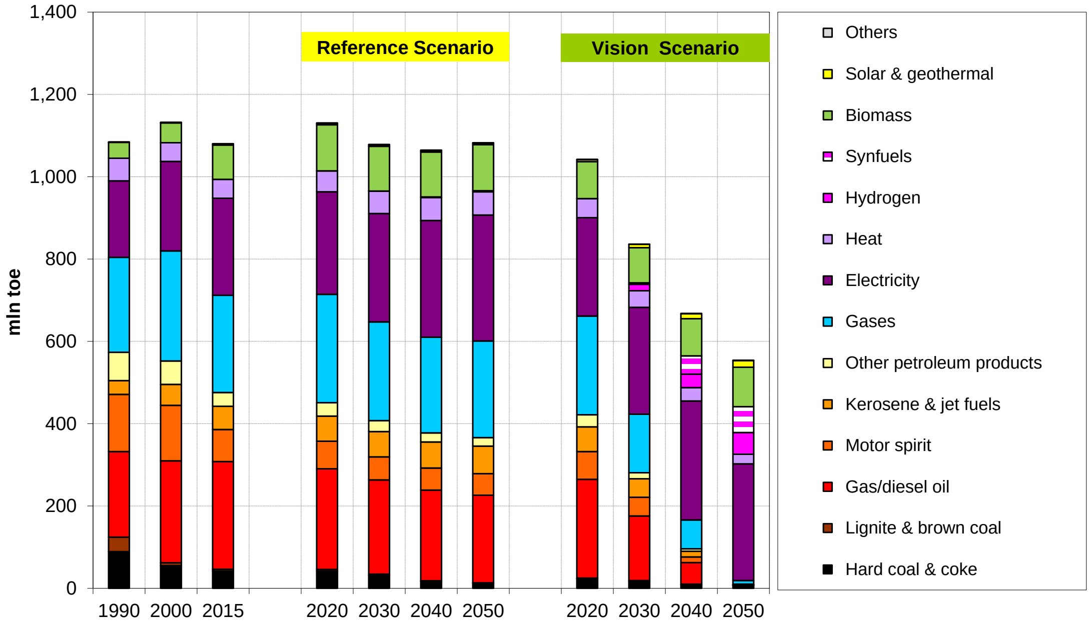
From a policy perspective, power-generated fuels should not be subsidised. Instead, applying a quota system would be the preferable option. Thus, users would pay for additional costs and there would be a strong incentive to use more energy-efficient vehicles or switch to energy-efficient modes.

6.1.5 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 6-5):

- In the Reference Scenario the total final energy consumption is almost stabilised at 2015 levels for the next three and a half decades. In 2030 and 2050 the final energy demand will remain at 2015 levels. In the Vision Scenario the final energy consumption peaks between 2015 and 2020 and falls steadily to a level which is 23% below 2015 levels in 2030 and 49% below 2015 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.

Figure 6-5: Total final energy consumption by fuel in the EU-28, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

- 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 22% in 2015 to 24% in 2030 and 28% in 2050 in the Reference Scenario and 31% in 2030 and 51% 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 by 2030 and grows by an additional 18 percentage points by 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 10% for the period from 2015 to 2030 and a consumption of 20% above 2015 levels in 2050.

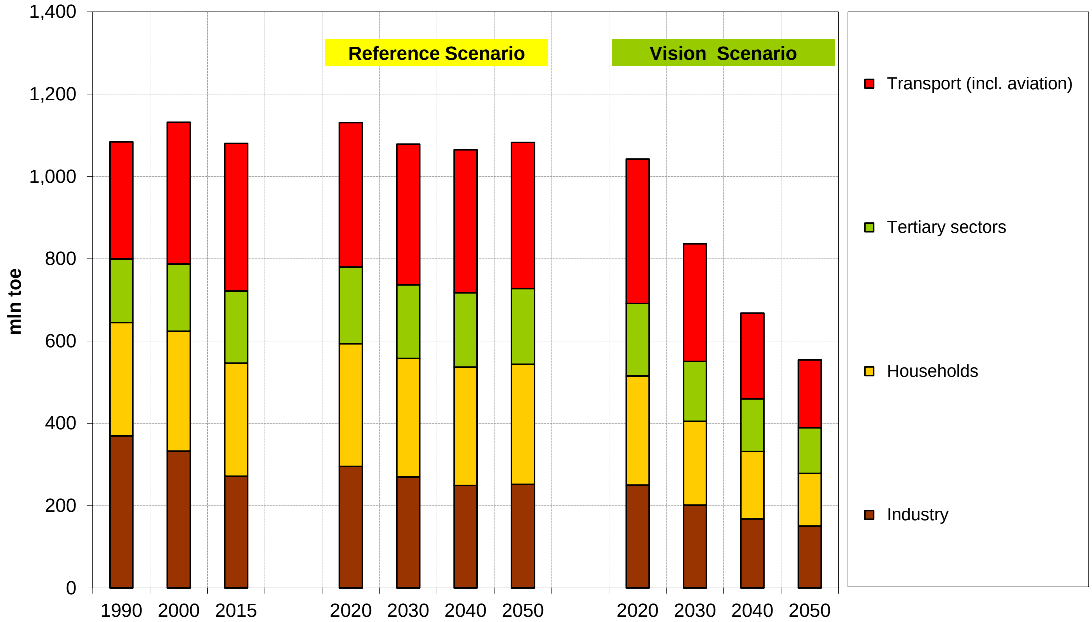
The most important contribution to the decreased final energy consumption in the Vision Scenario is made by the transport sector, which represents a share of 32% and 33% in total final energy consumption by 2030 and 2050 in the Reference Scenario and a 34% and 30% share in the Vision Scenario. Thus, the transport sector represents 23% of the total final energy savings by 2030 and 36% by 2050. The second important sector is the residential sector, which contributes 35% of the total final energy savings by 2030 and 31% by 2050. The industry and the tertiary sectors provide energy consumption reductions which are also significant. The final energy savings in the industry amount to 28% of total final energy savings by 2030 and 19% by 2050. The tertiary sectors represent a share of 14% in total energy savings by 2030 and 2050.

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 significantly in the Vision Scenario compared to 2015 levels but it is still significantly lower than in the Reference Scenario. The transport sector is the only sector which also shows a significantly higher electricity demand in the Vision Scenario in the long term 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 (5% by 2030 and 34% by 2050), the tertiary sectors (41% by 2030 and 36% by 2050) and industry (54% by 2030 and 30% by 2050).
- The breakdown of the reduction in natural gas consumption is as follows: 62% comes from measures in the residential sector by 2030 and 50% by 2050, 16% from the tertiary sectors by 2030 and 20% by 2050 and from industry 23% by 2030 and 25% by 2050.
- 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 (70% by 2030 and 87% by 2050). Approx. 5% to 6% come from the tertiary sectors (including agriculture), between 15% (2030) and 5% (2050) from households, and between 10% (2030) and 3% (2050) from industry.

- Hydrogen and novel (synthetic) fuels for the transport sector are new energy carriers for final energy consumption which are relevant for the period after 2030 and reach shares in total final energy consumption of 12% by 2040 and 21% by 2050. This comparatively high share results mainly from the very low conversion efficiency of, for example, internal combustion engines compared to electric motors.

Figure 6-6: Total final energy consumption by sector in the EU-28, 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 8% in 2015 to 12% in 2030 and 20% in 2050. Taking into account the contributions of renewable energies to power, heat and hydrogen production and assuming that novel fuels for the transport sector are fully accounted as renewable energy, the (direct and indirect) use of renewable energies in the Vision Scenario increases from 15% in 2015 to 37% in 2030 and to 96% in 2050.

In summary, the final energy consumption of the Vision Scenario is based on three major components:

- Aggressive improvements in energy efficiency for all energy sources;
- 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); and

- For the time horizon after 2030 novel, from the current perspective power-based fuels will need to play a role in parts of the transport sector and hydrogen starts to emerge as a significant fuel for the industry.

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.

6.2 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-28. The most significant energy sector in terms of GHG emissions is the power generation sector.

The net electricity production in the EU-28 rose by 26% in the years from 1990 to 2015. The most significant increase occurred from 1990 to 2005. From 2005 to 2015 power production in the EU-28 changed only slightly and was almost constant in average. Electricity imports and exports from and to the EU played only a negligible role in the last two decades.

In the Reference Scenario the power production returns to a steady growth, driven by a increasing demand. In 2030, power production exceeds 2015 levels by 11% and 29% by 2050. However, the structure of power generation changes significantly in this period:

- The level of nuclear power generation decreases slightly for the decades ahead, a few new-built plants and some lifetime extensions do not compensate for the policy- or market driven shut-down of plants. Thus, the level of nuclear power generation decreases by 9% from 2015 to 2030. For the period after 2030 nuclear power production decreases steadily to a level that is about 14% below the 2015 levels, mainly driven by the economic challenges of nuclear power in a system with approx. 53% of power generation coming from renewables. Against the background of increasing total power production, the share of nuclear power drops from 27% in 2015 to 22% in 2030 and to 18% in 2050.
- Power generation from hard coal decreases by 27% from 2015 to 2030 and by 94% by 2050. Against the background of increasing total power production, the share of power generation from hard coal drops from 14% in 2015 to approx. 8% in 2020 and less than 1% in 2050.
- Power production from lignite is an important source of power production in some EU-28 Member States. However, it represented only 10% of the total power generation in 2015. Power production from lignite falls by 18% from 2015 to 2030 and then decreases to a level which is 39% below 2015 levels. The

share in total power generation drops by 3 percentage points by 2030 and a further 2 points by 2050.

