FULL REPORT

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BLUEPRINT GERMANY

A strategy for a climate safe 2050

Final Report

Blueprint Germany

A strategy for a climate-safe 2050

A study commissioned by

WWF Deutschland

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Basel / Berlin,
October 15, 2009
31 - 6853

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1977

Activity
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Summary

Drastic reductions of anthropogenic greenhouse gas emissions worldwide by 2050 are needed to limit the rise in the global temperature to 2°C above pre-industrial levels. An international roadmap towards such reductions will succeed only if industrialised nations lower their emissions enough to give emerging nations some “wiggle room” in their greenhouse gas allowances to further develop their economies and increase prosperity.

To achieve such a target by 2050, Germany would have to reduce its greenhouse gas emissions by some **95% from 1990 emission levels**, which would mean per-capita emissions in 2050 of less than one metric ton of greenhouse gases.

This study examines possible greenhouse gas emission trends and—taking into account aspects of political strategy and what is technically and economically viable, and with a view to key policy approaches—formulates responses to the challenge of what can and must be done on a technical level and what the appropriate policies should be.

Two detailed quantitative scenarios have been developed, each supported by a model: a reference scenario reflecting an ambitious pursuit of current energy and climate protection policies, and an innovation scenario based on the transformation to a low-carbon emission society with a 95% reduction target. Each scenario examines the generation of electricity in options with and without carbon capture and storage (CCS). A third part of the project outlines additional initiatives that ensure targets can be reached. All scenarios and options are based on current laws pertaining to the life cycles of nuclear power plants.

Demographic and economic trends in Germany are the core points of departure in developing the scenarios. The **population** declines by 12.5% from 2005 to 2050 despite average net annual migration of some 150,000 people. The size of households shrinks as the trend towards one- and two-person households continues, while the average per-capita living space expands for an overall increase in populated area of nearly 9%. The real **gross domestic product** (GDP) in 2050 is about one third higher than that of 2005.

The **reference scenario** models an ambitious pursuit of current energy and climate protection policies. Existing energy policy tools involving energy saving, renewable energies and combined heat and power are continued. Building standards are gradually tightened, with increased use of renewable energies to generate heating in new and existing buildings. Efficiency technologies are developed consistently and effectively and spread quickly through the market.

The specific consumption of motor vehicles is further decreased. The automobile market sees the gradual introduction of hybrid vehicles, plug-in hybrids and electric cars. The addition of biofuels is mandated. Great strides continue to be made with regard to renewable energies: The price of electricity generated from thin-film solar cells continues to fall; the output of wind farms becomes more reliable as short-term forecasting improves; biomass processes become moderately more efficient; and more biogas is fed into the natural gas network.

These combined technological developments and political tools can lead to a reduction in greenhouse gas emissions by some 45% between 1990 and 2050. Per-capita emissions of all greenhouse gases are still about 9 metric tons in 2050. Cumulative greenhouse gas emissions (expressed as an emissions budget) for the period from 2005 to 2050 come to about 38 billion metric tons.

The **innovation scenario** focuses on the emission reduction targets and on additional guidelines (restrictions on the use of biomass, etc.). Key strategies were developed in response to the results of the reference scenario:

- The space heating demand is reduced to nearly zero. The energy demand of new buildings falls nearly to zero and the energy-saving refurbishment rate doubles in conjunction with ambitious renovation targets.
- A large share of the growing freight transport services are shifted to rail. A consistent trend towards electrification in (motorised) passenger transport is assumed, initially through hybrid vehicles, followed by plug-in hybrids and finally fully electric vehicles.
- Except for remnants of natural gas and liquefied petroleum gas, motorized freight transport and personal transport cease to use fossil fuels in favour of very efficiently produced second- and third-generation biofuels.
- There is an innovation offensive in technological development, especially in materials and processes.
- The technical changes lead to a re-organisation of markets, a strengthening of the trend towards services and a slight shift in industry structures.
- In the option without CCS, 84% of electricity demand is covered by renewable sources in 2050. In the option with CCS, that figure is 66%.

Under these conditions, the emission reduction is approx. 87% in the period from 1990 to 2050. Per-capita emissions of all greenhouse gases are about 2.2 metric tons in 2050, with per-capita CO_2 emissions at 1.6 metric tons. Total cumulative greenhouse gas emissions for the period from 2005 to 2050 are approx. 26 billion metric tons.

This background highlights the need for additional measures that in some cases go beyond the underlying guidelines of the innovation scenario and pave the way for a "**Blueprint Germany**" that achieves a 95% reduction in 1990 emission levels by 2050. Total per-capita greenhouse gas emissions are 0.9 metric tons in 2050, offsetting remaining greenhouse gas emissions against additional net CO_2 reductions created from CCS in biomass (-0.4 metric tons of CO_2 per person). Total cumulative greenhouse gas emissions in this model are about 24 billion metric tons between 2005 and 2050.

Reference scenario:

- The major emission reductions are achieved through the various energy efficiency measures. This accounts for some 46% of overall emission reductions by 2050, with critical contributions primarily from improved efficiency in the building sector and industry.

- 29% of overall emission reductions comes from the use of renewable energies.

Innovation scenario:

- 27% of additional emission reductions are achieved from increased energy efficiency. Massive increases in the efficiency of electrical appliances are critical here, representing about half of the overall contribution from additional energy efficiency.

- Additional emission reductions stem primarily from a greatly expanded use of renewable energies, accounting for 37% of total additional emission reductions. A further 7% is attributable to the indirect effects from the electrification of transport (which in the innovation scenario can also be interpreted as a contribution to renewable energy).

- The replacement of fossil energy sources is another significant source of additional emission reductions, accounting for 13%.

- CO_2 reduction programs account for some 4% of additional emission reductions.

Additional benefits of the "Blueprint Germany" option:

- The sizable base of remaining industrial CO_2 emissions can be further reduced to a significant extent by the comprehensive application of CCS to the relevant industrial processes (pig iron production, cement production).

- The rest of the heat needed for the industrial processes and the remaining need for natural gas and fuel oil in the service sector can be covered by the use of biomethane. This would achieve a significant further reduction in emissions, but given the limited capacities, it would also require integration into a comprehensive biomass strategy or complementary initiatives in the transport sector.

- The widespread replacement of conventional fuels with biofuels in aviation can yield significant additional emission reductions.

- Moving CO_2 from biofuel production into geological formations (biomass CCS) offers another option for reducing CO_2.

The **innovation scenario** yields approx. equal reductions in overall emissions (cumulative effects of the reference and innovation scenarios) from increased energy efficiency and the expanded use of renewable energies (each of the magnitude of 35% by

2050). Other key factors include the change in fossil energy sources (9%), emission reductions in industrial processes (6%) and soil and forest initiatives (2%). All other measures (agriculture, etc.) together account for 12% of overall emission reductions.

About half of overall additional emission reductions in the innovation scenario and some two thirds of energy-dependent emission reductions by 2050 are attributable to programs focusing on **capital stock with an especially long lifespan** (buildings, power plants, infrastructures, etc.). Here it is especially important to introduce the appropriate climate protection measures early on. Programs that still require significant **innovations** over the coming years (technology, costs, system integration) also account for about half of the emission reductions taking effect by 2050 under the innovation scenario.

A comparison of the innovation and reference scenario s shows **maximum overall economic net costs** of nearly €16 billion (about 0.6% of GDP) in 2024, decreasing thereafter. Cumulated over the entire period of the study (and based on a discount rate of 1.5%), this yields costs of about 0.3% of GDP. Savings outweigh investments starting in 2044. The total costs of electricity production in the reference and innovation scenarios, when viewed over the entire period of the scenarios, do not differ significantly.

An analysis of the innovation scenario with the additional potential outlined in the "Blueprint Germany" yields the following **strategic guidelines** to reach the stated objectives:

- Reduction of overall **greenhouse gas emissions** of 40% by 2020, 60% by 2030, 80% by 2040 and 95% by 2050 (based on 1990 emission levels)
- Annual improvement of 2.6% in overall economic energy productivity
- Increased share of **renewable energies** in the overall primary energy mix to 20% by 2020, 35% by 2030, 55% by 2040 and over 70% by 2050

Strategic guidelines for the various sectors are also recommended to monitor targets and progress.

Among the various greenhouse gas reduction options, ambitious climate protection strategies must also take into account a series of systemic relationships and interactions that are key to designing strategic climate protection and energy policies:

- Significant efforts to reduce emissions must be undertaken in **all sectors**. Initiatives in the electricity sector (demand and production), building sector (new and existing construction), passenger cars, freight transport by road, aviation, industry (including process emissions), agriculture, land use and forestry are of particular importance given the magnitude of the contributions required from these sources.
- The emission reduction targets by 2050 cannot be achieved without major progress in **energy efficiency** and a simultaneous massive increase in the share of **renewable energies**.

- Progress in a series of key emission reduction options is inextricably **linked to complementary options**. Without a systematic strategic approach, the envisioned reductions could fail:
    - The electrification of passenger cars is inextricably linked to both the development of additional options for electrical generation based on renewable energies (or CCS) and the creation of smart power distribution grids.
    - The large-scale use of biofuels in road and aviation is inextricably linked to the availability of biofuels that meet high standards of sustainability.
    - The use of decentralised efficiency technologies that are run initially on natural gas (such as decentralised combined heat and power) and the changeover in industrial process heat production to renewable energies require the medium- to long-term availability of significant quantities of biomethane to be fed into the natural gas networks.
- The introduction of new options for generating electricity and the creation of capacities to shift to more efficient modes of transport require long-term forward planning in **infrastructure development** (transport and distribution networks, CCS infrastructure, rail network).
- At least two key emission reduction options—the use of biomass and the introduction of CCS—have limited potential and require taking an active approach for **strategic resource management**.
- The climate-friendly restructuring of the energy and transport systems requires significant improvements in efficiency in how energy-intensive **products and materials** are used.

The following strategic approaches are of particular long-term importance to the **policy implementation tools**, whose focus and design will and must change over time:

- Ensuring **competitive markets** and an adequate **diversity of players** is key to developing robust and efficiently crafted climate protection policies.
- Policy implementation programs in all sectors must also promote a continuous and targeted **process of innovation** that delivers the fastest possible market viability for climate protection options.
- Attaching a significant **price** to greenhouse gas emissions is a necessary foundation for ambitious and successful climate protection policies.
- **Market structures** (such as the fluctuating feed-in of large quantities of electricity from renewable energies) should be incrementally adjusted to ensure their compatibility with climate protection options with a significant solution potential.

- Regulatory approaches are useful and necessary for highly **homogeneous** technologies and climate protection options requiring special support mechanisms.

- A proactive legal stance should be taken to ensure that certain market trends in the area of long-term capital stock do not lead to **dead-end situations** that obstruct the achievement of ambitious climate protection targets over the long term.

- The creation of a robust and sustainable **energy efficiency market** is essential for a broad and effective increase in energy efficiency.

- The development of **infrastructures** for restructuring the energy and transport systems requires long-term forward planning, so organising and advancing such development necessarily entails considerable uncertainties. This engenders a special (new) field of government responsibility and oversight.

Finally, an “integrated climate protection and energy program 2030” is developed to provide a legal framework for long-term climate protection policy, comprehensive climate policy tools, comprehensive tools to increase energy efficiency, innovation- and infrastructure-specific measures and a broad portfolio of sector-specific initiatives.

I Project description

1 Background and questions to be answered

1.1 Background

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 1 metric ton of CO_2 equivalent per capita per year, and must be stabilized there [Ecofys 2009]. The target time frame generally mentioned for the change is 2050. Today the emission levels of all industrialised countries are many times this figure. Mean emissions in Germany are currently about 11-12 metric tons per capita per year. Even some emerging countries have significantly exceeded the "limit level" in their process of catching up economically and industrially; only India is still below.

The latest research findings [Meinshausen et al. 2009] indicate that for the period from 2005 to 2050, the remaining global budget is approx. 800 billion metric tons for CO_2 emissions, and 1,230 billion metric tons of CO_2 equivalent for all greenhouse gas emissions, if there is to be a sufficient probability (75%) that the increase in mean global temperature over pre-industrial levels can be kept to less than 2ºC. Hence a rapid, sharp, sustainable reduction is indispensable, especially among large emitters. If an international agreement in this regard, including today's emerging economies, is to have a chance of implementation, the industrialised nations must commit to significant emission reductions. Moreover, they must provide the technologies to make these reductions possible.

In Germany, the task of greenhouse gas reduction has been on the political agenda since at least the federal government's first resolutions of 1990. The following medium-term targets have been adopted to date:

- 1990: Reducing CO_2 emissions in the Western German states 25% against 1987 levels by 2005, and more in the Eastern German states; this target was replaced by the 1995 target definition (and also was not achieved);

- 1995: Reducing CO_2 emissions 25% from 1990 levels by 2005; this goal was not achieved;

- 1997: Reducing greenhouse gas emissions (not including international aviation and shipping, and also not including most of the net emissions from land use and forestry) by 21% for mean emissions in 2008 through 2012, compared to the base year (1990 for carbon dioxide, methane and nitrous oxide emissions, 1995 for fluorinated greenhouse gas emissions) as part of EU Burden Sharing; this goal is expected to be achieved;

- 2007: Reducing greenhouse gas emissions 40% from 1990 levels by 2020, with concrete sub-targets for the CO_2 emissions covered by the EU emission trading system, the other greenhouse gas emissions, energy efficiency and renewable energy sources.

To date a number of energy policy and climate policy measures have been taken in the effort to achieve these targets. The German government's current Integrated Energy and Climate Program (IEKP) addresses numerous individual areas of energy consumption and generation, setting interim targets and applying a variety of instruments, from administrative law to subsidies for model projects. A number of policy instruments (the EU emissions trading system, consumption standards for vehicles and other equipment, etc.) are being implemented at the European Union level.

Current scenarios and forecasts for the German energy system by roughly 2030/2035 (e.g., [Prognos 2007], [Öko-Institut et al. 2007, 2009]) show that it may be possible to achieve this goal with the existing tools and others updated using a similar philosophy.

The energy system is rather 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 into 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.

WWF, as an environmental organisation that operates worldwide, has taken on the task of working out the specific details of a targeted 95% reduction in greenhouse gas emissions in Germany by 2050, stating the requirements for how the energy system, technologies, the economic structure and lifestyles must evolve over time. This is associated with the question of what choices of direction, strategies and instruments are needed in energy policy and other policy contexts, and what kind of global setting will be necessary in order to achieve such a goal.

WWF commissioned a consortium made up of Prognos AG, Öko-Institut e.V. and Dr. Hans-Joachim Ziesing to develop a long-term scenario for this objective and the related policy questions to be answered. The current conditions in Germany were to be taken as a basis. Changes in requirements and systems were to be compared, where possible, with the course of structural changes to date.

1.2 Questions to be answered

It is possible to reduce greenhouse gases 95% by 2050 in a highly industrialised country where a substantial percentage of electricity is generated from coal?

- What technical requirements must be met to achieve that goal?
- How will such requirements affect the country's economic structure?
- How must the global context be organised to make such a change possible?
- Will people have to change their ideas about patterns of living and consumption?

This study addresses such questions, providing a basis for societal debate.

The investigation is pursued in three phases:

If it is to be possible to estimate how far the target of a 95% emission reduction from 1990, posited as "Blueprint Germany," differs from the political, energy-policy and technological road taken so far – in other words, to determine where significant changes of course are needed if the targets are to be achieved – a reference development scenario is needed. This "reference scenario" is developed and calculated to 2050 on the basis of current reference development scenarios (both those produced for the 2007 energy summit [Prognos 2007], and others [Prognos 2009 a], [Prognos 2009 b]). In the next step, a scenario is developed and calculated that aims for a roughly 95% reduction in greenhouse gases by 2050, compared to 1990 levels. The emphasis here is on energy-related CO_2 emissions. The starting point here is today's situation, with the data from the current energy balance sheet. The scenario is intended to demonstrate whether technical developments and equipment conceivable today would make it possible to achieve this reduction, and what kinds of steps would be needed along what kind of time track. This scenario is called the "innovation scenario" here.

In terms of power generation, the innovation scenario assumes a consistent strategy of expanding renewable energy sources until 2050. Such a development depends on numerous assumptions, including technological developments, market penetration, and acceptance by the population. As there is some potential for uncertainty here, the scenario was also broken down into options with and without the carbon capture and storage (CCS) option. This option is currently thought to have great potential for solving problems, at least during a transitional period of one to two generations of power plants. But it is not possible to estimate whether and at what date it will be implemented in all steps. So it is also necessary to think the situation through without this option. In essence, both options require strategies with a long-term orientation, and are not readily interchangeable. For that reason, these options are worked out for both the reference scenario and the innovation scenario.

It is assumed that the phase-out of nuclear energy will continue as currently decided.

The Reference and innovation scenarios are developed and analysed on the basis of the Prognos bottom-up energy system models. In addition, Öko-Institut mapped and quantified the other greenhouse gas emissions in the other sectors where they arise. In the event that the innovation scenario cannot be achieved with the adopted strategic assumptions and quantity structures, the interfering factors and their principal causes are to be identified. On a more fully aggregated level, further packages of measures are proposed to close the gaps.

The results of these two scenarios – the reference scenario and the innovation scenario – are compared with one another. That comparison is taken as a basis for deriving policy strategies, with estimates about how deeply the necessary instruments must intervene. For this purpose, the components of the results are broken down with reference to various factors influencing the reduction of emissions – such as improving efficiency, renewable energy sources, replacing energy sources, innovative technologies, long-term and short-term investments. This breakdown into components is supplementarily overlaid over the results of the bottom-up modelling, using a top-down method.

1.3 Execution

The scenarios for the energy system were set up by Prognos AG, which also performed the model calculations. Öko-Institut calculated the greenhouse gas emissions for the other sectors (process emissions, waste management, agriculture, land use). The bottom-up preparation of the emission scenarios was then supplemented by a top-down analysis of the various components of effects, in a joint effort by Öko-Institut and Dr. Ziesing. On the basis of these analyses, the assumptions behind the scenarios, and the results, Öko-Institut and Dr. Ziesing drew conclusions for a strategic approach to a long-term climate policy. For the period up to 2030, Öko-Institut and Dr. Ziesing then developed a package of measures for an integrated climate and energy program to 2030, incorporating core policy tools for the first phase of implementation to achieve the long-term targets.

2 Method and organisation of Project

2.1 Boundaries, determining the emissions balance

The model calculations on energy consumption and energy-related emissions were performed using the bounds set for the national energy balance and the national greenhouse gas inventory. This means that direct, energy-relevant processes and types of use were tracked for four consumer sectors: residential, services, industry and transport. The energy inputs for power generation apply on top of these, as well as district heat generation and its fuel-based emissions, other conversion sectors (such as refineries producing fuels) and non-energy-related consumption. Relationships to per capita emissions were calculated on the basis of this national computation of energy and emission balances, taking national value-added processes into account. No allowance was made for process chain balancing or "grey energy" considerations. In the logic of international inventories, "grey emissions" generated beyond a country's borders and imported with products are attributed to the country from which they are imported. An analogous approach is taken with the goods exported from Germany; their production emissions are attributed to Germany.

Aircraft fuels are reported attributing emissions to the location where an aircraft fuels up; domestic aviation can be extracted.

For transport, this domestic concept based on fuel sales in Germany is similarly applied.

The data are updated to 2007 from current databases, wherever available, and at least up to 2005, the base year for the quantitative considerations.

Since this study is concerned with the energy consumption that is relevant to the greenhouse gas inventory, non-energy uses of primary energy sources are not considered. Hence primary energy consumption differs by this sector from the system used for the primary energy balance sheet. Accordingly, the total primary energy consumption is also lower for the past than is shown in the energy balance sheet.

2.2 Models

Prognos works with multiple models in its analyses, scenarios and forecasts concerning long-term energy consumption. Specifically, these are models:

- For changes in population and households,
- For overall economic development and the structures of economic sectors,
- For final energy consumption in households, in the commercial, retail, services and military sector, in industry, in transport, and in non-energy consumption,

- For changes in the conversion sectors for power generation and district heating,

- For determining emissions associated with energy use.

2.2.1 Bottom-up models for demand sectors

The analyses and forecasts for final energy consumption are based on a modular model system. This summarises the estimates made in the individual demand modules for energy consumption in the residential, service, industry and transport sectors.

The sector modules are robust bottom-up modules that reflect final energy consumption by sector and by energy source, on the basis of suitable lead variables described in further detail below, and that then extrapolate this consumption into the future on the basis of scenarios. Using bottom-up models makes it possible:

- To analyse developments already observed in the past as to the details of their causation,

- To make concrete assumptions about the future development of technological or socio-economic parameters, and thus discover the detailed ways in which alternative assumptions about the development of technological advances, demographics, economic growth, and economic structure will affect energy consumption,

- To take account of the changes in the capital stock relevant to energy consumption (such as heating systems, inventory of passenger cars) that are needed for long-term forecasts,

- To take due account of variations in parameters (policy measures) in scenarios and in calculating options,

- To investigate the impact of energy policy measures and their cost.

The effects of changes in energy prices (including tax measures) on energy consumption are estimated using econometric methods (elasticity approach) and integrated into the bottom-up models.

2.2.1.1 Residential

Energy demand in the residential sector is analysed and extrapolated into the future on the basis of a differentiation among uses for space heating, hot water, cooking and consumption by electric household appliances.

The sub-module of space heating for the residential sector is composed of two elements, the housing stock model and the energy demand model.

In the housing stock model, living space is differentiated and calculated by building type (single-family homes, duplexes, multi-unit dwellings), building age group, and heating structure broken down by energy source. For this purpose the model makes specific assumptions about additions of living space and their heating structure, and disposals of living space (broken down by type of building and building age group). In a substitution matrix, additional assumptions are made about replacing one heating system with another. The lead variables for the extrapolation of living space are population and assumptions about the development of average living space per capita. The energy performance standard of living space is modelled using thermal output demand specific to the class of building and building age group, and those needs in turn change due to additions, disposals, and energy-saving refurbishment of existing living space. In the energy demand model, the results of the housing stock model are aggregated and linked with heating systems (single-space heating or central heating, broken down by energy source) by way of hours of full use and utilisation ratios (the latter are mapped on an annual basis using cohort models). The result is the useful energy consumption and final energy consumption for space heating, broken down by energy source.

The central lead variables are projected forward for forecasts and scenarios. In addition to the building-specific inputs mentioned above, assumptions must be made about the development of specific thermal output needs in new structures, the frequency and efficiency of upgrades of existing stock, access to heating systems, and about those systems' utilisation ratios and average service lives.

The analyses, forecasts, and formation of scenarios of energy consumption for domestic hot water are based on a separate sub-model. Findings derived for the future are based on assumptions about the population's per capita useful energy consumption. Here there is a coordination with the space heating module, because in some centrally heated residences domestic hot water is heated in combination with the central heating system. Decentralised water heaters are used in homes heated with single-room heaters. For future projections, further assumptions must be made about the percentages of hot water heating coupled to furnaces, the energy structure of decentralised water heating, and the efficiency of the water heating systems.

Energy consumption for cooking is modelled by multiplying the average energy consumption of a stove by the number of stoves, which in turn is a function of the number of households and the number of appliances with which households are equipped. The figures are broken down by energy source (electricity, gas, coal/wood).

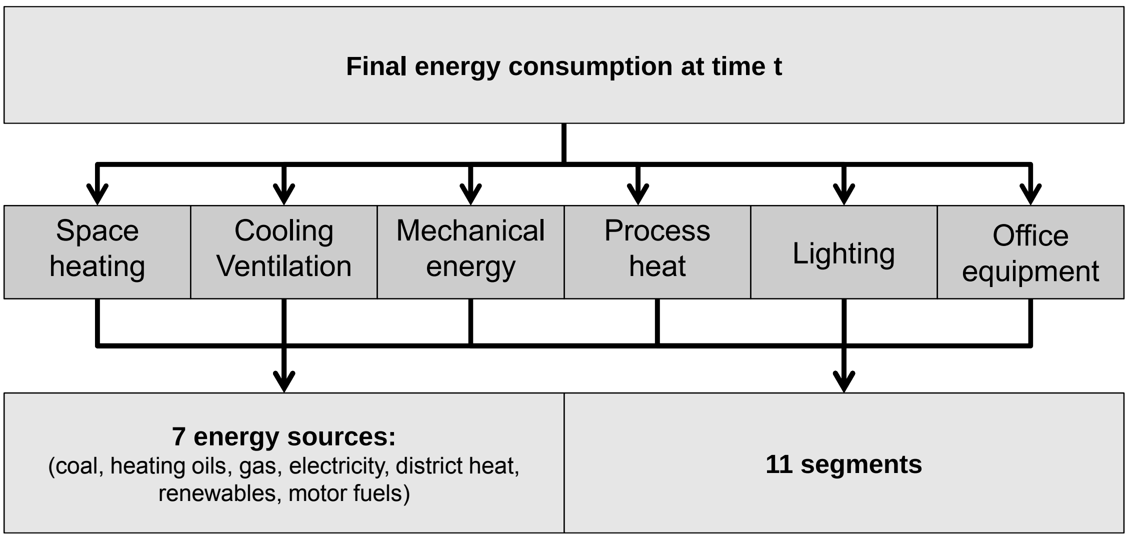
Electricity consumption for electric household appliances is determined from the numbers of appliances in the residential sector and the appliances' specific power consumption. For future projections, assumptions are made about the future development of appliance-specific power consumption, future numbers of appliances in the residential sector, the average service life of appliances (cohort models for refrigerators and freezers, washing machines, dryers, dishwashers, electric stoves, televisions).

2.2.1.2 Commerce, retail and service sector

The commerce, retail and service sector is abbreviated to "services" or the "service sector" below. Energy consumption in the service sector is modelled on the basis of a breakdown by type of use, energy source, and segment (see Figure 2.2-1). The types of use considered are space heating; cooling and ventilation; mechanical energy (power applications), process heat, lighting, and office equipment. Because the service sector is so heterogeneous, it is broken down into 11 segments: agriculture and gardening, small industrial and craft businesses, the construction industry, retail, the credit and insurance industry, transport and communications, other private services, healthcare, education, public administration and social insurance, and defence and military. Energy sources are broken down among coal, heating oils, electricity, district heating, renewable energy sources, and motor fuels.

Energy consumption is calculated individually for each type of use and energy source, and for each segment. Thus the energy consumption for a year is composed of 462 individual components.

Figure 2.2-1: Breakdown of final energy consumption in the service sector by type of use, energy source and segment



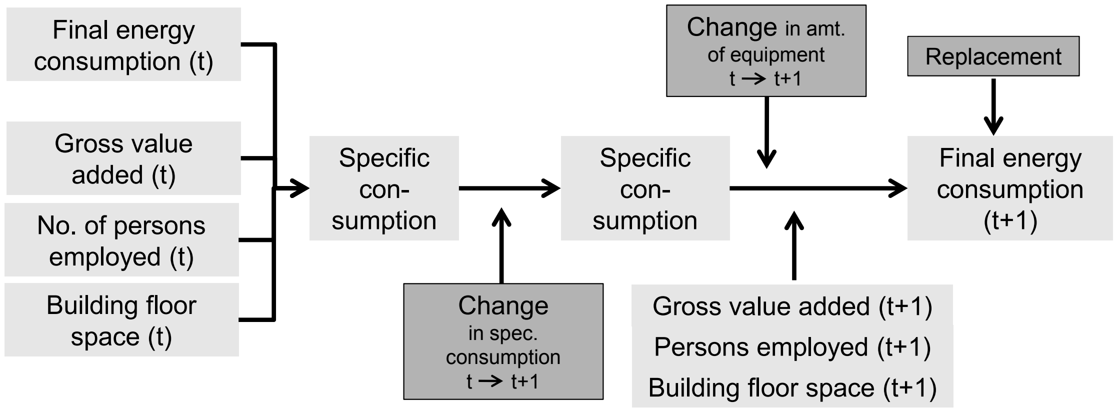
Source: Prognos 2009

The energy consumption for space heating is extrapolated on the basis of the development of employment and a space indicator (change in floor space per employed individual), because in contrast to the household sector, only gross figures on floor space are available for some dates, and there are no directly usable data for additions and disposals (of heated space). The renewal rate in this sector is significantly higher than in residential buildings and the residential sector. The models take this into account.

Energy consumption for other uses is extrapolated in annual steps from a base year onwards, using quantity indicators (number of persons employed, value added, amounts of machinery, installations, office equipment, etc.) and assumptions about technical and energy performance standards. Figure 2.2-2 illustrates the principles of the approach.

Based on the energy consumption in one year, the specific consumption per quantity indicator is calculated (e.g., energy consumption per billion euros). The choice of the quantity indicator is based on the type of use and the segment. For example, process heat is associated with gross value added as the quantity indicator, and lighting is associated with building area. The resulting specific consumption is corrected for the development of efficiency. This in turn is specified exogenously for each segment, energy source and type of use. This corrected specific consumption is multiplied by the change in the associated quantity indicator. Additionally, changes in the stock of equipment are included in the calculations. This yields the energy consumption for the next year. This calculation step is carried out individually for each type of use, energy source and segment. In addition, substitutions of energy sources can be taken into account after this step.

Figure 2.2-2: Projection of final energy consumption in the service sector

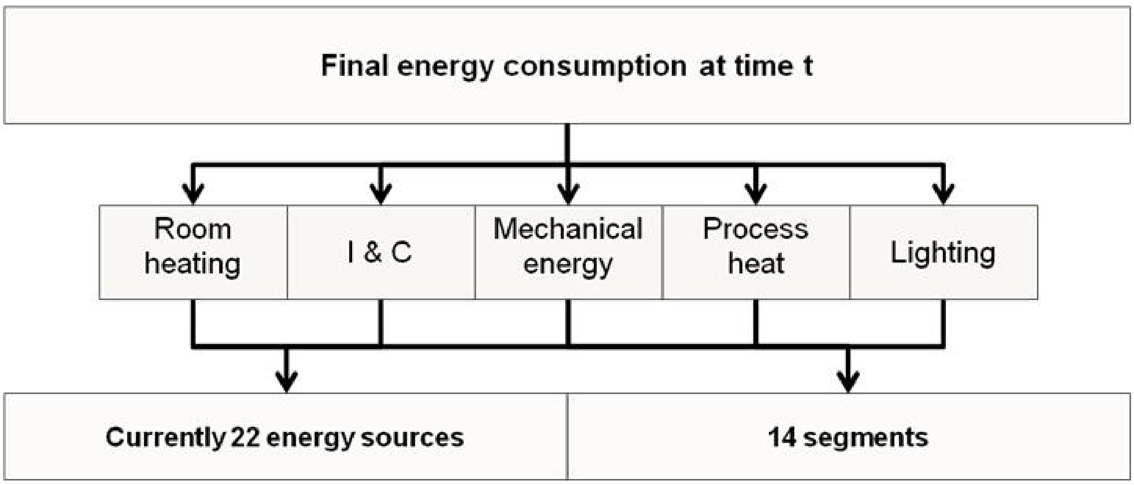


Source: Prognos 2009

2.2.1.3 Industry

In the industry sector, distinctions are made among type of use, energy source and segment. The types of use under consideration are space heating, information and communication (I&C), mechanical energy, process heat and lighting.