- The power production from natural gas is assumed to increase by 39% in the period from 2015 to 2030 and almost doubles by 2050. The share of natural gas-based power generation increases from 15% to 19% in the period from 2015 to 2030 and has a 23% share of total power generation by the end of the scenario period.
- Power production from renewable energies rises substantially. The share in terms of the total power generation increases from 30% in 2015 to 43% in 2030. In 2050 the share of renewables in total power generation is 53%, which corresponds to a total increase of 229% compared to 2015 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 approx. 310 TWh from 2015 to 2030 and by another 370 from 2030 to 2050. The electricity generation from solar energy increases by 130 TWh from 2015 to 2030 and by an additional 200 TWh by 2050. Electricity generation from biomass rises only slightly by 60 TWh from 2015 to 2030 and another 20 TWh from 2030 to 2050.

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

- The cap of the EU ETS is substantially tightened and incentivises the full decarbonisation of the power sector. Power generation based on coal is phased out by 2040. Approx. two thirds of the currently existing coal fleet is decommissioned by 2030.
- Nuclear power generation is substantially decreased by 2030 and completely phased out by 2045 due to the phase-out of power plants after a maximum lifetime of 40 years.
- Supplementary support programmes and changes in market design enable renewable energies to supply the electricity demand fully. This includes sufficient remuneration for investments in renewable generation capacities, backup and storage capacities as well as flexibility options at the demand side on the one hand. On the other hand a liquid wholesale market needs to generate price signals that can trigger the necessary coordination of a highly diversified system of generation, storage and demand response options which is, at least in part, strongly decentralised.
- 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:

- In addition to the final consumption of electricity, the production of hydrogen for final consumption and for balancing the electricity sector as well as the use of electricity for district heating (power-to-heat) emerge as new sources of electricity demand. The electricity demand for hydrogen production amounts to 230 TWh (7% of total consumption) in 2030 and 830 TWh (20% of total consumption) in 2050. The power demand of power-to-heat installations for district heating increase to approx. 40 TWh in 2030 and 80 TWh in 2050.
- The grid losses in the EU-27 network[11] decrease slightly from 7% in 2015 to levels of around 6% in 2030 and 2050, which is equivalent to a total loss of about 230 TWh in 2030 and 250 TWh in 2050.
- 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 after 2030;
- 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. hydrogen production) as a result of the phase-in of new fuels;

As a result, the demand for power generation is approximately 20% above the 2015 level in 2030, which is 5% higher than in the Reference Scenario. The necessary power generation increases by an additional 36 percentage points from 2030 to 2050 and reaches a level of 4,640 TWh, which is 18% higher than in the Reference Scenario.

Alongside this difference in production levels, there are major structural changes in conventional power generation in the Vision Scenario (Figure 6-7):

- 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 approx. 170 TWh, which corresponds to a 5% share of the total power generation. By 2045 nuclear power generation is phased out completely.

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

- 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 2015 levels the hard coal-based power generation decreases by about 72% by 2030 and is phased out by 2040. The production from lignite power plants drops by 76% by 2030 and is also phased out by 2040.
- Compared with 2015 levels, the power generation from gas rises by about 18% to 39% by 2030. For the period after 2030 the role of natural gas in power generation is reduced considerably. Production from fossil natural gas is also phased out by 2050. In the next two decades the share of gas in total power productions amounts, however, to between 14% and 18% (which is up to 3 points above the base level of 2015) and subsequently falls to zero in 2050.

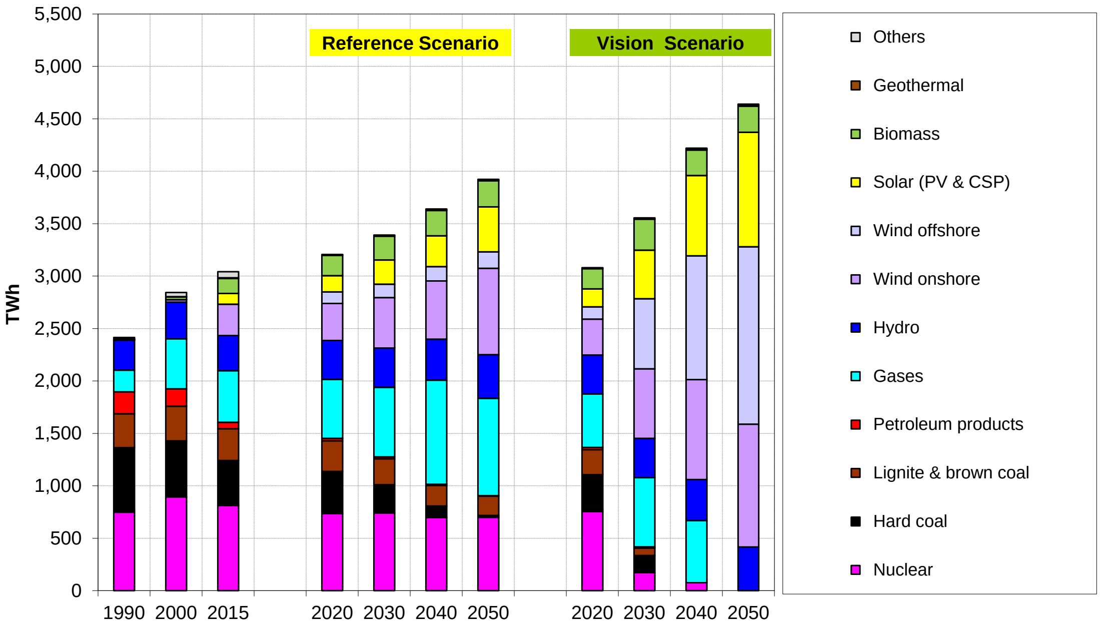
The Vision Scenario is characterised by a fundamental shift of the electricity system to renewable energy sources and reflects the current and foreseeable cost situation for renewable energy sources but also the constraints with regard to land availability and public acceptance:

- From 2015 to 2030 the installed capacity of onshore wind power plants increases from 131 to 300 GW, which equals an annual net capacity addition of 11 GW. In the period from 2030 to 2050, the capacity of onshore wind increases by another 160 GW or annually by 8 GW (net) to a total capacity of 460 GW. Compared to the Reference Scenario the onshore wind capacities increase by 83 GW (2030) and 137 GW (2050).
- The capacity of offshore wind power grows to 160 GW by 2030 and 400 GW by 2050. This equals an annual (net) increase of 11 GW from 2015 to 2030 and 12 GW from 2030 to 2050.
- The installed capacity of solar PV and concentrated solar generation plants grows from 97 GW in 2015 to 350 GW in 2030 and 750 GW in 2050. For this roll-out trajectory, the (net) annual capacity additions need to reach a level of 17 GW from 2015 to 2030 and 20 GW from 2030 to 2050.
- The installed capacity of biomass-based generation capacity almost doubles by 2030 to 53 GW and grows thereafter only slightly to 57 GW by 2050. This capacity expansion does not differ, however, from the trend that is projected in the Reference Scenario.

The new electricity system is based to a large extent on variable renewables. Such a system requires, however, significant firm capacities to ensure a sufficiently high level security of supply:

- In 2030 a firm capacity of almost 170 GW from backup power plants (fuelled by hydrogen), demand response or storage capacities will be needed in addition to the installed capacity of conventional, hydro and biomass capacity.
- From 2030 to 2040 and 2050 the need for additional firm capacity increases slightly to levels around 200 GW.

Figure 6-7: Net electricity generation in the EU-28, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

With such a generation fleet the power generation from renewable energy sources in the Vision Scenario is as follows:

- Power production from renewables is expanded from 909 TWh in 2015 to 2,470 TWh in 2030 and to 4,630 TWh in 2050. This is equivalent to growth of a factor of 2.7 by 2030 and 5.1 by 2050. In 2050 the share of renewables reaches 100% of total power production. Compared to the Reference Scenario, this means a further expansion of power production from renewable energies by 70% by 2030 and 100% by 2050. The main contribution to the growth of renewable energies in power production comes again from offshore wind energy by 2030, which expands to about 670 TWh in 2030 (approx. 130 TWh in the Reference Scenario). From 2030 to 2050, power generation from offshore wind farms also represents the largest share of production growth from renewable energy sources (approx. 1,025 TWh). The second largest increase of power generation from renewables comes from onshore wind and represents an additional production of 365 TWh from 2015 to 2030, compared with 360 TWh for solar electricity generation. Thereafter the growth of solar power generation (almost 630 TWh from 2030 to 2050) exceeds significantly the additional power production from onshore wind installations (510 TWh from 2030 to 2050). Power generation from biomass reaches a level of 295 TWh in 2030 (compared to approx. 170 TWh in 2015) and decreases slightly to 250 TWh by 2050. Geothermal power and other renewable energies make up only a small share of the total production in 2030 and 2050.

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.

The only significantly growing energy sector apart from the power generation is the production of hydrogen for end use or balancing of the electricity sector. The transformation losses for hydrogen electrolysis are projected to decrease slightly to 20% over time. Methanisation would significantly increase the transformation losses, raises the question of the source of climate-neutral CO_2 and is not expected to play a significant role over the scenario period. The demand for novel fuels in the transport sector is expected to be met fully by imports.

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, biogas, and biofuels.

6.3 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.

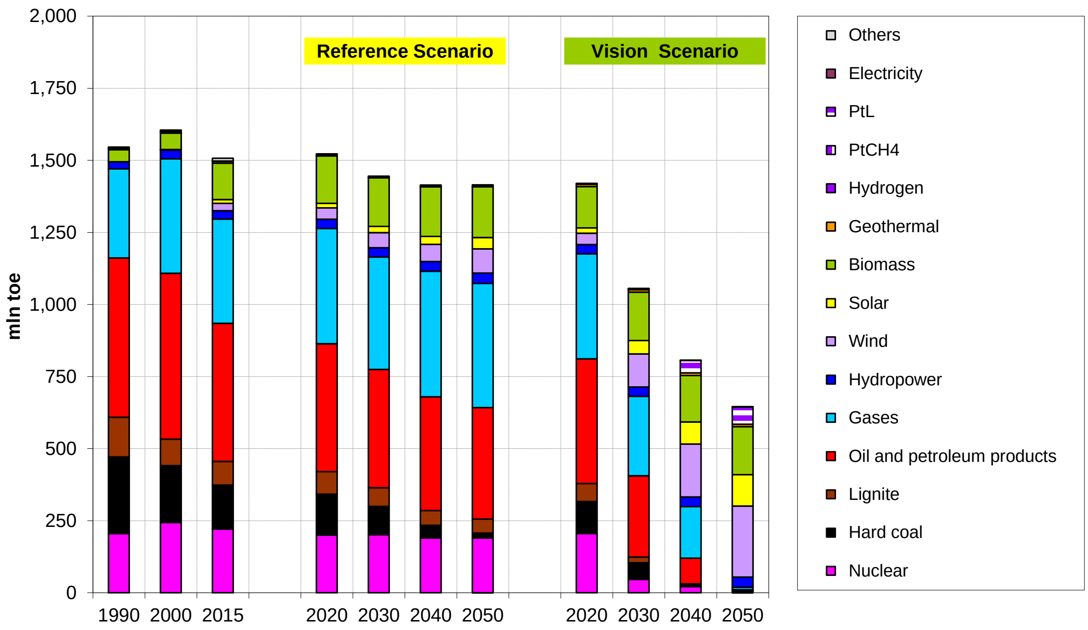
Following the general trends in final energy consumption and the energy sectors, the primary energy supply in the Reference Scenario falls slightly by 4% from 2015 to 2030. In 2050 the TPES is projected to be 6% below the 2015 level. In terms of the structure of the TPES, the trends can be divided into five main groups (Figure 6-8):

- The contribution of nuclear is only subject to small changes in terms of their level of supply from 2015 to 2030. In 2030 the supply of nuclear energy drops by 9% compared to 2015 and decreases further by another 5 percentage points. The share of nuclear energy in TPES decreases from 15% at present to 13% in 2030 and 2050.
- The contribution of crude oil and petroleum products to the TPES also decreases slightly and is 14% below the 2015 level in 2030 and 19% below 2015 in 2050. The share of mineral oil decreases slightly from 32% in 2015 to 28% in 2030 and 27% in 2050.
- The role of hard coal and lignite decreases significantly in the Reference Scenario. In 2030 hard coal presents a share of 7% of TPES and lignite a share of 5%, which constitutes a drop of 36% from 2015 to 2030 for hard coal and 21%

for lignite. From 2030 to 2050 the energy supply from hard coal further decreases to 89% below the 2015 level; the decrease for lignite amounts to 61%. Hard coal and lignite together represent only a share of 5% in TPES by 2050.

- Different to the trends for the other fossil fuels the consumption of natural gas is projected to increase in the Reference Scenario throughout the scenario period. From 2015 to 2030 the gas supply grows by 8% and by another 11 percentage points from 2030 to 2050. The share of gas in TPES increases from 24% in 2015 to 27% in 2030 and 30% in 2050.
- The contribution of renewables to the TPES shows strong dynamics and increases by almost one third from 2015 to 2030 and by approx. another third by 2050. The major driver here is wind energy, followed by solar energy and biomass. The share of wind energy in the TPES grows from 2% in 2015 to 4% in 2030 and 6% in 2050. The share of solar energy grows from 1% in 2015 to 2% in 2030 and 3% in 2050. For biomass the share in TPES increases from 8% in 2015 to 12% in 2030 and remains constant for the years after 2030.

Figure 6-8: Total primary energy supply in the EU-28, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

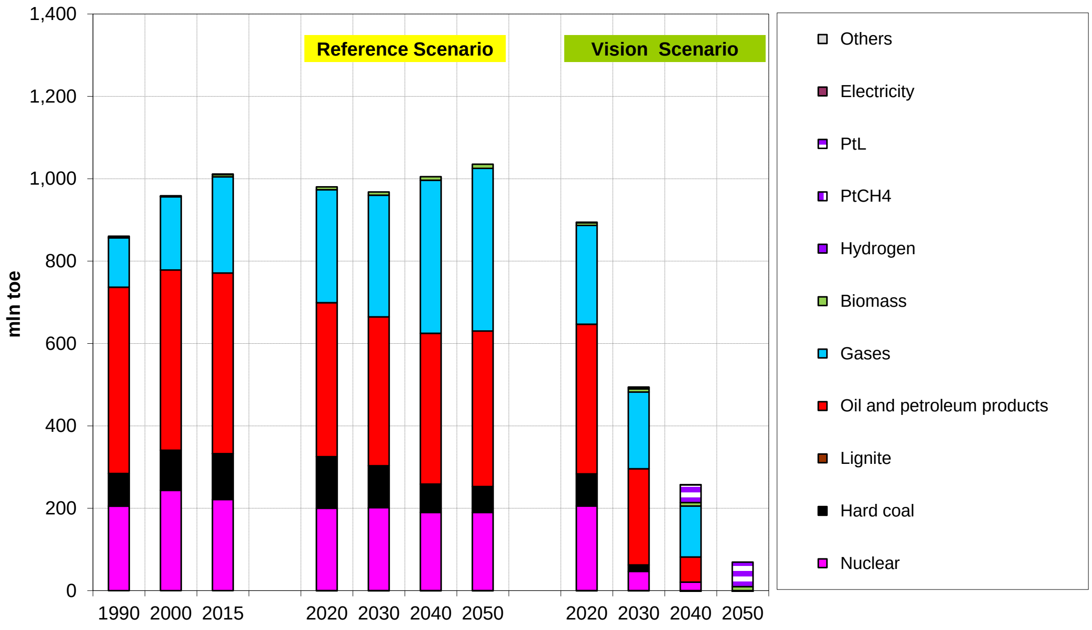
As a result, the structure of the TPES changes significantly even in the Reference Scenario. The contribution of renewable energies is extended from 14% in 2015 to 19% in 2030 and 24% in 2050.

In the Vision Scenario, the TPES steadily decreases over the course of the scenario. In 2030 the primary energy demand is about 30% below 2015 levels; in 2050 the modelling results in a level which is 57% below 2015.[12] 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 79% in absolute terms for the period from 2015 to 2030 and is phased out by 2045. The contribution to the TPES falls to 4% by 2030.
- The role of coal significantly decreases in terms of both the overall level of supply and the share of the TPES. In 2030 the level of hard coal demand is 62% lower than in 2015. In 2050 it comprises only 4% of the level of coal consumption in the base year of 2015; this quantity of coal is mainly used in the iron and steel industry for crude steel production. In 2030 the contribution of hard coal to the TPES is 5% in 2030 and 1% in 2050. The use of lignite decreases from 2015 to 2030 to levels which are 76% lower than in 2015 and is almost phased out by 2050. The share of lignite in TPES falls from 5% in 2015 to 2% in 2030 and is negligible in 2050.
- The use of oil in 2030 is about 41% less than in the year 2015 and is almost phased-out by 2050. Mineral oil contributes 27% to the total TPES in 2030 and 1% in 2050.
- Even for the total consumption of gas, the level of consumption decreases from 2020 onwards compared with the 2015 levels as a result of a decreasing demand for gas for direct use in the end-use sectors on the one hand and an increasing demand in the power sector on the other hand. In 2030, the consumption of natural gas is 24% less than in 2015; in 2050 it is about 98% below the 2015 levels. However, the share of gas in the TPES rises from 24% in 2015 to 26% in 2030 but decreases to 1% in 2050.
- The most significant change in terms of consumption levels and shares in the TPES occur for renewable energies. From 2015 to 2030 the total use of renewable energies increases by a factor of 1.8 and reaches a share of 35% in the TPES. In 2050 renewable energies represent 88% of the TPES which is equivalent to growth by a factor of 2.7 in the period from 2015 to 2050.
- A new element in the primary energy supply is the import of novel fuels, e.g. electricity-based motor fuels. In 2030 these imports represent 5% of the TPES and increase to 9% by 2050.

[12] 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.

Figure 6-9: Primary energy imports to the EU-28, 1990-2050



Source: Eurostat, DG Energy, Öko-Institut

The major differences in the structure of primary energy supply lead to significant changes in the role of energy imports to the EU-28. In 2015, the share of imported energies amounted to approx. 67%. In the Reference Scenario, this share remains almost constant by 67% by 2030 and grows slightly to approx. 73% in 2050.

In the Vision Scenario, the share of imported energies falls from 67% to 47% in the period from 2015 to 2020 and decreases further to 11% in 2050. The domestic potential of sustainable biomass in the EU-28 will be sufficient to cover the total demand and biomass imports must not occur in terms of availability. There will be, however, a need for imports of novel fuels from regions in the world where the conditions for the production of such fuels, be it based on electricity or other sustainable fuels which are currently not yet known. This new import stream makes it necessary for the EU to establish a concise strategy for safeguarding the sustainability standards of these fuels.