Figure 2.2-3: Breakdown of final energy consumption in the industry sector by type of use, energy source and segment

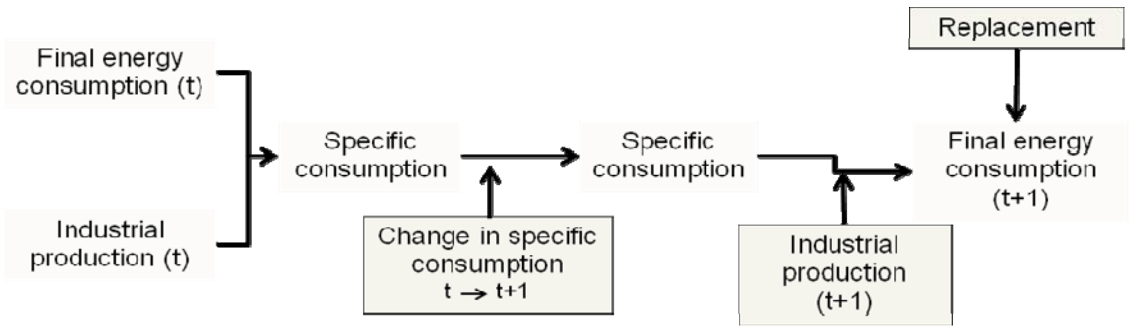


Source: Prognos 2009

The breakdown by energy source and segment follows the breakdown in the energy balance sheet. Currently the industry model takes account of 22 different energy sources and 14 industry segments (see Figure 2.2-3).

Final energy consumption in industry is calculated on the basis of the differentiated estimation of development in the various segments, on the basis of their production. For the especially energy-intensive segments (such as steel production), physical quantity figures are also taken into account (such as steel produced).

Figure 2.2-4: Projection of final energy consumption in the industry sector



Source: Prognos 2009

Based on energy consumption (according to the energy balance sheet) in one year, specific consumption (PJ/billion EUR) is formed on the basis of industrial production, which is used as a quantity indicator (see Figure 2.2-4). The development of the efficiency of specific consumption categories is added in. This first of all takes account of the energy source, type of use, and segment. It also reflects technological developments (such as the introduction of cross-application technologies in electric motors for force applications) and their improved efficiencies. Depending on the emphasis in the individual segments' production and processes, developments of specific fuel and electricity consumption vary over time. Together with the change in industrial production as a quantity indicator for the subsequent year, these yield the energy consumption for that year. These calculation steps are carried out for each type of use, each energy source, and each segment. Then final energy consumption can be further corrected for a substitution among energy sources. These substitution relationships can also reflect energy policy strategies.

2.2.1.4 Transport

The transport module distinguishes among road, rail, air and inland navigation, as modes of transport, and between freight and passenger transport. The lead variables in the energy consumption forecast for the transport sector are the expected transport volume in freight and passenger transport, changes in the modal split among modes of transport, and changes in capacity utilisation (freight transport) or occupancy rates (passenger transport).

For future projections, specifically, assumptions are made about existing equipment and its technological and energy performance standards (cars, buses, motorized two-wheeled vehicles and utility vehicles), about service life, and about the speed of implementation of new vehicles. These assumptions are reflected in the specific consumption of the individual vehicle categories. Additionally, assumptions are made about future usage and organisational changes (e.g., mobile management, traffic flow control, fleet management) and about energy source substitution among modes of transport (e.g., changing from diesel to electricity for rail, and from gasoline to diesel or gas for passenger cars).

Energy consumption for transport is calculated using the domestic consumption concept, as is common practice in energy balances.

2.2.2 Modelling the power plant fleet

2.2.2.1 Functioning of the power plant model

The power plant fleet in Germany was modelled using Prognos AG's European model for fleets of power plants. This model, in which all relevant technical and economic parameters of the power plant fleet are stored, takes account of (conventional) power plants (30 MW and above) and their power generation in the 27 EU countries. The model currently has a time horizon to 2050.

In the model, the future development of capacity in the German power plant fleet is based on annual power demand and the development of maximum demand (peak load). The basic principle is to ensure that loads are covered at every point in the year. The input quantities for power demand are therefore not only the total annual quantity of power in demand (energy), which derives as an external input from the sector's demand models, but also the change in power demand over time (load curve). In the modelling process, the load curve is adjusted according to the development of overall power demand, and matched with firm generating capacity on an hour-by-hour basis.

The development of capacity to cover electricity demand in the power plant model takes account of the usual downtime for maintenance and repair of conventional power generating facilities, as well as the fluctuating levels of power generated from wind and photovoltaic sources. These effects, which reduce the availability of installations, are incorporated into the model as type-specific deductions from installed capacity. For covering peak loads in particular, the remaining available (firm) installed capacity is then the deciding criterion. For conventional power plants, the availability, and thus secured capacity, of 85% of the installed capacity is used as an experience-based figure for the usual repair and maintenance cycles for all installations together. The following percentages of installed capacity are assumed to be fixed in the calculations for renewable sources:

- 85% for geothermal,
- 85% for biomass,
- 50% for hydroelectric,
- 10% for wind energy, and

- 1% for photovoltaics.

The model also includes future intensified measures to balance out power supply and power demand over time, for example by expanding power storage capacity and through load management. In terms of modelling technique, this is done with an according increase in the available capacity of the power plant fleet.

In modelling power generation, the use of conventional power plants is based on the associated load demand, and follows rginal cost logic (merit order). Accordingly, the power plant with the lowest marginal cost runs the longest over the course of the year; all other power plants are ranked according to their marginal cost until the load is covered for the full year. Here the last power plant to be used (with the highest marginal cost) determines the price. The development of prices for fossil energy sources and for CO_2 is specified exogenously.

Power generation from renewables (wind power, photovoltaics, biomass and geothermal) is not subject to the marginal cost logic described above, because financial subsidies ensure its cost-effectiveness. In the model, these systems contribute to power generation in accordance with their available capacity and the exogenously specified full use hours, and thus reduce the load to be covered by conventional power plants. Since generation from wind power and photovoltaic sources fluctuates, this compensation is applied on an hourly basis.

The opting-out of the peaceful use of nuclear power (“nuclear power phase-out”) in Germany is taken into account in the model according to the law’s requirements for decommissioning nuclear power plants. Decommissioning of fossil-fuel fired power plants is handled automatically in the model as soon as the specified service life of the given type of power plant has been reached. Depending on the scenario framework, it may happen that power plants cease to be cost-effective even before their technical service lives are over because of the service times indicated by the merit order (see paragraphs below). In that case their generation is subtracted from the fleet in accordance with the merit order.

The need for additional conventional power plant capacity (need for new buildings) is determined on the basis of the highest expected load from the current year and the supply available in each case (power plant fleet and renewables). Combined heat and power plants and renewables are automatically incorporated into the model on the basis of exogenous inputs (expansion scenarios). Their rising contribution to secured capacity is deducted from the demand for new buildings. The remainder is covered by conventional power plants selected according to the criterion of cost-effectiveness (maximum return on equity). Fifteen types of power plants are distinguished according to their fuel and type of operation. For (potential) new capacity coming into the fleet, first a position in the merit order is determined, and the revenue and cost situation is then calculated on that basis. The power plant with the highest total return over the next few years is included in the model.

The power plant model also calculates the annual full cost of conventional power generation on the basis of the adopted technical and economic parameters. These costs are a function of the exogenously specified prices of fuel and CO_2, the efficiencies of each power plant, the investment cost, and the fixed and other, variable operating costs of the individual plants within the fleet.

The CO_2 emissions associated with power generation result from the total fuel input, broken down by energy source for all power plants, in conjunction with the emission factors for the individual fuels. Where power plants use carbon capture and storage (CCS), the achieved emission reductions are taken into account.

2.2.2.2 Status quo of the German power plant fleet

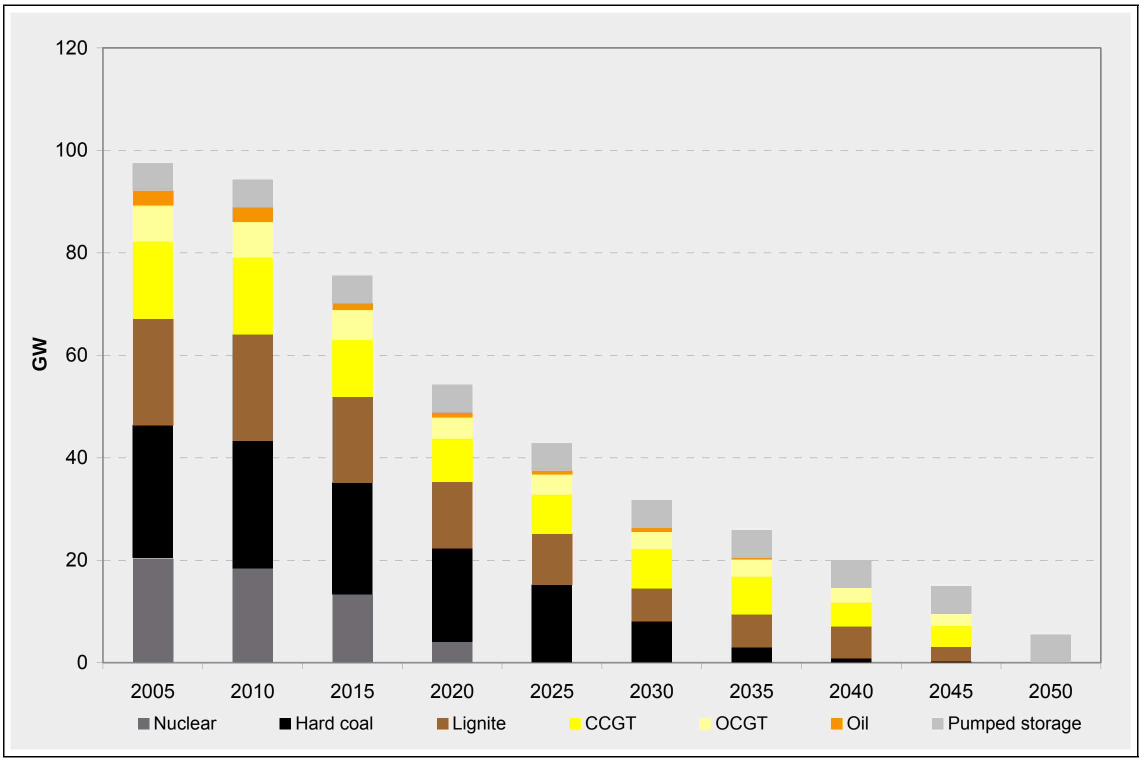
In 2005, the installed net capacity of conventional power plants in Germany came to about 93,400 MW. Of this figure, about 28,000 MW was from hard coal-fired plants, 20,000 MW was from gas-fired and gas and steam power plants, and about 20,000 MW each was from nuclear energy and lignite-fired plants. In addition, Germany still has oil-fired power plants that account for some 5,000 MW, and pumped storage power plants which account for more than 5,000 MW.

The installed capacity of installations to generate power from renewable energy sources was approx. 35,000 MW. Here wind power (onshore) was the dominant generating technology, at over 28,400 MW. Hydroelectric power followed, with just under 5,000 MW. Photovoltaics and biomass accounted for about 2,000 MW of installed capacity each. Geothermal, at 12 MW, and offshore wind were not yet quantitatively significant in 2005.

2.2.2.3 Assumptions about development of current power plant fleet (obsolescence), without new construction

By 2050, all conventional power plants currently in operation will have been shut down, except for the pumped storage power plants, for which no time limit is assumed (see Figure 2.2-5). The reasons here are the exhaustion of the statutorily defined remaining power output limits in the case of nuclear power plants, and the reaching of typical service lives for other, conventional power plants. The service life is assumed to be 45 years for hard coal and lignite-fired plants, and 40 years for natural-gas and oil-fired plants. These assumptions do not take account of retrofits that may extend service lives.

Figure 2.2-5: Installed net capacity of existing conventional power plants in Germany (as of 2009) in GW



Source: Prognos 2009

2.2.3 Modelling of non-energy-related greenhouse gas emissions

In addition to greenhouse gas emissions from combustion, the following source sectors must also be taken into account for a full consideration of the development of emissions and the options for emission mitigation:

- Fugitive emissions from the energy sector include greenhouse gas emissions that result as fugitive (methane) emissions in the production, processing and distribution of fuels (especially the production of coal, natural gas and petroleum, the transport and distribution of natural gas, etc.).

- The group of process-related emissions includes greenhouse gas emissions generated in industrial processes other than combustion (other chemical reactions and processes). By convention, process-related emissions also include the CO_2 emissions from the use of coke and other fuels to reduce iron in the steelmaking industry. But for modelling reasons, this study treats these emissions as energy-related CO_2 emissions (see Sec. 2.6). The group of process-related emissions also includes the release of fluorinated greenhouse gases into the atmosphere.

- A number of other greenhouse gases are produced in the use of products (CO_2 as a refrigerant, use of nitrous oxide).

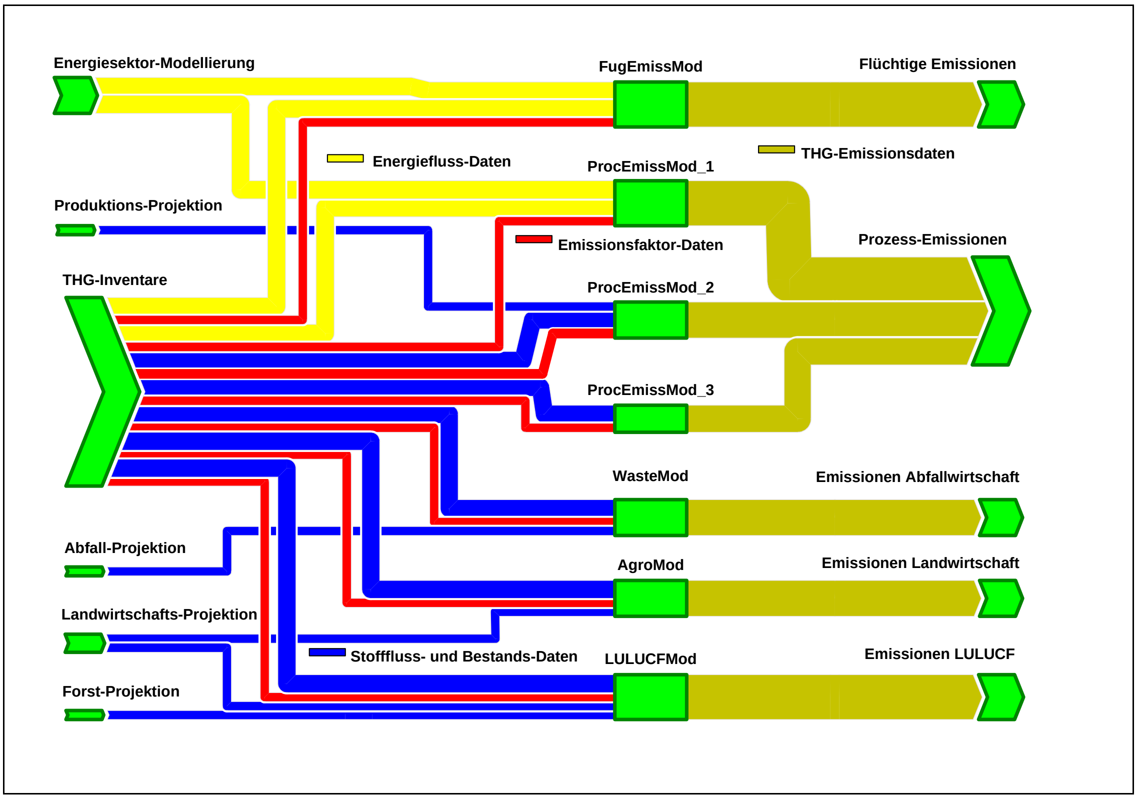
- Methane and nitrous oxide emissions are especially generated in the waste management industry (dumps, waste treatment facilities, sewage treatment).