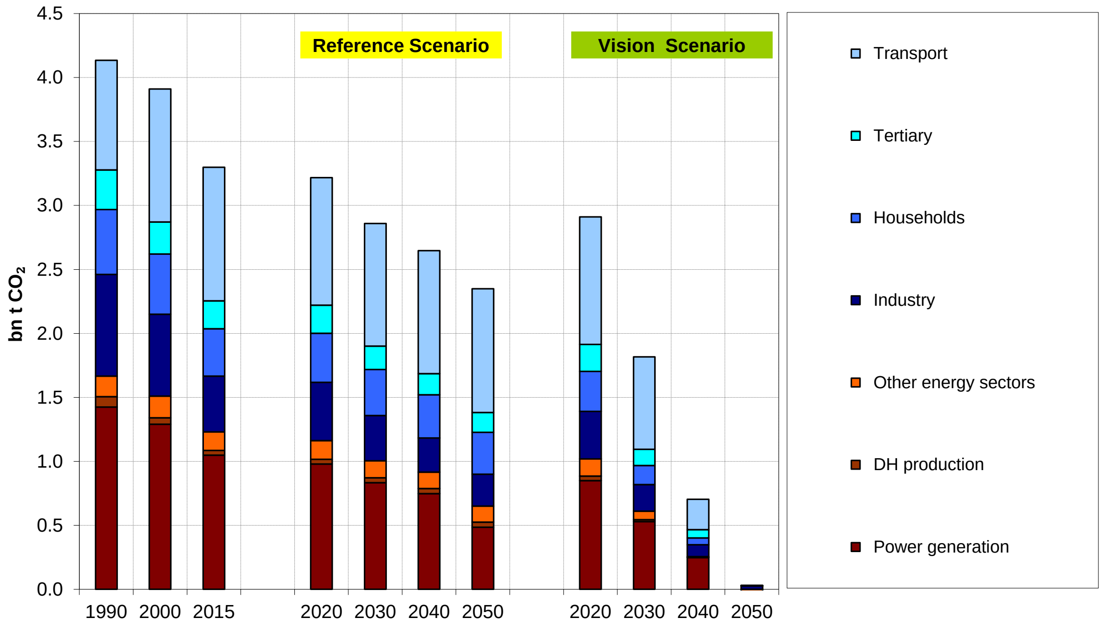
To summarise the effects on import dependence, the Vision Scenario makes a major contribution to decreased import dependence by means of diversification of energy sources and energy savings. Thus, the vulnerability of the EU-28's economies to price spikes and volatilities on the global energy markets is significantly lower.

7 Greenhouse gas emissions

7.1 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.[13] Figure 7-1 indicates the general trend and sectoral breakdown of energy-related CO_2 emissions in the Reference Scenario and the Vision Scenario.

Figure 7-1: CO_2 emissions from energy use in the EU-28, 1990-2050



Source: UNFCCC, Eurostat, Öko-Institut

In the Reference Scenario, the energy-related CO_2 emissions decrease slightly throughout the next decades. In 2030, the total energy-related CO_2 emissions amount to about 2,860 Mt, which is 31% below 1990 levels. In 2050, the emissions reach a level of approx. 2350 Mt or -63%, which is far off any ambitious emission reduction targets.

[13] 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 29% – the major share of total emissions in 2030 which decreases only slightly to 21% in 2050.[14] However, in line with the overall emission trend, the emissions of the power sector decrease by 21% from 2015 to 2030 and by another 33 percentage points by 2050.

The least ambitious emission decrease is to be found in the transport sector. Although the CO_2 emissions decrease by 8% from 2015 to 2030, they are projected to remain approximately constant for the decades after 2030. Different dynamics result, however, for air transport. The total emissions from kerosene and jet fuel use increase by approx. 8% in the period from 2015 to 2030 and by an additional 10 percentage points from 2030 to 2050. In 2030, 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 7% and reach a level of 9% in 2050.

In the Vision Scenario, the energy-related CO_2 emissions decrease significantly, reaching a level of about 56% below 1990 emissions in 2030. By 2050 they are reduced to almost zero; the energy sector has been nearly fully decarbonised by then based on the 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 2015 to 2030 the emissions for most energy sectors decrease by 30% to 50% and almost 100% from 2015 to 2050. However, the most significant emission reduction comes from the power sector and the transport sector. When compared to 2015 levels, the decrease of emissions from the transport sector amounts to approx. 1,040 Mt CO_2 by 2050. In the same period, the emissions from power production drop by approx. 1,050 Mt CO_2.

The period up to 2030 is characterised by major emission reductions in the power sector; it halves its emissions compared to 2015 in this period and creates the basis for additional emission reductions in the other sectors. In the 20 years after 2030 the emissions decrease by another quarter per decade. The emissions of the transport sector are reduced by approx. 30% from 2015 to 2030 and then by another 45 percentage points from 2030 to 2040 before decreasing to zero by 2050.

A special mitigation option is introduced in industry and the energy transformation sector from 2030 onwards. In the 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 and the abatement of CO_2 emissions from the iron and steel industry by CCS installations, a net carbon sink is created, which amounts to 70 Mt CO_2 in 2040 and approx. 230 Mt

[14] 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.

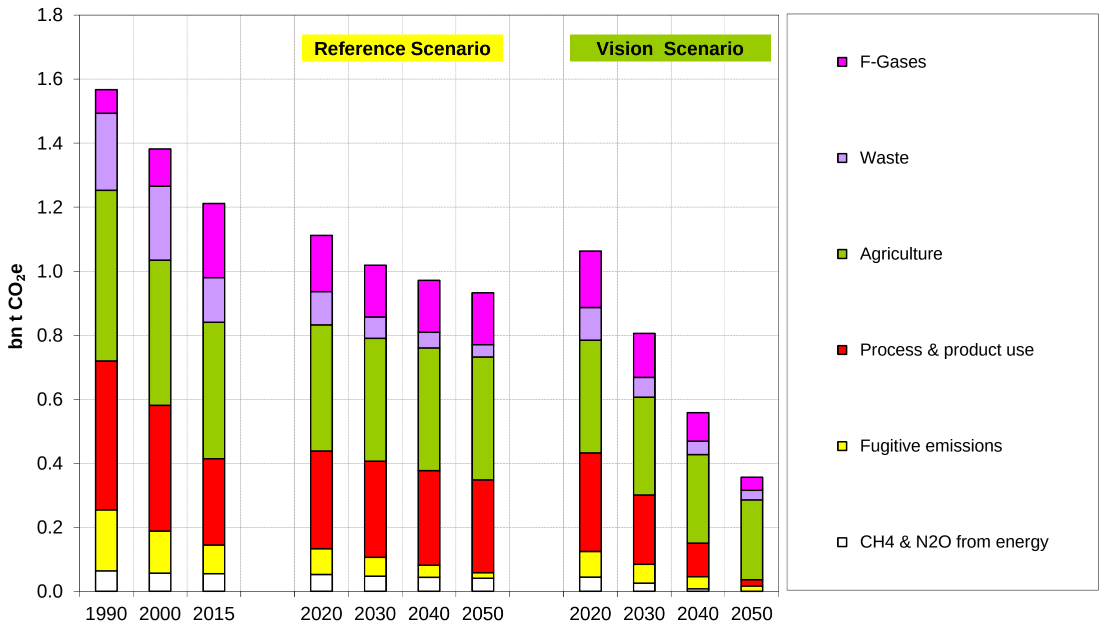
CO_2 in 2050. This corresponds to 7 percent of the total reduction of energy-related emissions from 2015 to 2050.

It will be of crucial importance to design appropriate strategies and policies that reflect the substitution cycles, inertia and lead times for infrastructure and innovation in the different sectors.

7.2 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 7-2: Non-energy and non-CO2 greenhouse gas emissions in the EU-28, 1990-2050



Source: UNFCCC, Öko-Institut

Figure 7-2 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 2015 is projected to slow down in the next decades. From 2015 to 2030 an emission decrease of -16% will be achieved and by 2050 the emissions are expected to be approx. 23% below 2015 levels.

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 includes:

- 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 20% from 2015 to 2030 and approx. 93% 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.[15] About 64 Mt CO_2 will be avoided by CCS from process emissions in 2030, about 15 Mt CO_2 in 2040 and 215 Mt CO_2 in 2050.

15 Process emissions from coal use in the iron and steel industry are accounted for in the energy-related emissions for modelling reasons.

Agriculture provides the second largest contribution by 2050 (about 180 Mt CO_2e or -42% compared to 2015) to the total emission reduction for non-energy and non-CO_2 greenhouse gases. The total emission mitigation in agriculture from 2015 to 2050 results from reductions in CH_4 (110 Mt CO_2e) and N_2O (70 Mt CO_2e) emissions.

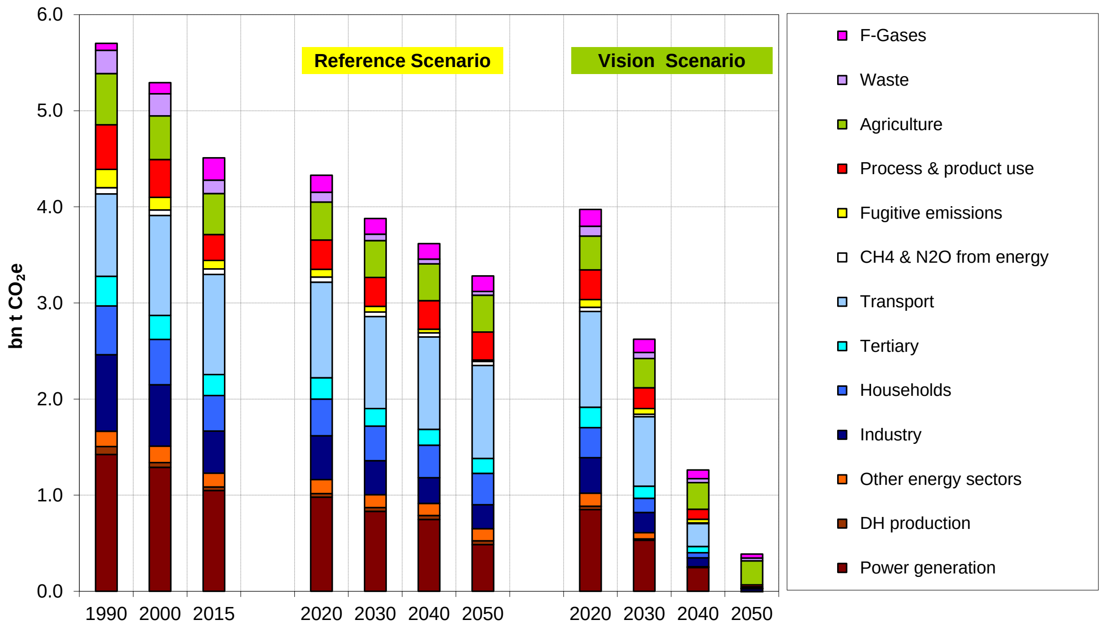
Other significant emissions reduction contributions can be attributed to the waste sector (about 110 Mt CO_2e from 2015 to 2050), mainly from avoided methane emissions from landfills.

Mitigation measures with regard to HFC, PFC and SF6 provide a further contribution of 190 Mt CO_2e from 2015 to 2050.

7.3 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 7-3).

Figure 7-3: EU-28 greenhouse gas emission trends in the Reference Scenario and the Vision Scenario by sectors, 1990-2050



Source: UNFCCC, Öko-Institut

The total GHG emissions reduction in the Reference Scenario from 2015 to 2030 amounts to approx. 630 Mt CO_2e and to almost 1,230 Mt CO_2e from 2015 to 2050. The decrease of 20% by 2050 is equivalent to an overall emissions reduction of 42% compared to 1990 levels. In 2030 an emissions reduction of 32% compared to 1990 levels is achieved.

- The main share of the emission reductions results from energy-related CO_2 emissions. From 2015 to 2050 these emissions decrease by about 970 Mt CO_2, from 2015 to 2030 the respective emission reduction is about 450 Mt CO_2. The power sectors contribution is about 215 (2030) and 560 Mt CO_2 (2050). The second most important emissions reduction stems from the industrial sectors, which contribute 80 (2030) and almost 190 Mt CO_2 (2050) to the total CO_2 emission reductions. The third largest emissions reduction originates from the transport sector, which reduces 85 (2030) and almost 75 Mt CO_2 (2050) in total. The other end-use sectors bring about a combined emission reduction of about 45 Mt CO_2 by 2030 and between 110 Mt CO_2 by 2050.
- The CH_4 emissions decrease by about 125 Mt CO_2e from 2015 to 2030 and 185 Mt CO_2e for the period 2015 to 2050. The major share of the emission reduction results from waste management (about 100 Mt CO_2e from 2015 to 2050) and fugitive emissions from energy production and distribution (about 70 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 25 Mt CO_2e from 2015 to 2050 results from 4 Mt CO_2e of mitigation measures in industrial processes and about 14 Mt CO_2e from changes in agriculture.
- The total emission reduction from HFC, PFC and SF_6 is about 70 Mt CO_2e in the period 2015 to 2050.

The corresponding emission reduction from the installations regulated by the European Union Emissions Trading Scheme (EU ETS) is about 33% for 2030 and 50% for 2050, compared to 2005 levels (Table 7-1).

Table 7-1: EU-28 greenhouse gas emission trends the Reference Scenario and the Vision Scenario by gases, 2015-2050

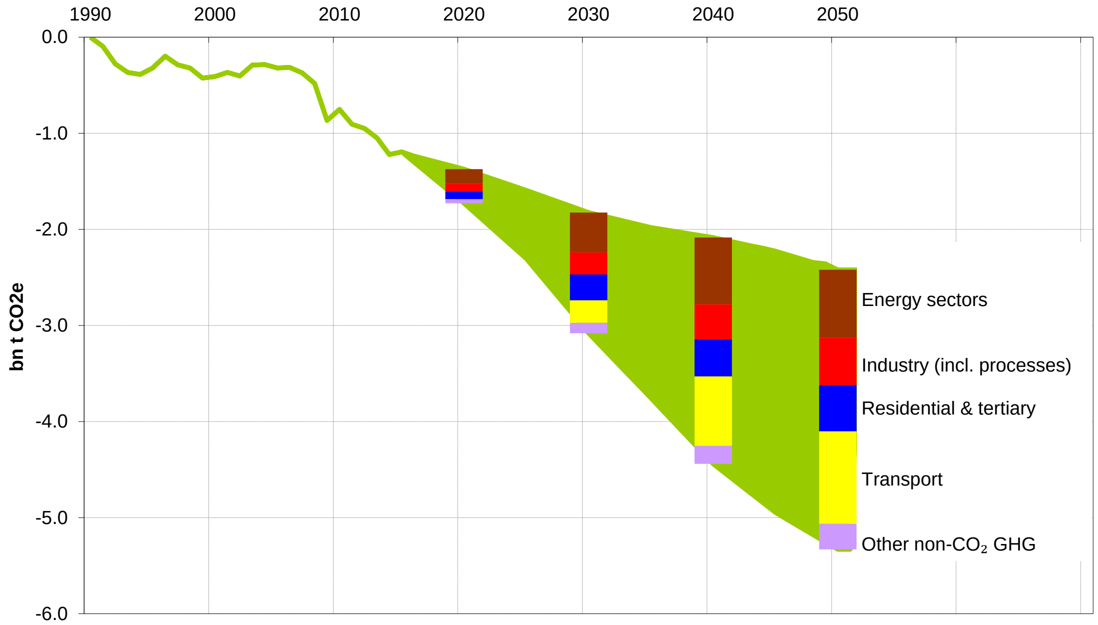
	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO_2e								
CO_2 from energy	3.32	3.24	2.88	2.66	2.35	2.94	1.83	0.71	0.02
CO_2 from non-energy	0.26	0.29	0.29	0.28	0.28	0.30	0.21	0.10	0.01
CH_4	0.46	0.39	0.33	0.30	0.27	0.37	0.28	0.22	0.17
N_2O	0.24	0.22	0.22	0.22	0.22	0.20	0.16	0.14	0.13
F-Gases	0.23	0.18	0.16	0.16	0.16	0.18	0.14	0.09	0.04
Total	4.51	4.33	3.88	3.62	3.28	3.97	2.62	1.26	0.37
Change of emissions									
Total from 1990	-21%	-24%	-32%	-37%	-42%	-30%	-54%	-78%	-93%
Total from 2005	-16%	-20%	-28%	-33%	-39%	-26%	-51%	-77%	-93%
ETS from 2005	*-23%*	*-23%*	*-33%*	*-40%*	*-50%*	*-32%*	*-58%*	*-83%*	*-99%*

Source: UNFCCC, Öko-Institut

In the Vision Scenario the emission pathway exceeds the -20% target (compared to 1990 levels) for 2020 and results in a reduction of -54% in 2030 and -93% in 2050.

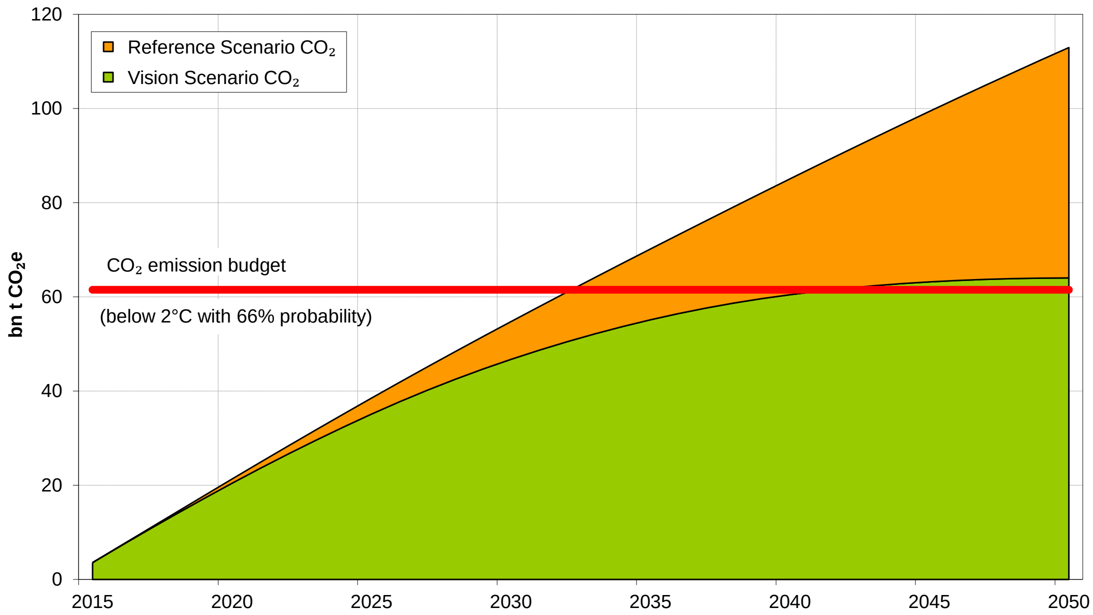
- Energy-related CO_2 emissions are again the main driver for the emission reduction. The respective sectors bring about 3,280 Mt CO_2 of the total emission reduction of approx. 4,140 Mt CO_2e in the Vision Scenario from 2015 to 2050. The key sector is the power sector which contributes about 1,050 Mt CO_2 over the scenario period. The emission reduction from the transport sector reaches nearly the same magnitude (1,040 Mt CO_2). However, the emission reductions from the other sectors (industry 410 Mt CO_2, households 370 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 290 Mt CO2e, and mainly from waste management (110 Mt CO_2e), agriculture (110 Mt CO_2e) and fugitive emissions from the energy sector (about 70 Mt CO_2e).
- CO_2 emissions from non-energy sources drop significantly, by about 240 Mt CO_2 from 2015 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 lower level of emission reductions (110 Mt CO_2e from 2015 to 2050) stems from N_2O emissions, coming mainly from agriculture (70 Mt CO_2e) and industrial processes (40 Mt CO_2e).
- Significant emission reductions (180 Mt CO_2e) result from HFC use; the contribution of PFC and SF_6 amounts to approx. 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 230 Mt CO_2 by 2050; process emissions account for 215 Mt CO_2 of this emission reduction and the use of bio-energy with CCS (BECCS) accounts for the remaining 14 Mt CO_2. However, the key contributions from CCS occur after 2030 in the Vision Scenario.