- Agricultural greenhouse gas emissions (other than from the use of fuels or energy-related emissions) result from both animal husbandry and plant production.

- Land use, land use change, and forestry (LULUCF) covers all greenhouse gas emissions from land use and forestry, and the absorption of CO_2 by trees during the growing phase.

This range of greenhouse gas emissions (called non-energy-related greenhouse gas emissions below) is analysed using the inventory-based modelling instruments of Öko-Institut (Figure 2.2-6).

Figure 2.2-6: Inventory-based models for analysing non-energy-related greenhouse gas emissions



Source: Öko-Institut 2009

The historical emission changes are analysed here in as much detail as possible, by size of activity and emission factors. Both parameters are extrapolated on the basis of production or demand projections (activity factors) and technical options for mitigating emissions (changes in emission factors).

The activity factors (energy demand, industrial production figures, materials flows in waste management, flock sizes in agriculture, land and soil use structures, etc.) are either derived from the basic data of the scenario analysis (value added figures), or result from the modelling of the energy sector, or are derived from separate production or inventory projections, or are extrapolated as separate expert estimates.

The modelling of technical mitigation measures apart from changes in demand or production is based on individual process-specific or sector-specific analyses (replacement of fossil hydrogen, use of catalysts or CCS, fertilizer management, etc.), and the results come from a calculation of specifically adjusted emission factors.

Emissions of non-energy-related greenhouse gases are then calculated in the inventory structures as a product of the extrapolated activity factors and the extrapolated or specifically adjusted emission factors.

The methodological approach for the waste management industry presents an unusual aspect. In modelling methane emissions from waste dumps, the kinetic model (UBA 2009) used in preparing the German greenhouse gas inventories for the waste management source group was expanded to calculate methane emissions for the time horizon to 2050, and was parameterised on the basis of an extrapolated waste forecast.

The strict relationship with the structures and actual data of the German greenhouse gas inventories makes it possible to carry out a full, consistent accounting and analysis of all source groups for greenhouse gases in Germany.

2.3 Scenarios

Model-based scenarios were used as a basis for preparing the quantitative and qualitative foundations for decisions.

Scenarios have the task of developing consistent pictures of potential futures involving controlled changes in certain basic conditions and political-social prerequisites. In contrast to forecasts, which seek to describe a "most probable possible future," scenarios also make it possible to estimate the effects of major changes in assumptions compared to current conditions [Prognos 2004].

Scenarios are complex "if-then" conclusions. For the purposes of this study, they may fundamentally focus in two directions:

- In the one case, premises such as basic conditions, political strategies and sometimes individual policy measures, along with technical steps to be taken, are defined or derived. Their effects on the overall energy system over time (consumption, energy source mix, percentage of renewables, etc.) are calculated and assessed in the light of strategic criteria or objectives. These scenarios focus on the question "what would happen if…?" ("strategy" scenarios). This method is used for the reference scenario.

- On the other hand, concrete or strategic targets can be set for a certain date. Model calculations can then be used to derive a set of necessary measures, and if applicable also tools, and thus to derive the policy-strategy requirements that are needed to achieve these targets. The resulting findings take the form of "what needs to happen so that…?" This method is used for the innovation scenario.

Here it must be pointed out that quantitative, model-based work permits quantitative conclusions about (physical, technical) measures and, where applicable, framework data. Further considerations are needed in order to derive tools, and these are discussed and described in more detail in Chapters 8 and 9.

2.4 The carbon dioxide capture and storage (CCS) option

CCS currently appears to be one option for reducing CO_2 emissions, especially those from large-scale processes for power generation and from industrial processes, especially steel production. In principle, this technology would make it possible to continue burning fossil fuels, yet pollute the atmosphere with only a fraction of the former emissions. If the technology is applied in the combustion or conversion of biomass, moreover, it can activate CO_2 sinks.

Questions about chemical processes have largely been solved, and the essential functionality of the processes has been demonstrated. Large-scale demonstration projects are under construction and in operation.

Currently, transporting the segregated CO_2 via pipelines appears to be a probable option, especially for reasons of cost.

However, questions of safety in transport and storage, and especially questions of the associated acceptance, remain largely unanswered. The search is still in progress for deposit sites, as is testing for serviceableness, safety and eligibility for permits.

For that reason, scenarios are calculated with and without CCS, to make it possible to develop a contingency plan against the event that the ambitious target pathways for renewable energy sources in power generation cannot be taken. However, treating these as a “fallback option” should be viewed with the reservation that both technology paths involve long terms and considerable lead times work in planning, technological development, clarification of background conditions, and acceptance.

2.5 Limitations on potential

2.5.1 Renewable power generation

Estimating the development of renewable power generation in Germany to 2050 is not a subject of this study. The current "official" estimate used here is [DLR 2008]. It assumes that 472.4 TWh of electricity from renewable energy sources is a possibility by 2050, 121 TWh of this figure from the European interconnected power system (91 TWh of solar thermal electricity, 30 TWh from other sources). Thus 351.4 TWh will be available as internal generation. Assuming that intensive emission reduction and a strategic changeover to renewable energy sources cannot be accomplished (and is also not reasonable) if the country must work alone, it should be assumed that even with the European interconnected system, the available renewable potential will not be unlimited. Generator countries will have higher internal consumption of power generated from renewable sources, and will have a priority interest in using the energy generated from renewable sources themselves. There is extensive discussion at present of building solar thermal power plants in North Africa and connecting them to Europe, under the "Desertec" name. Apart from the fundamental technical possibility of making such projects a reality, there are numerous political, economic and logistical problems still to be solved here. It is unclear at present whether this option can be brought to fruition in the foreseeable future (i.e., with power plant construction starting in 2020 – 2030). For that reason, the demand for imported electricity that may still arise residually in the calculations cannot be allocated to a single, unequivocal source.

The projections in [DLR 2008] include 53.8 TWh of biomass-based electricity by 2050. Due to the restrictions on domestic biomass that come from other directions (see next subsection), we take a more conservative approach, and limit the potential biomass available for conversion to electricity to a maximum output of 41.3 TWh.

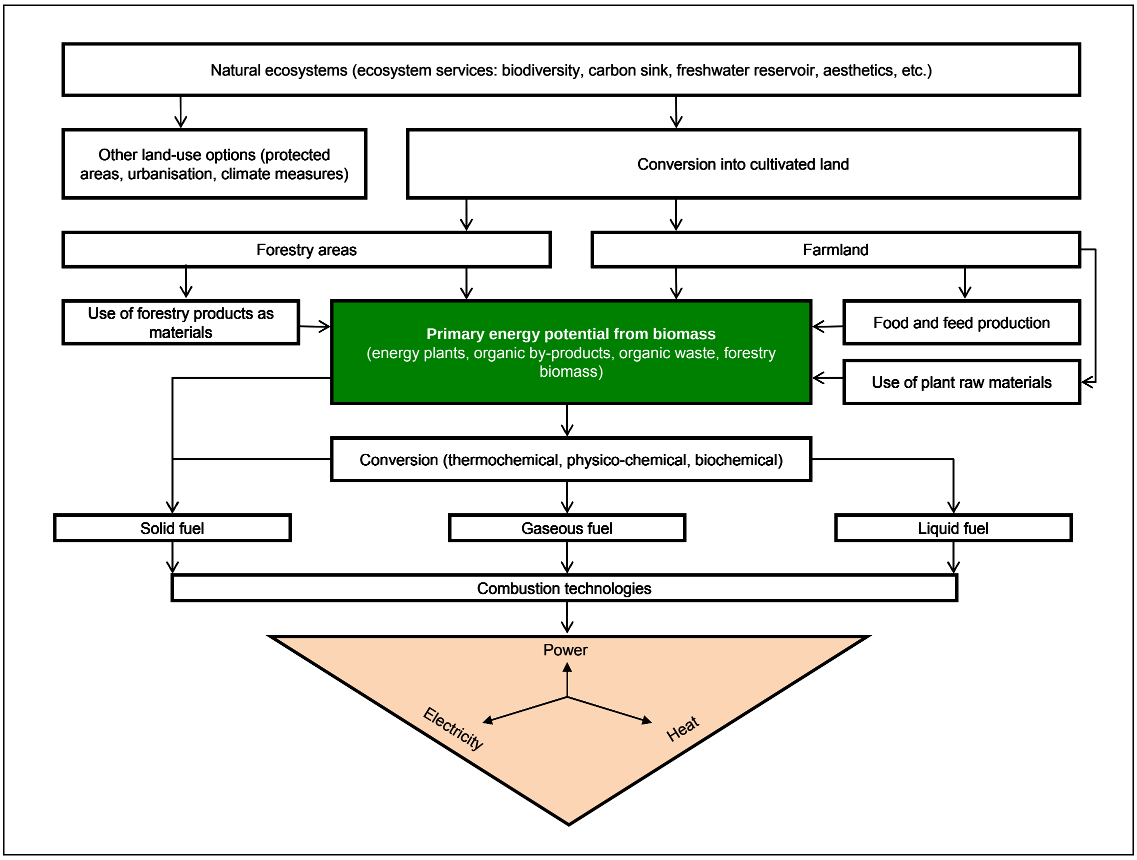
The scenario results explicitly indicate the amount of renewable sources needed for each case.

2.5.2 Biomass

Points similar to those already made in Sec. 2.5.1 apply to the use of biomass as an energy source. Particularly in the international trading of biomass products usable for energy purposes, massive competition may arise to the detriment of food production in developing and emerging countries, so that here the potential for biomass is limited for now to domestic, "sustainable" sources. To clarify the concepts and for a concrete quantification of potential, the following explanations are provided, which represent an abridged version of the comments in the Appendix:

The use of biomass for energy purposes has recently been a topic of extensive debate. Advocates often cite the contribution that bioenergy can make to protecting the climate and environment, to ensuring a reliable supply of energy, and to rural development. Critics emphasize the harmful effects that may result from land use changes. Using soil to grow bioenergy withdraws area from other potential uses, so that competition among uses may arise which, as shown in Figure 2.5-1, can go through multiple conversion phases.

Figure 2.5-1: Biomass conversion steps – Schematic



Source: Prognos 2009

In contrast to other potential uses of the available space, such as for preserving natural ecosystems and the associated system services, or for food production, cultivation of bioenergy plants is replaceable, and should therefore always be given a lower priority. In this way, the area potential available for cultivating bioenergy will be gradually restricted in each conversion phase. The primary energy potential obtainable from the available area can be estimated by modelling plant yields. The total primary energy potential from bioenergy results when one then adds in the flows of wastes and residues that arise from other forms of use for biomass.

In its publication “Future bioenergy and sustainable land use” [WBGU, 2008], the WBGU (the German Advisory Council on Global Change) calculates the global sustainable potential of primary energy from biomass. In its model it takes separate account of sustainability requirements by translating non-replaceable forms of land use into areas used exclusively for bioenergy cultivation. In this way the WBGU calculates a global potential from energy-producing plants that fluctuates between 30 and 120 EJ per year, depending on which scenario is assumed for the future area needed for agriculture and to protect biodiversity. To this is added a figure of 50 EJ per year for residues from agriculture and forestry, leading to a total worldwide sustainable bioenergy potential of 80 – 170 EJ per year.

For Germany, no results can be derived from the model used by the WBGU because the model was conceived for global application. The German Advisory Council on the Environment [SRU, 2007] believes a sustainable potential for Germany can most readily be derived from the results of two studies, “Materials flow analysis for the sustainable energy use of biomass" [Öko-Institut et al., 2004] and "Ecologically optimised expansion of the use of renewable energy sources in Germany" [DLR et al., 2004) (Table 2.5-1).

Table 2.5-1: Biomass potential according to various studies

Study/year	2000	2010	2020	2030	2040	2050
Potential from residues (PJ/yr)						
Öko-Institut	520	525	536	545		
German Aerospace Center (DLR)	543	677	696	705	715	724
Area potential, excluding grassland (mln ha)						
Öko-Institut		0.61	1.82	2.94		
German Aerospace Center (DLR)		0.15	1.1	2.0	3.1	4.2

Assuming that some 4 million hectares will be available in 2050, cultivation of energy plants on this land can yield between 415 and 522 PJ/yr of primary energy, depending on how the climate develops [Kollas, C. et al., 2009]. In combination with roughly 700 PJ/yr from residues, the total potential for bioenergy in Germany in 2050 could well be approx. 1,200 PJ/yr.

The final energy may be provided by way of a large number of technical use pathways that differ in their ecological, economic, technical and geographic criteria. Which pathways should preferably be implemented will depend on the desired objective. There are a number of assessment criteria, some of which may have conflicting goals:

Often the maximum reduction of greenhouse gas emissions is mentioned as the goal. In that case, pathways are prioritised that achieve a high mitigation of greenhouse gases, relative to the quantity of primary energy used, all along their preparation chain. A second assessment criterion is a pathway's specific cost of mitigating greenhouse gases. This results from the fact that bioenergy use is only one of multiple options for protecting the climate, and therefore relatively expensive pathways are inefficient if the aim is to minimise the emissions of the energy system as a whole. The expert evaluations by Müller-Langer et al., 2008, and Fritsche/Wiegmann, 2008, prepared for the WBGU assessment, show that these targets are best achieved via pathways that provide electricity as the final energy, and heating as a by-product. The most efficient are those pathways that use biowaste and residues, since obtaining these rarely triggers land use changes, and such changes as do occur are only very minor. Among energy plants, corn (maize) silage and millet yield somewhat better results than short-rotation plantations of poplars. There are no major differences among combustion technologies, except that new technologies like fuel cells are not likely to become competitive within the near future. In terms of conversion to fuel, biogas plants and gasification plants are of particular interest, because this form of use can utilise the existing natural gas infrastructure.

In rapidly achieving large total reductions on the basis of the system already in place, the criterion of "no alternative" comes into play: biomass can be used not only for direct heat generation, but for power generation (most efficiently in combined production with heat), and to produce motor fuels. It serves as a substitute for fossil energy sources in all three areas. In power and heat production, normally other renewable energy sources can also be used, and in the case of space heating in particular there is the possibility of saving extremely large percentages of current energy demand for space heating through greater efficiency. For motor fuels used in passenger transport, according to current assessments there is a fundamental possibility of replacement with electricity-based technologies. In freight transport, the electric option is not expected to see widespread use within the longer term, because of the power needed by the necessary traction engines, and the limitations of the currently conceivable power densities of batteries. If fossil energy sources are to be replaced here – after the broadest possible shift to rail transport – there is no alternative to biogenic motor fuels. Therefore, although use for power generation would be more efficient in energy terms, the innovation scenario sets a priority on using biomass for generating biofuels.

Here it is assumed that in the future, second and third-generation biofuels especially will be available, and that their production will become increasingly efficient.

As in the case of renewable sources for electric power generation, here too the potential may not suffice to cover the demand entirely. The possible demand for imports remains an open variable.

Even with only these limitations on potential, it becomes evident that in order to resolve the above conflicts over space and goals, both for the use of domestic biomass and for imports, it seems indispensable to develop an integrated, sustainable strategy for safeguarding food and biomass production, within which the sustainable energy use of biomass will be carried out, especially for the production of biofuels.

2.6 Development of greenhouse gas emissions from 1990 to 2007, and their allocation by sector

A number of methodological questions are of particular significance both in preparing the scenario analyses and in evaluating and categorising the results.

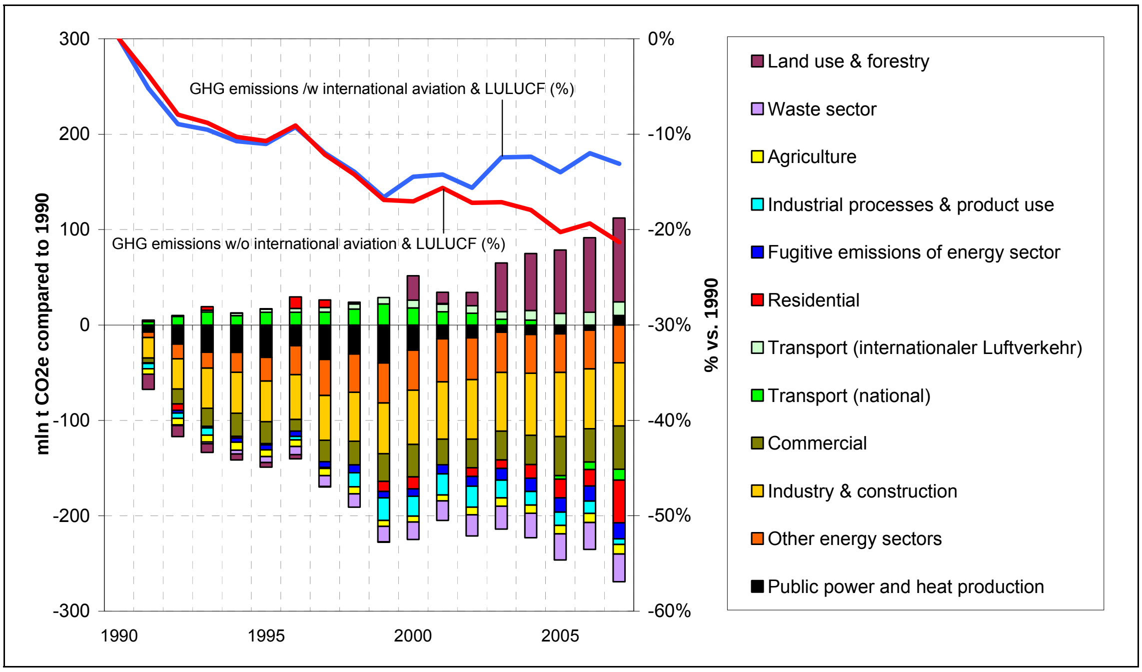
A first important question concerns the definition of the system boundaries for the target emission reduction and the development of the scenario. It is true that greenhouse gas emissions are inventoried all-inclusively in the context of international climate protection commitments. But the reduction commitments undertaken so far under the Kyoto Protocol do not refer to all source groups for greenhouse gas emissions.

Consequently emissions from international aviation (more specifically: emissions from the volumes of fuel filled into tanks in Germany for international aviation) are excluded, as are emissions from marine navigation. For Germany, to be sure, these are not the dominant emission quantities, yet they do achieve levels that are not merely negligible, and have seen substantial and dynamic growth in the case of international aviation. In 2007, emissions from international aviation for Germany came to approx. 25 million metric tons of CO_2 equivalent. Emissions from maritime navigation came to some 10 million metric tons of CO_2 equivalent. This represents an increase of 121% against 1990 for international aviation, and about 24% for maritime navigation.

Furthermore, in checking compliance with commitments, under the Kyoto Protocol only partial account is taken of changes in emissions in land use, land use changes and forestry (LULUCF, also called land use and forestry below). So forests, as a sink or source for CO_2 emissions, are taken into account for Germany only up to a volume of

1.24 million metric tons of carbon, or 4.55 million metric tons of CO_2, in the context of the commitments under the Kyoto Protocol.[1] That means that in demonstrating compliance with the commitments under the Kyoto Protocol, Germany can include the emission situation in forestry (both as a source and as a sink for CO_2) only up to a maximum of 0.4 percentage points of the base year emissions established for the commitment. Consequently, compared to the total emission reduction commitment of 21% by 2008/2012, changes resulting from sources or sinks in forestry have only minor effects. Finally, it should be pointed out that changes in the source or sink situation in forests between the base year and the commitment period (2008-2012) are not taken into account under the Kyoto Protocol. Thus if forests' sink function is reduced or enhanced, this is addressed to only a very limited degree within the existing (international) emission reduction commitments.

Figure 2.6-1: Development of total greenhouse gas emissions in Germany by sector, 1990 – 2007



Source: UNFCCC, Krug et al. 2009, Öko-Institut 2009

Figure 2.6-1 makes clear that these limitations in regard to international aviation, as well as land use and forestry, are not incidental to the definition of long-term goals. The figure first summarises emission reductions from 1990 to 2007 on the basis of the most current data from the national greenhouse gas inventories (UBA 2009), supplemented by the latest (published) data for LULUCF as a source group (Krug et al. 2009). Within the bounds relevant for the commitments under the Kyoto Protocol, greenhouse gas emissions in Germany decreased 20.3% from 1990 to 2005, and by 21.3% to 2007. But if one takes account of all emission sources (except for maritime navigation, for which a number of special factors must be taken into account), the picture is significantly different. Development in soil and forests especially, but also the growth of emissions from international aviation, yields a greenhouse gas emission reduction here

[1] Decision 16/CMP.1 of the Treaty States to the Kyoto Protocol (December 9-10, 2005). For the modalities of fulfilling commitments under the Kyoto Protocol, see UNFCCC (2008). For the specification of Germany's commitment under the Kyoto Protocol, see UNFCCC (2007).

of only 14% for 1990 through 2005, while the equivalent figure for 1990 through 2007 is 13.1%.

In the context of long-term strategies for climate protection, broad system boundaries are imperative. Hence the analyses in this study take full account of emissions from international aviation and from land use and forestry. The consequence is that the gap to be closed up in order to achieve the 95% reduction target relative to 1990, on the basis of 2005 emissions, is not just 75 percentage points, but 81 percentage points.

The individual sectors' contributions to the emission reduction that has been achieved since 1990 vary widely. While industry and the service sector, agriculture, waste management and the energy conversion sector other than public power generation have made consistent contributions towards reductions since 1990, the other sectors' contributions have been inconsistent over time. Public power and heat utilities reduced their emissions substantially in some cases during the 1990s, but exceeded 1990 emission levels again after 2005. Greenhouse gas emissions attributable to national transport increased in the 1990s. But since the turn of the millennium, emissions here have fallen below 1990 levels again, and still show a declining trend. A similar developmental pattern appears in the residential sector, though it is less distinct and began earlier in regard to effective contributions to reduce emissions. A serious change appears in land use and forestry. While the balance of CO_2 emissions and CO_2 sinks in the 1990s represented a net sink for this segment, since the turn of the millennium land use and forestry have become a net source of CO_2 emissions. Finally, consistently rising contributions of emissions are attributable to international aviation.

In conclusion, to categorise the sector-by-sector emission data, one may also look at the following differences in definition of sector boundaries between the national greenhouse gas inventories and the models used in this study:

- In the national greenhouse gas inventories, emissions from power plants in industry are attributed entirely to the industry sector, while in the present study they are taken into account in the overall consideration of the electric power sector. This definition of boundaries means that in this study, power generation has a larger role in emissions than it does in the national greenhouse gas inventories.

- In the national greenhouse gas inventories, the transport sector includes not only road, rail and aviation and inland navigation, but also transport in the construction industry (which is attributed to the commerce, retail and service sector in the energy balance sheet and in the models used here), as well as emissions from pipeline transport (attributed to the energy conversion sector in the energy balance sheet and in the model used here). The effects of this allocation do result in slightly higher emission volumes for the transport sector in the national greenhouse gas inventories, but the differences are not so significant that they would have to be taken explicitly into account in this study.

- The national greenhouse gas inventories quite predominantly do not treat the CO_2 emissions from the use of carbon in blast furnaces (coke, heavy heating oil, etc.) as energy-related emissions (i.e., emissions from the combustion of fossil energy sources), but instead the CO_2 emissions from the energy source input attributable to the reduction of iron ore are treated as process-related emissions. This definition of boundaries tends to lead to lower energy-related

CO_2 emissions for the industry sector, so that an overall assessment of industrial greenhouse gas emissions is useful only if energy-related and process-related greenhouse gas emissions in industry are considered together. In this study, by contrast, the use of fossil fuels in the iron and steel industry is entirely attributed to the energy-related emissions of this industrial branch, so that the analysis of the industry emissions thus defined already yields a viable picture. The process-related emissions in the iron and steel industry due to iron ore reduction are therefore indicated for information in the analysis of process-related emissions, and are then subjected to a separate analysis in connection with mitigation measures.

Given this background, the appropriate reclassifications must be taken into account in comparing the actual data from the national greenhouse gas inventories and the model data presented below. However, the model and inventory data have been balanced out against one another in such a way that consistent emission levels are applied at the level of total emissions.

II Quantitative scenarios

3 Base data shared by all scenarios

The reference scenario and the innovation scenario generally adopt identical assumptions about the development of socio-economic parameters, energy prices and the climate factors. These assumptions are based on the current, regularly recurring studies by Prognos AG on general economic development, such as the Germany Report and the World Report. The initial data for population forecasts are based on the Eleventh Coordinated Population Projection of the German Federal Statistical Office [STaBu 11. Koord].

Achieving the emission targets in the innovation scenario implies deviations from the base development in industrial production. These deviations are described in section 5.3.3.1.

3.1 Socio-economic framework data

3.1.1 Population, age structure

The assumptions about population change are based on Option 1-W.1 of the Eleventh Coordinated Population Projection of the German Federal Statistical Office. The population extrapolation used for the scenarios differs from the German Federal Statistical Office version in its assumptions about migration. The Statistical Office assumes annual net immigration of 100,000 persons. By contrast, the Prognos population projection assumes that net immigration will average 150,000 per year to 2030. This net immigration is not distributed uniformly across all years. Instead, it is considerably lower than the average at the start, and considerably higher in the second half of the projection period.

The other assumptions made in extrapolating population are the same as those of the German Federal Statistical Office:

- An almost constant birth rate of 1.4 children per woman,

- A moderate increase in life expectancy from 81.5 years in 2002-2004 to 88.0 years for girls born in 2050, and from 75.9 years in 2002-2004 to 83.5 years for boys born in 2050.

Based on these assumptions, population will decrease by somewhat more than 10 million by 2050, when it will be 72.2 million (Table 3.1-1). The decrease will accelerate from 2030 onwards.

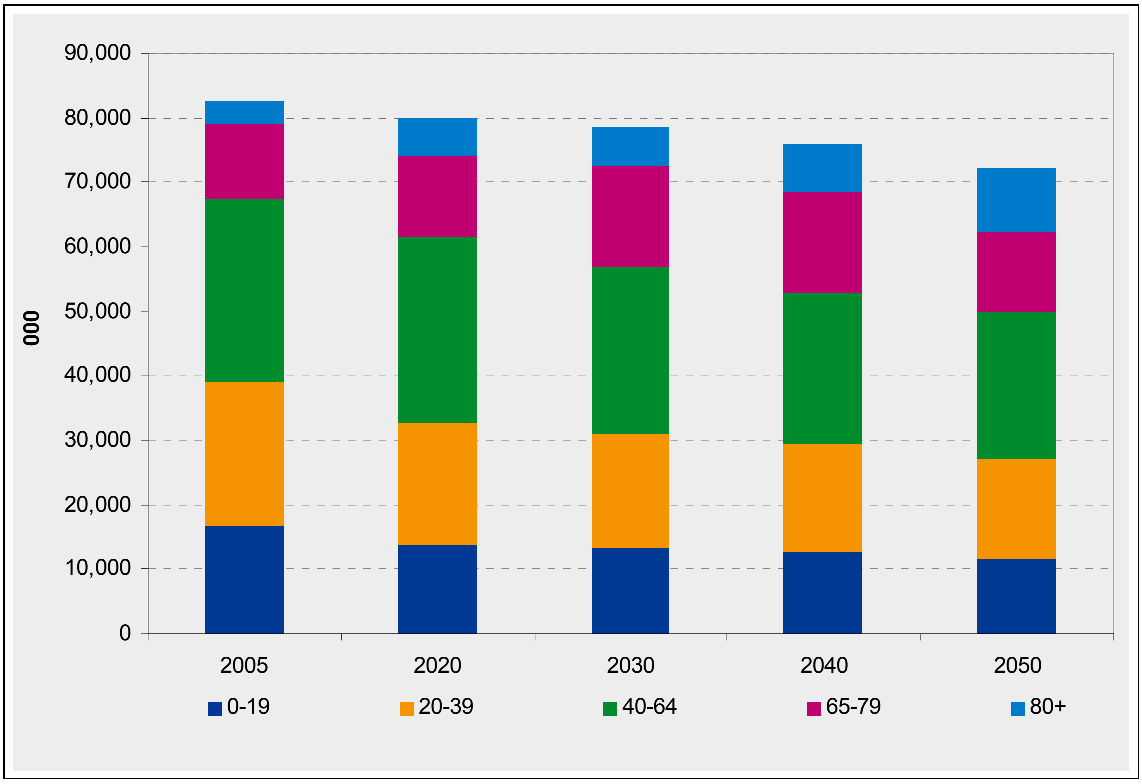
Table 3.1-1: Population by age group, 2005 – 2050 (annual mean, in thousands) and change per year in %

		2005	2020	2030	2040	2050
Population in 000						
Total		82,516	79,799	78,576	75,967	72,178
of which: age	0-19	16,808	13,674	13,157	12,613	11,710
	20-39	22,113	19,014	18,017	16,754	15,355
	40-64	28,481	28,835	25,764	23,506	22,750
	65-79	11,611	12,619	15,595	15,545	12,689
	80+	3,503	5,657	6,044	7,549	9,674
			2020	**2030**	**2040**	**2050**
Index, 2005=100						
Total			97	95	92	87
of which: age	0-19		81	78	75	70
	20-39		86	81	76	69
	40-64		101	90	83	80
	65-79		109	134	134	109
	80+		161	173	216	276

Source: Prognos 2009

As the population decreases, there will be a sharp change in its age structure. The percentage of those aged 65 and above will rise from over 18% in 2005 to 31% in 2050. The number of those over the age of 80 will nearly triple.

Figure 3.1-1: Population by age group, 2005 – 2050 (annual mean, in thousands)



Source: Prognos 2009

These changes will cause the age structure quotient, defined here as the proportion of persons of retirement age (aged 65 and older) to those of earning age (20 to 64), to rise from 32% to 59% in the period under consideration.

Although the population will decrease substantially, the number of households in Germany will decrease by only 0.5 million between 2005 and 2050 (–1.1%). The number of households will continue to increase slightly until 2035 (Table 3.1-2). The reason is decreasing household size. From 2035 onwards, the effect of declining population will be stronger than the ongoing trend towards smaller households. The decrease will accelerate from 2040 onwards.