Figure 7-4: Sectoral contributions to the EU-28 greenhouse gas emission trends in the Vision Scenario, 1990-2050



Source: UNFCCC, Öko-Institut

Figure 7-5: Cumulative CO_2 emissions in the Reference Scenario and the Vision Scenario and the CO_2 budget, 2015-2050



Source: Öko-Institut

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 7-4) 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 55% 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. The industrial sectors deserve major attention because of the broad range of innovation and structural change needed in key industries.

The level of cumulative GHG or CO_2 emissions is the key indicator for the impact of certain greenhouse gas emissions trajectories on global warming (Figure 7-5). 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 the major portion of its fair share in the global CO_2 emission budget within the next one (Reference Scenario) or two decades (Vision Scenario).

In the Reference Scenario, CO_2 emissions from the EU exceed the EU's fair share in the global budget from 2032 onwards. Even in the ambitious Vision Scenario, the level of the EU's cumulative CO_2 emissions approaches the level of the EU's emission budget in 2040 and only the last and rapid steps for a shift to a zero-emission economy after 2040 keeps levels close to the CO_2 emission budget.

With a view to the fact that the CO_2 emissions budget is slightly exceeded even in the Vision Scenario, it should be highlighted that very ambitious emission reduction strategies for the non-CO_2 greenhouse gases, which are not reflected in the emission budget approach in this study, form an essential element of an appropriate strategy for avoiding dangerous climate change.

8 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 8-1: Energy indicators for the Reference Scenario and the Vision Scenario, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
Share of renewables									
Power generation	29%	37%	43%	45%	53%	39%	70%	84%	100%
District heat*	26%	24%	23%	22%	22%	27%	60%	84%	96%
Final energy*	15%	19%	22%	24%	27%	19%	38%	65%	96%
Industry	*18%*	*24%*	*30%*	*34%*	*38%*	*24%*	*47%*	*68%*	*88%*
Tertiary	*18%*	*23%*	*28%*	*31%*	*36%*	*23%*	*48%*	*69%*	*99%*
Households	*25%*	*28%*	*29%*	*30%*	*33%*	*29%*	*55%*	*78%*	*100%*
Transport	*4%*	*7%*	*7%*	*8%*	*9%*	*7%*	*14%*	*57%*	*99%*
Primary energy*	13%	17%	19%	21%	24%	17%	35%	63%	97%
Energy efficiency	Change from 2005								
Final energy	-9%	-5%	-9%	-11%	-9%	-12%	-30%	-44%	-53%
Industry	-17%	-10%	-17%	-24%	-23%	-23%	-38%	-49%	-54%
Tertiary	-16%	-17%	-32%	-42%	-49%	-22%	-44%	-59%	-69%
Households	-11%	-4%	-7%	-7%	-6%	-14%	-34%	-47%	-59%
Transport	-3%	-5%	-8%	-6%	-4%	-5%	-23%	-44%	-55%
Primary energy	-11%	-10%	-15%	-17%	-17%	-16%	-38%	-52%	-62%
Energy efficiency	Change from Primes Baseline 2007**								
Primary energy	-	-18%	-23%	-	-	-23%	-44%	-	-
Primary energy imports***	67%	64%	67%	71%	73%	63%	47%	32%	11%

Notes: * The share of renewable energy sources includes indirect contributions from electricity, heat, hydrogen & synfuels. The statistically unaccounted ambient heat delivered by heat pumps represents additional contributions to the energy supply from renewables. - ** The 2007 Primes Baseline projection for the EU-27 was adjusted for Croatia. This projection does not present reference levels for the period beyond 2035. - *** Excluding primary energy for non-energy uses, nuclear fuel was fully considered as imported primary energy. - **** Including international aviation and excluding LULUCF.

Source: Eurostat, Öko-Institut

The set of indicators for energy efficiency improvements (Table 8-1) highlights some of the key issues for robust energy and climate strategies backed by the Vision Scenario:

- Achieving primary energy savings of 38% from 2005 to 2030 and 62% from 2005 to 2050 is a key objective of the Vision Scenario. Compared to 2015 this equals primary energy savings of 27% by 2030 and 51% by 2050. In terms of primary energy reduction compared to the Primes Baseline 2007 (which has been used as the business-as-usual case for the existing EU targets), the Vision Scenario achieves energy efficiency gains of 44% in 2030.

- 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 lower 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 8-2), 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 35% in 2030 and 97% in 2050 (if ambient heat used with heat pumps is included in the accounting approach, the share in 2030 would increase by approx. 2 percentage points).
- The share of renewables in the final energy consumption of the end-use sectors ranges from 14% to 55% for the years up to 2030 and between 88% and 100% in 2050. The share of renewables in total final energy consumption reaches 38% in 2030 and 96% in 2050 (if ambient heat is also included, the share in 2030 could reach up to 40%).
- The power sector undergoes an early transition towards renewable energies; the share of renewables in net power generation is 70% in 2030, 84% in 2040 and 100% in 2050.

Table 8-2: Greenhouse gas emission reduction indicators for the Reference Scenario and the Vision Scenario, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
Total emissions									
from 1990	-21%	-24%	-32%	-37%	-42%	-30%	-54%	-78%	-93%
from 2005	-16%	-20%	-28%	-33%	-39%	-26%	-51%	-77%	-93%
ETS emissions									
from 2005	-23%	-23%	-33%	-40%	-50%	-32%	-58%	-83%	-99%

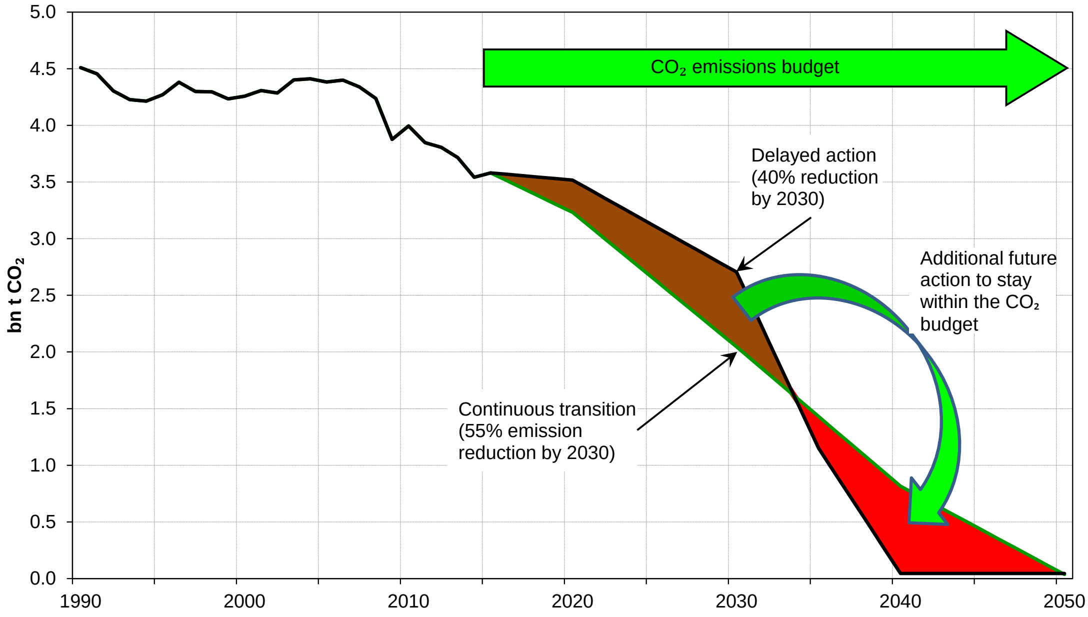
Source: UNFCCC, Öko-Institut

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 54% in 2030 are consistent with a long-term target of more than 90% by 2050, based on 1990 levels. Furthermore, such interim targets are appropriate, also within the concept of cumulative emissions.
- From the modelling database, targets for the cap under the EU ETS can also be derived. The cap should be 58% below 2005 levels for 2030 and 83% below 2005 levels for 2040. In 2050 all ETS-regulated installations should be nearly decarbonised.