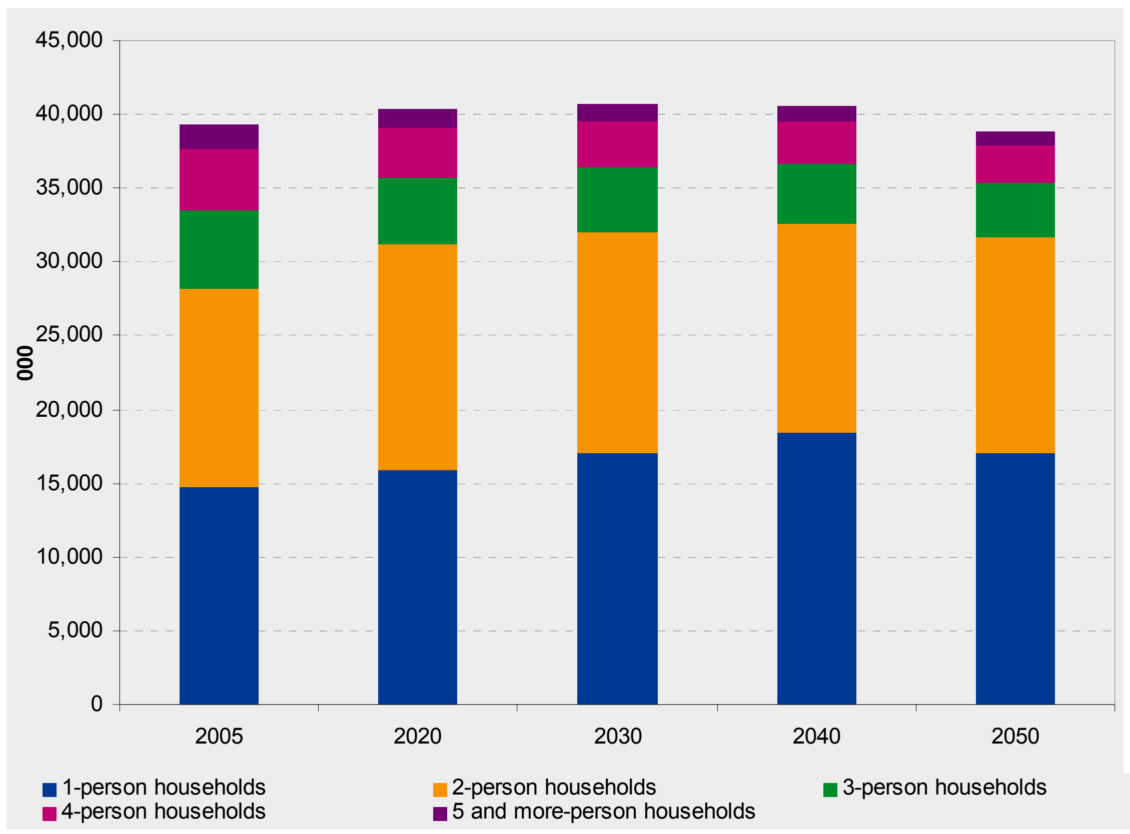
The number of one-person and two-person households will increase by nearly 10 percentage points during the period, while the number of households with 5 or more persons will decrease by almost half (–42%). As a consequence of this change, about 82% of all households will have one or two persons in 2050, while the figure was 72% in 2005. These changes will cause the average household size to decrease from 2.11 persons per household in 2005 to 1.86 in 2050.

Table 3.1-2: Private households by household size, 2005 – 2050 (annual mean, in thousands), average household size and changes from 2005

		2005	2020	2030	2040	2050
Households in 000						
Total		39,274	40,327	40,716	40,617	38,823
of which:	1-person households	14,678	15,838	17,038	18,422	17,033
	2-person households	13,460	15,332	14,957	14,132	14,669
	3-person households	5,368	4,557	4,366	4,067	3,636
	4-person households	4,190	3,377	3,206	2,951	2,586
	5 and more person households	1,578	1,222	1,150	1,046	898
avg. household size		2.11	1.99	1.94	1.88	1.86
			2020	**2030**	**2040**	**2050**
Index, 2005=100						
Total			103	104	103	99
of which:	1-person households		108	116	126	116
	2-person households		114	111	105	109
	3-person households		85	81	76	68
	4-person households		81	77	70	62
	5 and more person households		77	73	66	57

Source: Prognos 2009

Figure 3.1-2: Private households by size of household, 2005 – 2050 (annual mean, in thousands)



Source: Prognos 2009

The changes in population and in population structure will affect energy consumption both directly and indirectly. For example, older persons will often remain in their apartments or their own houses, even when their children have moved out and the living space has become too large. Apart from rising per capita income, this is one reason why living space will initially rise further even though the population declines. As the decline in the number of households begins around 2035, living space will begin to decrease (Table 3.1-3).

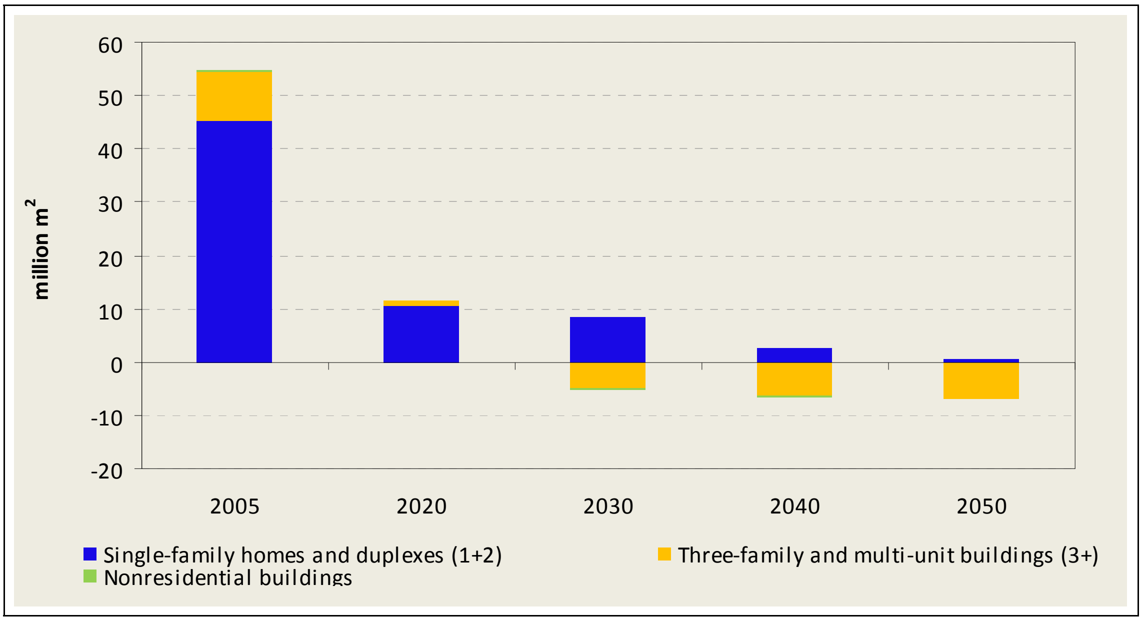
Table 3.1-3: Additions of living space (net) and occupied living space, 2005 – 2050 (million m^2)

	2005	2020	2030	2040	2050
Net addition of living space					
Total	54.8	11.5	3.2	-3.9	-6.6
Single-family homes and duplexes (1+2)	45.2	10.6	8.4	2.6	0.5
Three-family and multi-unit buildings (3+)	9.1	0.9	-5.0	-6.3	-6.9
Non-residential buildings	0.4	0.0	-0.1	-0.2	-0.2
Living space (occupied)					
Total	3,223	3,485	3,583	3,576	3,525
Single-family homes + duplexes	1,856	2,069	2,171	2,220	2,235
Multi-unit buildings/non-residential	1,367	1,415	1,412	1,356	1,290
Vacancy rate	4.2%	3.6%	3.2%	3.1%	3.1%

Source: Prognos 2009

Building types will change variably. Living space in single-family homes and duplexes will continue to expand until 2050, when it will be 20% greater than in 2005. Living space in multi-unit buildings will reach a maximum around 2025. After that, it will decrease, and in 2050 it will be slightly less than 6% below the 2005 level. Since the growth in living space in single-family homes and duplexes will exceed the decrease in living space in multi-unit buildings and non-residential buildings, total living space will increase until 2050 (+9%).

Figure 3.1-3: Net additions of living space, 2005 – 2050 (million m^2)



Source: Prognos 2009

3.1.2 Economic development

The scenarios are based on average real economic growth of 0.7% per year. Here it is assumed that the current financial and economic crisis will be overcome by 2010-2011. In the period from 2011 to 2020, growth rates will be more than 1% per year. Between 2020 and 2030, growth will slacken because of the sharp decline in the potential workforce. Then it will accelerate somewhat.

Because of declining population, the growth of per capita income will average 1% per year above the GDP growth rate. Real GDP per capita will increase from just under EUR 26 thousand in 2007 to more than EUR 41 thousand in 2050.

The overall economic performance will be based on sometimes very different changes in individual sectors (Table 3.1-5). The segment for quarrying of stone and soils and the construction industry will have lower gross value added – in real terms – in 2050 than in 2005.

After a decline caused by the economic crisis until 2010, the number of employed individuals will still rise slightly until 2015. After that the number of persons employed will decrease, but increases in productivity will be greater than GDP growth rates. A total of some 33.1 million persons will be employed in 2050, about 15% less than in 2005 (Table 3.1-6).

Growth is a defining parameter for the development of employment. As a rule, more growth means more employment. On the other hand, changes in employment are a defining parameter for the development of unemployment. Also playing a role are how the job supply changes, and how many people who are currently unemployed are willing and able to work. This in turn depends on the number of persons of employable age (generally age 20-64), and their age-specific propensity to work. The link between the two yields the potential workforce. The scenario studies made no explicit assumptions about propensity to work, but did make assumptions about changes in the figures for persons of employable age and about employment rates.

The following conclusions may be drawn from Table 3.1-4:

1. The number of persons of employable age (age 20 – 64) will decrease by 12.5 million by 2050, and even if the age range is expanded to 20 – 79, the number will still decrease by 11.5 million.

2. The number of individuals employed will decrease 5.7 million by 2050 – in other words, significantly more slowly than the number of persons of employable age.

3. This means that jobs can be filled only if workforce potential is utilised more fully than before.

4. Referred to persons of employable age, capacity utilisation will rise from just under 77% (2005) to 87% (2050); if the employable age is extended, the ratio will rise from 62.5% (2005) to 65.2% (2050).

5. At the same time, the difference between the number of persons of employable age and the number of persons employed will decrease from 11.7 million to 5.0 million (or, with the expanded age range, from 23.4 million to 17.7 million).

6. This permits the conclusion that unemployment will decrease drastically. A greater problem may be to fill all job openings with appropriately qualified persons in the long term.

In sum, one can say that in these scenarios unemployment decreases substantially as early as the years following 2010, with a crucial role being played by demographic change.

Table 3.1-4: *Persons of employable age and persons employed in the reference scenario (the innovation scenario differs slightly)*

		2005	2020	2030	2040	2050
Age 20-64	000	50,594	47,849	43,780	40,261	38,105
Age 20-79	000	62,205	60,467	59,376	55,806	50,794
Employed	000	38,851	39,125	36,736	34,475	33,135
Employed percentage age 20-64	%	76.8%	81.8%	83.9%	85.6%	87.0%
Employed percentage age 20-79	%	62.5%	64.7%	61.9%	61.8%	65.2%
Unemployed age 20-64	000	11,743	8,724	7,045	5,785	4,970
Unemployed age 20-79	000	23,354	21,342	22,640	21,330	17,659

Table 3.1-5: *Gross value added (GVA) by economic segment, 2005 – 2050, in EUR bn (2000), GDP per capita, and annual change in %*

	2005	2020	2030	2040	2050
GVA (real), 2000 basis					
Agriculture and forestry; fisheries	23	23	23	23	23
Mining, quarrying of stone and soils	3	3	3	3	2
Manufacturing	457	555	572	587	615
Energy and water utilities	40	38	39	40	41
Construction	76	71	69	66	65
Retail; repairs of autos and durable goods	215	234	252	268	294
Hospitality	29	30	31	31	33
Transport and telecommunications	114	145	159	173	196
Banking and insurance	69	85	90	95	107
Real estate, brokerage, corporate services	474	572	638	708	806
Government, defence, social insurance	116	129	129	129	133
Education	84	91	92	93	97
Healthcare, veterinary care, social services	141	178	192	209	233
Other public & private service providers	95	102	108	114	125
All branches of economy	1,934	2,259	2,399	2,543	2,775
Gross domestic product	2,124	2,457	2,598	2,743	2,981
GDP per capita in EUR 000	26	31	33	36	41
		2020	**2030**	**2040**	**2050**
Change p.a. in %					
Agriculture and forestry; fisheries		0.2	-0.1	-0.1	0.1
Mining, quarrying of stone and soils		-1.2	-0.5	-0.6	-1.0
Manufacturing		0.6	0.2	0.3	0.5
Energy and water utilities		0.5	0.3	0.3	0.4
Construction		0.1	-0.4	-0.4	-0.1
Retail; repairs of autos and durable goods		1.0	0.6	0.7	0.9
Hospitality		0.7	0.2	0.2	0.5
Transport and telecommunications		1.3	0.8	0.9	1.2
Banking and insurance		1.5	0.4	0.5	1.2
Real estate, brokerage, corporate services		1.4	1.0	1.0	1.3
Government, defence, social insurance		0.4	-0.2	0.0	0.3
Education		0.5	0.0	0.2	0.4
Healthcare, veterinary care, social services		1.2	0.7	0.8	1.1
Other public & private service providers		1.0	0.5	0.5	0.9
All branches of economy		0.9	0.5	0.6	0.9
Gross domestic product		0.9	0.5	0.5	0.8
GDP per capita in EUR 000		1.1	0.6	0.9	1.4

Source: Prognos 2009

Table 3.1-6: Persons employed, by economic segment, 2005 – 2050, in thousands, and annual change in %

	2005	2020	2030	2040	2050
Employed persons in 000					
Agriculture and forestry; fisheries	853	702	611	533	464
Mining, quarrying of stone and soils	89	55	49	45	39
Manufacturing	7,512	6,379	5,692	5,083	4,568
Energy and water utilities	289	230	201	175	153
Construction	2,185	1,968	1,834	1,686	1,597
Retail; repairs of autos and durable goods	5,903	5,628	5,345	5,081	4,813
Hospitality	1,759	2,008	1,893	1,769	1,722
Transport and telecommunications	2,118	2,187	2,179	2,175	2,132
Banking and insurance	1,239	1,127	1,082	1,037	1,005
Real estate, brokerage, corporate services	5,131	6,041	5,659	5,272	5,073
Government, defence, social insurance	2,671	2,409	2,207	2,026	1,884
Education	2,281	2,521	2,403	2,298	2,282
Healthcare, veterinary care, social services	4,036	4,830	4,655	4,504	4,625
Other public & private service providers	2,785	3,041	2,926	2,793	2,779
All branches of economy	38,851	39,125	36,736	34,475	33,135
		2020	**2030**	**2040**	**2050**
Change p.a. in %					
Agriculture and forestry; fisheries		-1.4	-1.4	-1.4	-1.4
Mining, quarrying of stone and soils		-2.1	-0.9	-1.0	-1.4
Manufacturing		-1.1	-1.1	-1.1	-1.1
Energy and water utilities		-1.5	-1.4	-1.4	-1.4
Construction		-0.4	-0.8	-0.8	-0.5
Retail; repairs of autos and durable goods		-0.5	-0.5	-0.5	-0.5
Hospitality		0.3	-0.7	-0.7	-0.3
Transport and telecommunications		-0.2	0.0	0.0	-0.2
Banking and insurance		-0.3	-0.5	-0.4	-0.3
Real estate, brokerage, corporate services		0.1	-0.8	-0.7	-0.4
Government, defence, social insurance		-0.7	-0.9	-0.9	-0.7
Education		0.1	-0.6	-0.4	-0.1
Healthcare, veterinary care, social services		0.7	-0.6	-0.3	0.3
Other public & private service providers		0.4	-0.5	-0.5	-0.1
All branches of economy		-0.2	-0.7	-0.6	-0.4

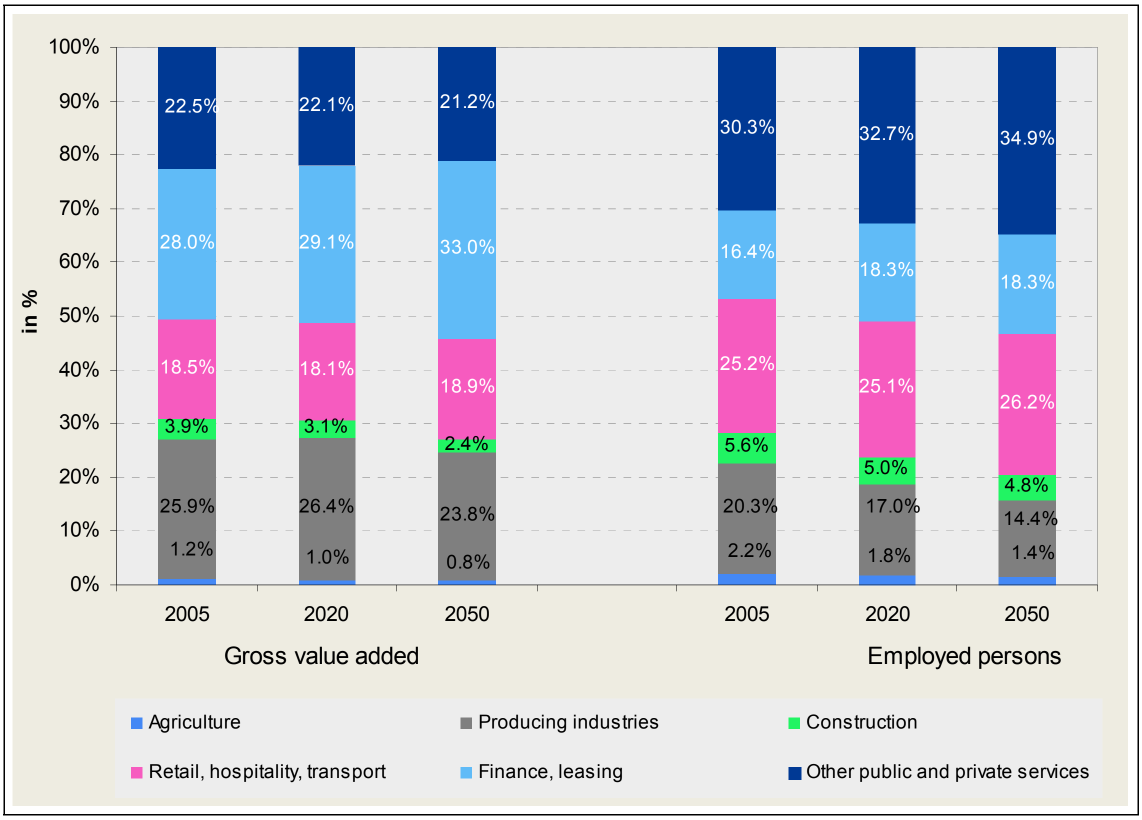
Source: Prognos 2009

3.1.2.1 Structural change

The trend towards a service and knowledge society will hold for the long term. Services' share of gross value added will rise from 69% in 2005 to 73% in 2050 (Figure 3.1-4). Above-average growth rates will be seen in the areas of real estate, leases and services for business (+70%); healthcare, veterinary care and social services (+65%); and transport and communications (+72%).

The structural change will be more evident in employment than in economic output. With employment generally declining, the proportion of persons employed in the service sector will rise from 72% in 2005 to more than 79% in 2050. Healthcare, veterinary care and social services is the only area where employment will still expand significantly.

Figure 3.1-4: Economic structure in Germany in 2005, 2020 and 2050, gross value added (GVA) and persons employed, in %



Source: Prognos 2009

3.1.2.2 Manufacturing (industry)

Industrial production will increase from EUR 430 billion in 2005 to EUR 581 billion in 2050 (in real terms, 2000 prices). Thus industry will grow more slowly than the services sector. Measured in terms of gross value added, manufacturing will lose somewhat in significance. Its share will decrease from 24% in 2005 to 22% in 2050.

The trends in inter-industrial structural change that have been observed in the recent past will continue during the period under study. This means, for one thing, further losses of share for consumer-related segments (food and tobacco, textiles) and in the energy-intensive primary goods segment (paper industry, basic chemicals, and iron, steel and ferroalloy production). On the other hand, segments oriented to capital goods in high-tech and cutting-edge technologies, which produce primarily for the world market, will gain share. These include machine construction, radio/television and communications technology, the production of equipment and systems for electric power generation, and the production of office machinery and IT systems.

Table 3.1-7: Industrial production at factor cost, 2005 – 2050, categories in industrial statistics, in EUR bn (2000), and annual change in %

	2005	2010	2015	2020	2025	2030	2040	2050
Industrial production at factor cost								
Stone and soil quarrying, other mining	1.9	1.4	1.4	1.3	1.2	1.1	1.0	0.9
Food and tobacco	37.3	35.9	37.1	37.0	36.6	36.3	35.7	37.0
Textiles	4.5	3.8	3.6	3.3	3.0	2.7	2.4	2.4
Apparel	1.8	0.9	0.9	0.8	0.8	0.8	0.7	0.6
Leather goods	0.7	0.7	0.7	0.6	0.6	0.5	0.4	0.4
Wood industry (n/incl. furniture production)	6.2	5.7	5.4	5.3	5.2	5.1	5.0	5.2
Paper	10.4	11.0	11.4	11.1	10.7	10.6	10.5	10.7
Printing and publishing	19.2	17.8	18.7	18.7	18.8	18.8	18.8	19.5
Basic chemicals	20.7	19.6	20.5	20.1	19.4	19.1	19.0	19.8
Other chemical industry	23.0	25.6	28.1	29.0	29.4	29.7	30.4	32.0
Rubber and plastic goods	20.6	22.0	23.5	24.0	24.1	24.2	24.5	25.5
Glass, ceramics	5.2	6.1	6.3	6.3	6.1	5.9	5.7	5.7
Stone and soil processing	8.0	7.5	7.9	7.9	7.9	7.8	7.7	8.0
Iron, steel, ferro alloy production	6.0	5.9	6.0	5.9	5.4	4.9	4.4	4.4
Tube and pipe production	2.0	2.2	2.3	2.3	2.2	2.2	2.2	2.2
Other rough machining of iron, steel, ferro alloy production	0.9	1.0	1.1	1.0	1.0	1.0	0.9	0.8
Production and rough machining of non-ferrous metals	4.5	4.4	4.5	4.4	4.4	4.3	4.2	4.3
Foundry industry	3.8	4.1	4.4	4.5	4.5	4.5	4.5	4.7
Metal products	38.4	42.7	46.5	48.1	49.2	49.9	51.6	54.4
Machine construction	64.0	77.7	87.1	91.9	95.6	97.9	102.4	108.7
Office equipment, EDP	4.8	8.2	9.4	10.2	10.6	11.0	11.9	13.1
Production of electric generating equipment	35.6	39.9	44.0	46.4	48.5	50.5	52.6	55.2
Radio, TV and information technology	15.9	25.7	30.3	33.3	35.6	37.6	41.2	44.2
Med. & measuring techn., control and instrumentation, optics	16.9	18.5	19.8	20.0	20.2	20.3	20.6	21.6
Automobiles and automotive parts	57.3	59.4	64.0	66.6	68.3	69.6	73.3	77.8
Other vehicle construction	10.7	10.5	11.1	11.2	11.2	11.0	11.1	11.5
Prod. of furniture, jewelry, musical instruments, etc.; recycling	9.9	10.3	10.9	11.0	10.9	10.8	10.7	11.1
Total manufacturing	430.3	468.3	506.6	522.0	531.4	538.1	553.4	581.3
		2010	**2015**	**2020**	**2025**	**2030**	**2040**	**2050**
Change p.a. in %								
Stone and soil quarrying, other mining		-5.7	-0.4	-1.8	-1.3	-1.6	-1.1	-0.4
Food and tobacco		-0.7	0.7	-0.1	-0.2	-0.2	-0.2	0.4
Textiles		-3.4	-0.8	-1.8	-2.0	-1.7	-1.2	-0.2
Apparel		-12.3	-1.8	-0.5	-1.0	-1.3	-1.3	-1.3
Leather goods		-1.1	0.0	-0.9	-1.6	-1.4	-2.0	-0.7
Wood industry (n/incl. furniture production)		-1.6	-1.0	-0.6	-0.2	-0.4	-0.1	0.4
Paper		1.1	0.6	-0.5	-0.7	-0.2	-0.1	0.2
Printing and publishing		-1.5	1.0	0.1	0.1	0.0	0.0	0.3
Basic chemicals		-1.0	0.9	-0.4	-0.7	-0.3	-0.1	0.4
Other chemical industry		2.2	1.8	0.6	0.3	0.2	0.2	0.5
Rubber and plastic goods		1.2	1.4	0.4	0.1	0.0	0.1	0.4
Glass, ceramics		3.2	0.8	-0.2	-0.5	-0.6	-0.4	0.0
Stone and soil processing		-1.3	0.9	0.2	-0.2	-0.3	-0.1	0.3
Iron, steel, ferro alloy production		-0.6	0.4	-0.4	-1.7	-1.8	-1.0	-0.2
Tube and pipe production		1.8	1.2	0.2	-0.6	-0.2	-0.2	0.0
Other rough machining of iron, steel, ferro alloy production		1.7	0.6	-0.4	-0.6	-0.8	-0.9	-0.9
Production and rough machining of non-ferrous metals		-0.8	0.7	-0.3	-0.4	-0.3	-0.2	0.1
Foundry industry		1.7	1.4	0.4	0.1	0.0	0.0	0.2
Metal products		2.2	1.7	0.7	0.4	0.3	0.3	0.5
Machine construction		4.0	2.3	1.1	0.8	0.5	0.4	0.6
Office equipment, EDP		11.2	2.7	1.7	0.9	0.7	0.8	0.9
Production of electric generating equipment		2.3	2.0	1.1	0.9	0.8	0.4	0.5
Radio, TV and information technology		10.0	3.4	1.9	1.3	1.1	0.9	0.7
Med. & measuring techn., control and instrumentation, optics		1.8	1.3	0.3	0.2	0.1	0.1	0.4
Automobiles and automotive parts		0.7	1.5	0.8	0.5	0.4	0.5	0.6
Other vehicle construction		-0.4	1.1	0.2	-0.1	-0.2	0.0	0.4
Prod. of furniture, jewelry, musical instruments, etc.; recycling		0.7	1.1	0.1	-0.1	-0.2	0.0	0.3
Total manufacturing		1.7	1.6	0.6	0.4	0.3	0.3	0.5

Source: Prognos 2009

3.2 Energy prices

The prices of petroleum, natural gas and hard coal as energy sources are largely determined by the world energy markets, and will rise significantly until 2050. In the world market, the real price of oil in 2030 will be USD 125 (2007) per barrel, more than 130% higher than in 2005. This development is based on estimates from the IEA World Energy Outlook 2008 (IEA, 2008). The price increase will intensify after 2030. In 2050, the real price of oil will be USD 210 (2007) per barrel, four times the 2005 figure (Table 3.2-1).

The real cross-border prices of crude petroleum, natural gas and hard coal will change roughly in parallel with world market prices. The cross-border price of natural gas is oriented to the development of oil prices, and will rise by 135% by 2030, to EUR 0.039 per kWh, and 300% by 2050, to EUR 0.066 per kWh (real in 2007 prices). Since it is more readily available, hard coal will not grow expensive as fast as oil and natural gas. The real price of hard coal in 2030 will be EUR 118 / t Mtoe, 78% higher than in 2005; by 2050 it will rise to EUR 199 / t Mtoe (+200%).

Table 3.2-1: Nominal and real primary energy prices, 2005 – 2050

	2005	2020	2030	2040	2050
Nominal					
Price of oil fob (USD/barrel)	51	123	182	276	429
Cross-border price					
Crude oil (EUR/t)	314	684	1,012	1,534	2,383
Natural gas (euro cents/kWh)	1.6	3.7	5.5	8.1	12.5
Power plant hard coal (EUR/t Mtoe)	65	115	166	247	376
Real (2007 price base)					
Price of oil fob (USD (2007)/barrel)	54	100	125	160	210
Cross-border price					
Crude oil (EUR/t)	322	565	720	940	1,259
Natural gas (euro cents/kWh)	1.7	3.1	3.9	5.0	6.6
Power plant hard coal (EUR/t Mtoe)	67	95	118	151	199

Source: Prognos 2009

Domestic prices to German consumers are based on the cross-border prices of energy sources, additionally taking account of the costs of processing, shipping, storage, and sale, as well as profit mark-ups, taxes and CO_2 prices.

The CO_2 prices included in the prices will rise linearly from EUR 10 per metric ton of CO_2 in 2010 to EUR 50 per metric ton of CO_2 (real, in 2007 prices). Theoretically, the CO_2-prices may be implemented by way of certificates or CO_2 taxes. The scenarios assume that the CO_2 prices will be added on to the prices of energy sources from 2010 onwards, in accordance with the sources' CO_2 factors. The same CO_2 prices are applied in both scenarios. The reference scenario assumes that CO_2 trading will remain primarily a European model, and will be supplemented with further international instruments, such as CDM and JI. If the goals are then tightened moderately, the caps will gradually be adjusted and CO_2 prices will rise. The innovation scenario assumes that CO_2 trading uses the recognised compensation principle. Large emitters – the USA, Australia, Canada, China and Japan – have comparable regulations on greenhouse gas emissions with specific mechanisms to cushion hardships for developing and emerging countries. The innovation scenario also assumes that global targets will be tightened comparably to those for Germany. Thus the potential for CO_2 reduction will be expanded, but the global cap will also be more demanding.

Based on the dynamics in the [GWS/Prognos 2007] study on international climate negotiations, we assume that these two effects will roughly cancel one another out, and that therefore the development of CO_2 prices will be similar in both scenarios. The innovation scenario assumes for Germany that the trading mechanisms will be expanded to further segments of the industry sector, and will be supplemented with further well-fitting, effective tools in the other sectors.

When the CO_2 prices are included, the real prices of energy to the consumer rise substantially between 2005 and 2050 (Table 3.2-2). For residential, light heating oil, which triples, shows the sharpest rise in prices. Consumer prices for natural gas, diesel and gasoline more than double by 2050, and firewood prices rise 90%. The percentage of these price increases represented by the cost of CO_2 over time (with a decreasing trend) is 12 - 20 percent for light heating oil, 13 - 18 percent for natural gas, 9 - 12 percent for gasoline, and 11 - 18 percent for diesel. Thus the largest portion of the price increases derives from the higher procurement cost and from price changes in the international fuel markets.

Prices for industrial customers move in the same direction. But the relative changes between 2005 and 2050 are sharper than for residential, where the various forms of higher taxes on energy sources mitigate the price increase. For industrial customers, heating oil will be more expensive by 210%, natural gas by 236%, and hard coal by 380%. The share of CO_2 charges in these price increases (once again declining over time) will be 15 - 22.5% for light heating oil, 14 - 18% for heavy heating oil, 17 - 20% for natural gas, and 52 - 63% for hard coal. Here too the price increase will be dominated by the rising procurement cost for fossil energy sources; only in the case of hard coal will the price increase be (slightly) predominantly determined by the CO_2 cost.