Figure 8-1: Cumulative CO_2 emissions in the Vision Scenario and an delayed action scenario arriving at the same CO_2 budget, 1990-2050



Source: UNFCCC, Öko-Institut

Figure 8-1 indicates the implications of an illustrative scenario with delayed action that results in the same effect on climate change than the Vision Scenario. For this scenario a level of only 40% CO_2 emission reduction is reached, compared to 1990. In order to compensate for the missed emission reduction from 2015 to 2030, the CO_2 emissions would need to reach almost zero by 2040, i.e. within only one decade. This complementary thought experiment underlines the importance of early emission reductions to maintain some flexibility for emission reductions in the longer term.

9 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 there and a half 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 decarbonization strategies indicates additional emission mitigation potentials from LULUCF which could probably enable a 95% emissions reduction for the European Union by 2050. Additional emission reduction changes could be achieved by means of significant changes in lifestyle patterns or the structural implications of a transition towards a circular economy, which were not reflected in this modelling exercise.

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 to 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.

    - Cumulative emissions are the most appropriate metrics for assessing the consistency of emission trajectories and emission targets with a 2°C limit. Cumulative CO_2 emissions of 61.5 Gt from 2015 onwards would represent a fair share in the global CO_2 emission budget.

    - If the long-term emission reduction target for all greenhouse gases is at least -90% (compared to the 1990 levels) for the EU-28 or even more ambitious (e.g. -95%), the emission reduction target must be set at least at 55% 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 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.

- With regard to CO_2 emissions the targets need to be even more ambitious. In 2050 the CO_2 emissions from the energy system and industrial processes need to reach the level of net-zero.
- A coherent target for the installations in the EU-28 which are regulated by the European Union Emissions Trading Scheme (EU ETS) would be -58% in 2030 (compared to the 2005 emission levels) and a full decarbonization by 2050.

2. To ensure comprehensive and robust emission reductions, targets for energy efficiency are imperative to set:
   - A target of 38% in absolute primary energy reduction for the period from 2005 to 2030 is in line with the greenhouse gas reduction target mentioned above. Compared to the traditionally used business-as usual-case, the Primes Baseline 2007 (EC 2008), this equals a reduction of primary energy consumption for energy uses by 44%.
   - A first sectoral energy efficiency target should be set for the 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 34% by 2030 (compared with 2005 levels) and 69% by 2050 is appropriate and consistent with the emission reduction targets.
   - A second sectoral efficiency target should be set for the transport sector, e.g. to safeguard the restrictions on the use of sustainable motor fuels. With energy savings of about 23% by 2030 and 55% by 2050 (based on 2005 levels) the transport sector could undergo the necessary transition without exceeding the acceptable consumption level of biomass or novel motor fuels.
3. Renewable energies will be the second key pillar for the necessary emission reductions:
   - A contribution of at least 35% to the total primary energy supply for 2030 is consistent with the medium- and long-term emission reduction target. For 2050 this target should be set close to 100%.
   - 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 70% in 2030 and 100% in 2050.

Compared with the recent proposals for the 2030 target framework it should be highlighted that these are not compatible with a 2°C limit if extremely steep emission reductions beyond 2030, which might lead to the need for disruptive changes, are to be avoided.

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 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 a limited period 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 2015 will not be significantly exceeded in the upcoming years and the natural gas imports will be reduced steadily. In contrast, the gas consumption rises in the Reference Scenario for the next two decades, peaking in 2040 and staying significantly above the 2015 levels until 2050. However, the imports of natural gas are projected to grow steadily in the Reference Scenario.
- 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 92% in 2015 to about 78% by the year 2030 and almost zero by 2050 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 novel motor fuels or sustainable biofuels is one of the major challenges within the issue of energy imports. If it is assumed that international markets for electricity-based motor fuels or new forms of biofuels will develop rapidly, the certification of these fuels will be crucial to ensure the sustainability of the transport sector strategy. An accountable system of certification of sustainability of novel fuel imports will be of key importance if significant imports must be considered after 2030 as projected in the Vision Scenario.
- The total dependency on energy imports decreases significantly in the Vision Scenario from 67% in 2015 to 47% in 2030 and 11% 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 production of the technologies for the emerging capital-intensive energy system ensures added domestic value and jobs. Most of these technologies are, however, global technologies. Only an early roll-out and maintenance of the EU’s role as a lead market can create the necessary competitive advantages.

The implementation of an energy and climate policy framework such as the one outlined by the Vision Scenario requires a broad range of interventions. Key strategic goals for such a transformation 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, lorries 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 and for diesel fuels.
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 international motor fuel supply
   - by setting an analytical, political and regulatory framework to assess and safeguard the environmental effects of novel fuels properly (including the effects from electricity and fresh water us or the direct and indi-

rect land use change) for the domestic supply of biomass as well as fuel 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 and roadmaps 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;
    - hydrogen as a fuel for the end-use sectors (e.g. industries) as well as a balancing option for the power system;
    - 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.);
    - zero-emission technologies for industries with significant process emissions (iron and steel, cement, chemicals, 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-28 especially for the next two decades, which is crucial especially for Central and Eastern Europe. However, the role of gas will decrease significantly, at the latest after 2030, even if hydrogen starts to play a larger role in the energy system of the EU. This will trigger the need for conversion and/or cutback of gas infrastructures. Careful and seriously forward-looking planning for the investments is needed for the gas infrastructures in the years ahead in order to avoid stranded investments on a large scale.
- District heating systems can play a significant role in the decarbonisation of the heat supply for all sectors. These network infrastructures are an important option for integrating heterogeneous sources of renewable or waste heat. The heat network structures must, however, also undergo significant changes to be able to deliver this new function. These changes are relevant with respect to technologies, operations and regulatory issues (third party access, regulation, etc.).
- 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 (Öko-Institut 2010; IEA 2011, 2017). 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:

- Carbon pricing and the EU ETS are central elements 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 even after the current structural reform[16] in a way that in all investments and for all operational decisions the full price of carbon is reflected. A tightened cap and a carbon price floor as well as provisions for continuously safeguarding the integrity of the scheme (e.g. with a view to the future use of offsets) will be of key importance. With the introduction of an emissions trading scheme for aviation, another crucial sector is 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 renewable energies and the long lead-times for the upgrade of infrastructure, the establishment of, to the necessary extent, technology-specific and regionally

[16] It should also be highlighted that the current reform has led to mechanisms (market stability reserve, cancellation provisions) that make companion policies fully additional. The parameterisation of these mechanisms needs, however, significant adjustments.

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 changing patterns of imports (phase-out of fossil and nuclear fuel imports, phase-in of imports for novel fuels, etc.) and the EU's role in supplying transformative technologies for decarbonisation to the global markets will also require a new EU policy approach to its external relations on mainly two tracks:

- The economic ties to traditional energy exporters will loosen in a comparatively short period of time. Clean technology innovation will open new markets abroad but may create the need for technology imports from new sources. These changing relations need to be actively managed.
- Secondly, major imports of, for example, novel fuels to the EU will necessitate new relations with the exporting countries. This includes early engagement with, for example, development aid for countries that currently face major gaps in electricity and/or freshwater supplies. If novel fuels are to play a role in the EU's decarbonisation strategy, major support of these countries is needed for

one or two decades before they will then be able to export novel fuels that can be assessed as sustainable energy supplies to the EU. The creation of a new governance scheme that ensures the sustainability and integrity of the imported novel fuels will be of crucial importance. Furthermore, efforts to diversify these new supplies in order to avoid new dependencies from (new) monopolies or oligopolies should be clearly identified as a field of action to be taken.

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.

Finally, the development of comprehensive, consistent, flexible and learning policies and measures within the framework of the European Union, which contains 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 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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Annex

Table A- 1: Final energy consumption industry, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	32	34	26	14	10	22	17	9	6
Lignite & brown coal	2	3	2	1	1	2	1	1	1
Petroleum products	28	26	20	13	12	22	9	4	2
Gases	87	95	75	68	70	85	50	26	9
Electricity	86	89	90	93	97	82	75	73	73
Heat	15	16	20	21	21	13	14	12	10
Biomass	21	33	37	38	40	24	29	31	34
Solar & geothermal	0	0	0	0	0	0	0	0	0
Hydrogen & synfuels	0	0	0	0	0	0	6	11	17
Others	1	1	1	1	1	0	0	0	0
Total	272	295	270	249	252	250	202	168	151
Share of renewables									
direct	*8%*	*11%*	*14%*	*15%*	*16%*	*9%*	*14%*	*19%*	*22%*
direct & indirect	*18%*	*24%*	*30%*	*34%*	*38%*	*24%*	*47%*	*68%*	*88%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 2: Final energy consumption tertiary sectors, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	2	2	1	1	0	1	1	0	0
Lignite & brown coal	0	0	0	0	0	0	0	0	0
Petroleum products	31	28	23	19	17	28	16	6	0
Gases	49	54	47	44	44	52	32	19	0
Electricity	76	81	89	96	102	78	77	77	72
Heat	9	11	11	10	10	9	7	6	5
Biomass	6	8	8	8	9	6	7	8	10
Solar & geothermal	1	1	1	2	2	1	1	1	1
Hydrogen & synfuels	0	0	0	0	0	0	4	10	23
Others	0	1	0	1	1	0	0	0	0
Total	175	186	179	181	184	176	145	128	111
Share of renewables									
direct	*4%*	*5%*	*5%*	*6%*	*6%*	*4%*	*6%*	*8%*	*10%*
direct & indirect	*18%*	*23%*	*28%*	*31%*	*36%*	*23%*	*48%*	*69%*	*99%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 3: Final energy consumption households, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	8	7	5	3	2	0	0	0	0
Lignite & brown coal	1	1	1	1	0	0	0	0	0
Petroleum products	35	30	25	22	19	26	9	2	0
Gases	97	111	111	111	110	100	52	20	0
Electricity	68	73	77	84	92	74	75	73	63
Heat	21	24	24	25	25	23	19	14	9
Biomass	42	50	43	42	41	39	35	34	32
Solar & geothermal	2	2	2	2	2	3	7	11	15
Hydrogen & synfuels	0	0	0	0	0	0	7	10	9
Others	0	0	0	0	0	0	0	0	0
Total	275	298	288	288	292	265	204	164	128
Share of renewables									
direct	*16%*	*17%*	*16%*	*15%*	*15%*	*16%*	*20%*	*27%*	*37%*
direct & indirect	*25%*	*28%*	*29%*	*30%*	*33%*	*29%*	*55%*	*78%*	*100%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 4: Final energy consumption transport sector, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Diesel	200	190	185	184	181	190	134	44	0
Motor spirit	77	67	55	53	52	67	45	14	0
Kerosene & jet fuels	51	56	58	60	64	56	44	13	0
Heavy fuel oil	1	1	1	1	1	1	1	1	0
Gases	9	10	13	16	19	10	13	7	1
Electricity	5	6	8	11	14	6	32	66	76
Hydrogen & synfuels	0	0	0	1	2	0	2	47	67
Biofuels	14	21	21	21	22	21	15	17	21
Others	0	0	0	0	0	0	0	0	0
Total	359	351	341	347	355	351	286	208	164
Share of renewables									
direct	*4%*	*6%*	*6%*	*6%*	*6%*	*6%*	*5%*	*8%*	*12%*
direct & indirect	*4%*	*7%*	*7%*	*8%*	*9%*	*7%*	*14%*	*57%*	*99%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 5: Total final energy consumption, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Hard coal & coke	42	42	31	17	12	23	17	9	6
Lignite & brown coal	4	4	3	2	1	2	1	1	1
Gas/diesel oil	261	245	229	220	213	240	157	53	1
Motor spirit	78	67	56	54	52	67	45	14	0
Kerosenes & jet fuels	57	61	61	63	67	60	45	13	0
Other petroleum products	33	33	27	22	21	29	15	6	2
Gases	236	263	239	233	235	240	142	70	9
Electricity	236	249	264	284	306	239	260	289	284
Heat	46	51	54	56	57	46	40	32	23
Hydrogen & synfuels	0	0	0	1	2	0	16	33	53
Biomass	83	112	109	109	112	90	85	90	96
Solar & geothermal	3	4	3	3	3	5	8	12	16
Others	1	1	1	1	1	1	1	1	1
Total	1,080	1,131	1,078	1,065	1,083	1,042	833	624	492
Share of renewables									
direct	*8%*	*10%*	*10%*	*11%*	*11%*	*9%*	*11%*	*16%*	*23%*
direct & indirect	*15%*	*19%*	*22%*	*24%*	*27%*	*19%*	*38%*	*65%*	*96%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 6: Net power generation, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	TWh								
Nuclear	813	736	741	698	699	756	172	77	0
Hard coal	430	402	270	110	19	350	163	0	0
Lignite & brown coal	302	292	247	195	184	238	71	0	0
Oil	61	23	18	12	4	22	12	0	0
Gases	492	563	664	992	929	509	660	592	0
Hydro	335	371	374	391	417	371	374	391	417
Wind onshore	299	353	481	556	823	344	664	954	1,172
Wind offshore	0	110	128	136	157	117	669	1,179	1,692
Photovoltaics	102	155	232	293	429	171	462	768	1,091
Concentrated solar	0	0	0	0	0	0	0	0	0
Biomass	144	193	227	243	249	193	295	243	249
Geothermal	6	7	7	7	7	7	7	7	7
Others	58	1	2	5	7	2	6	10	13
Total	3,042	3,205	3,391	3,640	3,923	3,080	3,555	4,221	4,640
Share of renewables									
total	*29%*	*37%*	*43%*	*45%*	*53%*	*39%*	*70%*	*84%*	*100%*
variable	*13%*	*19%*	*25%*	*27%*	*36%*	*20%*	*50%*	*69%*	*85%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 7: Total primary energy supply (excl. non-energy use), 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Nuclear	221	200	202	190	190	206	47	21	0
Hard coal	152	142	98	44	17	111	58	9	6
Lignite	82	78	65	51	49	62	19	1	1
Oil & petroleum products	479	443	410	394	387	433	282	89	3
Gases	362	400	390	436	430	364	276	178	9
Hydropower	29	32	32	34	36	32	32	34	36
Wind	26	40	52	59	84	40	115	183	246
Solar	13	16	22	27	39	18	47	77	108
Biomass	126	164	168	172	177	143	167	162	167
Geothermal	6	1	1	1	1	8	9	9	8
Hydrogen	0	0	0	0	0	0	0	0	0
Synthetic methane	0	0	0	0	0	0	0	0	0
Synthetic fuels	0	0	0	0	0	0	3	43	60
Electricity	1	2	0	0	0	2	0	0	0
Others	10	5	5	5	5	2	2	2	2
Total	1,507	1,522	1,445	1,414	1,415	1,420	1,056	807	646
Share of renewables	*13%*	*17%*	*19%*	*21%*	*24%*	*17%*	*35%*	*63%*	*97%*

Source: Eurostat, DG Energy, Öko-Institut

Table A- 8: Total primary energy imports to the EU-27, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	mln toe								
Nuclear	221	200	202	190	190	206	47	21	0
Hard coal	111	125	102	69	62	78	16	0	0
Lignite	0	0	0	0	0	0	0	0	0
Oil & petroleum products	439	374	362	366	378	363	233	61	0
Natural gas	233	275	295	372	395	240	186	124	0
Biomass	6	7	8	9	10	6	8	9	10
Hydrogen	0	0	0	0	0	0	0	0	0
Synthetic methane	0	0	0	0	0	0	0	0	0
Synthetic fuels	0	0	0	0	0	0	3	43	60
Electricity	1	0	0	0	0	2	0	0	0
Others	0	0	0	0	0	0	0	0	0
Total	1,011	980	968	1,005	1,035	894	494	257	69
Share of imports	*67%*	*64%*	*67%*	*71%*	*73%*	*63%*	*47%*	*32%*	*11%*

Source: Eurostat, DG Energy, Öko-Institut.

Table A- 9: Greenhouse gas emissions by sector, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO_2e								
Power generation	1.05	0.98	0.83	0.75	0.49	0.85	0.53	0.25	0.00
Other energy sectors	0.18	0.18	0.17	0.17	0.17	0.17	0.08	0.01	-0.01
Industry	0.44	0.46	0.35	0.27	0.25	0.37	0.21	0.09	0.03
Households	0.37	0.38	0.36	0.34	0.33	0.31	0.15	0.05	0.00
Tertiary	0.22	0.22	0.18	0.16	0.16	0.21	0.13	0.06	0.00
Transport	1.04	1.00	0.96	0.96	0.97	1.00	0.72	0.24	0.00
CH_4 and N_2O from energy	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.01	0.00
Fugitive	0.09	0.08	0.06	0.04	0.02	0.08	0.06	0.04	0.02
Industrial processes* and product use	0.27	0.31	0.30	0.30	0.29	0.31	0.22	0.11	0.02
Agriculture	0.43	0.39	0.38	0.38	0.38	0.35	0.31	0.28	0.25
Waste	0.14	0.10	0.07	0.05	0.04	0.10	0.06	0.04	0.03
F-Gases	0.23	0.18	0.16	0.16	0.16	0.18	0.14	0.09	0.04
Total	4.51	4.33	3.88	3.62	3.28	3.97	2.62	1.26	0.37
CO_2 mitigation by CCS	0.00	0.00	0.01	0.01	0.15	0.00	0.07	0.16	0.23
Change of emissions									
Total from 1990	-21%	-24%	-32%	-37%	-42%	-30%	-54%	-78%	-93%
Total from 2005	-16%	-20%	-28%	-33%	-39%	-26%	-51%	-77%	-93%
ETS from 2005	-23%	-23%	-33%	-40%	-50%	-32%	-58%	-83%	-99%
Note: * excluding CO_2 emissions from crude steel production from blast furnaces (included in industry sector emissions).									

Source: Eurostat, DG Energy, Öko-Institut

Table A- 10: Greenhouse gas emissions by gas, 2015-2050

	Reference Scenario					Vision Scenario			
	2015	2020	2030	2040	2050	2020	2030	2040	2050
	bn t CO_2e								
CO_2 from energy	3.32	3.24	2.88	2.66	2.35	2.94	1.83	0.71	0.02
CO_2 from non-energy	0.26	0.29	0.29	0.28	0.28	0.30	0.21	0.10	0.01
CH_4	0.46	0.39	0.33	0.30	0.27	0.37	0.28	0.22	0.17
N_2O	0.24	0.22	0.22	0.22	0.22	0.20	0.16	0.14	0.13
F-Gases	0.23	0.18	0.16	0.16	0.16	0.18	0.14	0.09	0.04
Total	4.51	4.33	3.88	3.62	3.28	3.97	2.62	1.26	0.37
Change of emissions									
Total from 1990	-21%	-24%	-32%	-37%	-42%	-30%	-54%	-78%	-93%
Total from 2005	-16%	-20%	-28%	-33%	-39%	-26%	-51%	-77%	-93%
ETS from 2005	*-23%*	*-23%*	*-33%*	*-40%*	*-50%*	*-32%*	*-58%*	*-83%*	*-99%*

Source: Eurostat, DG Energy, Öko-Institut