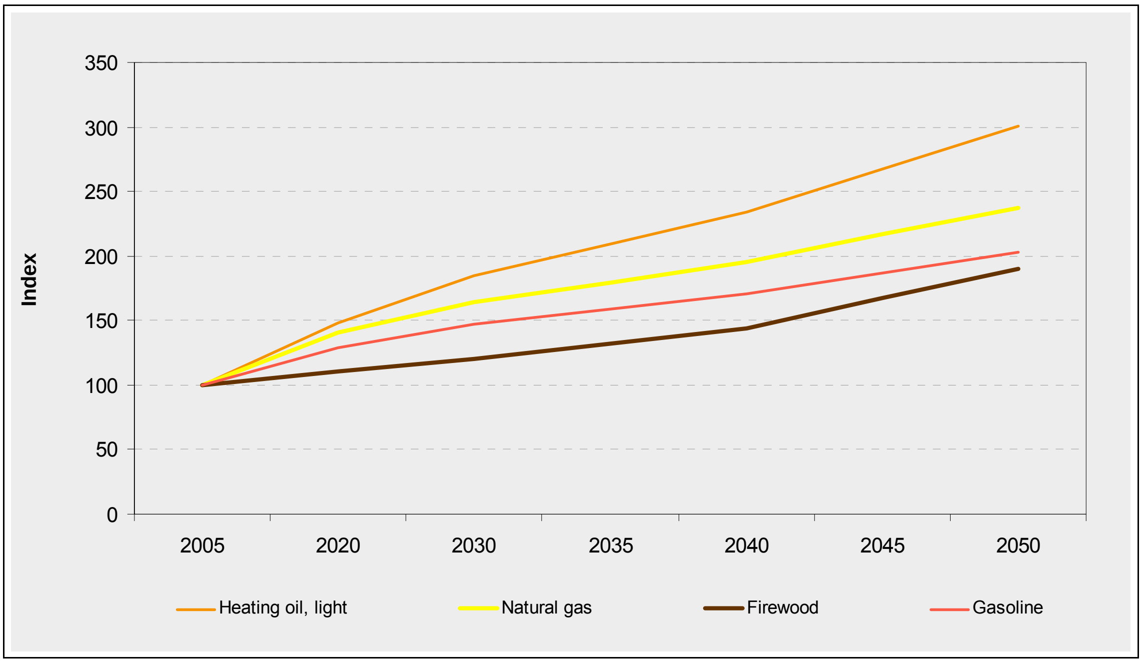
Because of the variable changes and use structure of the power plant fleet, prices to the end user for electricity differ in the reference scenario and the innovation scenario. These changes are described in the chapters on those scenarios.

Table 3.2-2: Consumer prices of petroleum products, natural gas, hard coal and firewood, 2005 – 2050, with CO_2 surcharge from 2010 onwards

	2005	2020	2030	2040	2050
Nominal					
Industry (n/incl. VAT)					
Heating oil, light (EUR/t)	499	960	1,377	2,009	2,994
Heating oil, heavy (EUR/t)	243	734	1,114	1,704	2,639
Natural gas (euro cents/kWh)	3	6	8	11	16
Hard coal (EUR/t Mtoe)	71	200	304	452	666
Residential (incl. VAT)					
Heating oil, light (euro cents/l)	53.6	98.9	142.4	209.2	312.3
Natural gas (euro cents/kWh)	5.3	9.3	12.6	17.4	24.6
Firewood (EUR/stere)	80.2	109.5	138.4	193.4	295.8
Gasoline (EUR/l)	1.2	1.9	2.5	3.4	4.7
Diesel (EUR/l)	1.1	1.7	2.3	3.2	4.4
Real (2007 price base)					
Industry (n/incl. VAT)					
Heating oil, light (EUR/t)	511	793	980	1232	1582
Heating oil, heavy (EUR/t)	249	606	793	1044	1394
Natural gas (euro cents/kWh)	2.6	4.6	5.6	6.9	8.7
Hard coal (EUR/t Mtoe)	73	165	216	277	352
Residential (incl. VAT)					
Heating oil, light (euro cents/l)	54.9	81.6	101.3	128.2	165.0
Natural gas (euro cents/kWh)	5.5	7.7	9.0	10.7	13.0
Firewood (EUR/stere)	82.1	90.4	98.5	118.6	156.2
Gasoline (EUR/l)	1.2	1.6	1.8	2.1	2.5
Diesel (EUR/l)	1.1	1.4	1.7	2.0	2.3
Price of CO_2 (nominal, EUR/t)		24.2	42.2	65.3	94.7
Price of CO_2 (real, EUR (2007)/t)		20.0	30.0	40.0	50.0
VAT rate	19%	20%	22%	24%	25%

Source: Prognos 2009

Figure 3.2-1: Development of real consumer prices for residential sector, 2005 – 2050, index, 2005 = 100



Source: Prognos 2009

3.3 Climate

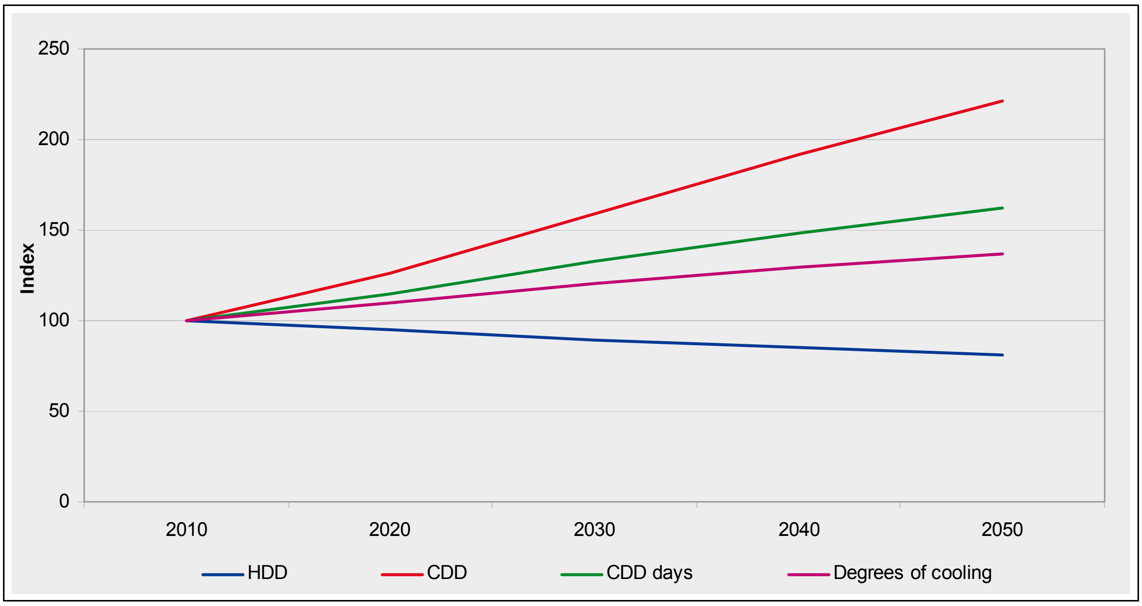
The increase in the concentration of greenhouse gases in the atmosphere will cause a continuous rise in mean annual temperature. Drawing on the work in the [Prognos 2007 b] study based on the detailed regional climate scenarios in [OcCC 2004], for purposes of operationalisation we assume that the mean annual temperature will rise 1.75ºC in the Central European region during the scenario period from roughly 1990 to 2050. This will cause both a decrease in mean heating degree days (HDD) and an increase in cooling degree days (CDD).

Heating days are counted when the mean daily temperature does not rise above a set heating limit, which is generally 12ºC or 15ºC. For heating degree days, these days are weighted by the difference between interior room temperature (usually 20ºC) and the mean daily temperature. By 2050, the number of heating degree days per year will decrease 18.4%, thus reducing energy demand to maintain the desirable room temperature (Figure 3.3-1).

Cooling days are counted if the mean daily temperature exceeds 18.3ºC. For cooling degree days, cooling days are weighted by the degrees of cooling, which are defined here as the difference between the mean daily temperature and 18.3ºC. Since both the annual number of cooling days (+62%) and the mean degree of cooling (+36.7%) increase by 2050, the annual cooling degree days increase more than proportionately (+121.4%). This will be associated with heavier demand for building cooling and room air conditioning.

Both scenarios are based on the same climate changes. Alternatively, the innovation scenario might have used a smaller increase in mean temperature because of global efforts to protect the climate and the resulting lower atmospheric concentration of greenhouse gases. But this was rejected for practical reasons. The change in climate parameters is derived from studies by the Swiss Federal Office of Energy (BFE, 2007).

Figure 3.3-1: Change in heating degree days (HDD), cooling degree days (CDD), days with cooling degrees, and mean cooling degrees on cooling days, 2010 – 2050, index, 2010 = 100



Source: IEA 2008, BFE 2007

4 Reference scenario

4.1 Overview of the scenario

Table 4.1-1: Numerical assumptions and results from the reference scenario, without CCS

			Reference scenario (without CCS)			
	Unit	**2005**	**2020**	**2030**	**2040**	**2050**
Price of oil (real) (2007 price base)	USD (2007) / bbl	54	100	125	160	210
Price of CO2 certificates (real) (2007 price base)	EUR (2007) / t	-	20	30	40	50
Socio-economic framework data / Germany						
Population	M	82.5	79.8	78.6	76.0	72.2
Residential	M	39.3	40.3	40.7	40.6	38.8
GDP (real) (2000 price base)	EUR bn (2000)	2,124	2,457	2,598	2,743	2,981
Industrial production (real) (2000 price base)	EUR bn (2000)	430	522	538	553	581
Passenger cars	M	45.5	48.5	48.7	47.8	45.8
Passenger transport volume	bn pkm	1,084	1,111	1,104	1,075	1,023
Freight transport volume	bn tkm	563	775	869	944	1,033
Household prices (incl. VAT), real (2005 price base)						
Heating oil, light	euro cents(2005)/l	53.6	92.5	131.3	191.9	287.3
Natural gas	euro cents(2005)/kWh	5.3	8.8	11.8	16.1	22.7
Electricity	euro cents(2005)/kWh	18.2	28.9	34.3	41.8	50.3
Regular gasoline	euro cents(2005)/l	120.0	186.9	244.2	327.9	450.9
Wholesale prices (not incl. VAT), real (2005 price base)						
Heating oil, light (industry)	EUR(2005) / t	499	884	1,244	1,802	2,694
Natural gas (industry)	euro cents(2005)/kWh	2.5	5.1	7.0	10.0	14.6
Electricity (industry)	euro cents(2005)/kWh	6.8	13.2	15.6	19.5	23.9
Primary energy consumption	PJ	13,532	11,298	9,808	9,024	8,330
Petroleum	%	32.6	29.2	28.1	25.4	22.4
Gases	%	23.9	24.9	23.6	21.4	21.5
Hard coal	%	12.9	16.7	13.0	14.1	12.8
Lignite	%	12.3	8.9	12.8	13.2	14.6
Nuclear energy	%	12.3	2.9	0.0	0.0	0.0
Biomass	%	3.1	8.0	10.6	12.1	13.1
Other renewable	%	3.1	9.3	11.9	13.8	15.6
Final energy consumption	PJ	9,208	8,178	7,291	6,644	6,099
Residential	%	29.7	27.9	27.6	26.7	25.7
Services	%	15.9	14.3	12.8	12.3	12.0
Industry	%	26.3	28.1	28.7	29.5	31.3
Transport	%	28.1	29.7	30.9	31.5	31.0
Petroleum products	%	41.2	37.6	35.2	32.3	28.6
Natural gases	%	27.0	26.2	24.1	22.5	22.7
Coal	%	4.3	3.9	3.4	3.1	2.9
Electricity	%	19.9	21.6	23.3	25.6	27.5
District heating	%	3.3	3.2	3.1	2.9	2.7
Renewables	%	4.3	7.5	10.9	13.7	15.6
Renewables incl. share for conversion	%	5.7	13.5	18.6	22.4	25.2
Net power generation	TWh	583	554	530	529	520
Nuclear	%	25.9	5.5	0.0	0.0	0.0
Hard coal	%	21.9	30.6	22.8	25.8	21.0
Lignite	%	26.1	18.4	29.9	28.8	31.9
Natural gas	%	11.5	11.1	9.3	6.8	7.0
Renewable energy sources	%	9.8	29.5	32.6	33.1	34.4
Other	%	4.8	4.9	5.3	5.4	5.7
Efficiency indicators						
PEC per capita	GJ per capita	164	142	125	119	115
GDP (real) 2000 / PEC	EUR / GJ	157	217	265	304	358
Industrial prod. / FEC ind.	EUR / GJ	177	227	257	282	305
Passenger-km / FEC passenger transp.	pkm / GJ	576	648	722	787	891
Metric ton-km / FEC freight transp.	tkm / GJ	800	1,088	1,204	1,303	1,391
GHG emissions						
Total GHG emissions	million t	1,042	888	785	717	658
Cumulative GHG emissions from 2005 on	million t	1,042	15,607	23,992	31,395	38,214
Total CO_2 emissions	million t	913	803	703	638	581
Cumulative CO_2 emissions from 2005 on	million t	913	13,988	21,539	28,140	34,176
Energy-related CO_2 emissions	million t	844	705	606	542	486
Energy-related GHG emissions	million t	852	714	614	549	492
Other GHG emissions	million t	190	175	171	168	166
GHG indicators						
GHG emissions / GDP (real)	g / EUR(2000)	490	362	302	261	221
CO_2 emissions / GDP (real)	g / EUR(2000)	430	327	271	232	195
Energy-related GHG emissions / GDP (real)	g / EUR(2000)	401	290	236	200	165
GHG emissions per capita	t per capita	12.6	11.1	10.0	9.4	9.1
CO_2 emissions per capita	t per capita	11.1	10.1	8.9	8.4	8.0
Energy-related GHG emissions per capita	t per capita	10.3	8.9	7.8	7.2	6.8

Source: Prognos / progtrans 2009

4.2 General assumptions

4.2.1 Description of scenario

The scenario continues a development of the "world as we know it" with the application of the changes discussed above. The changes in consumption habits essentially follow known patterns that are influenced by demographics and the development of technology (e.g., expansion of living space per capita, more or less saturated ratio of vehicles per capita, continuing growth in individual leisure travel). The convergence of electronic applications for information, communication, work, entertainment and media in general will continue. All areas of life and business will be pervaded by information technology; the availability of information, process optimisation, controls, and automation will continue to expand.

The economic structural change described in the framework data above will continue the changes already observed to date: towards services and towards industry making knowledge-based, highly specialised products that employ materials more and more efficiently, and often also enjoy high brand values.

The assumption is that energy policy and policies for climate protection will remain roughly within the same bounds as efforts to date. In considerations about investments in the energy-industry target triangle of reliable supply, cost-effectiveness and environmental friendliness/sustainability, the first two aspects will be assigned a very high value.

The various players will particularly implement efficiency measures when by their own calculations the measures will "pay off" immediately by way of direct savings on energy costs. The cost-effectiveness imperative will be paramount.

4.2.2 Energy policy and policies for climate protection

- The Integrated Energy and Climate Program will be continued and expanded, especially in administrative law regarding construction, and in accompanying subsidization programs. There will be a continuous, moderate tightening of the German Energy Saving Ordinance (2012, 2015) that will particularly affect new buildings, to the point of a passive house standard (specific energy demand for space heating less than or equal to 15 kWh/m^2/yr) for new buildings by 2050. Upgrade rates will not increase, but the quality of energy upgrades carried out will rise. No mandatory upgrade requirements will be introduced.

- For appliances and other equipment, labelling requirements will be continued and gradually tightened; the quality of the best classes will be updated continuously by way of best practice evaluations.

- Smart metering will be gradually introduced, but not used as an active control instrument yet.

- Support for power generation from renewable energy sources via the Renewable Energy Sources Act will continue; the goal for 2020 (25% to 30% share of net electric power generation) will be achieved; the cost degression requirements for new installations will continue to be configured ambitiously and reviewed; some offshore wind farms will be built.

- Continuous increase of heating using renewable energy sources (Act for Heat from Renewable Energy Sources, with continuous expansions).
- Trading and auctioning of CO_2 certificates; as a trading system, this will remain limited primarily to Europe; international negotiation processes will remain sluggish.
- In the option with CCS, the technology will be "authorised in principle" starting in 2020; following the merit order, it will enter the power plant fleet as a function of the cost and necessity of additional power plant construction.
- Subsidization options for combined heat and power will continue.
- The phase-out of nuclear power will be implemented as decided; there will be no transfer of remaining power output limits to old power plants.
- With the incentive of the EU Efficiency Services Directive (and successor projects), power utilities will make increasing efforts to utilise potential for efficiency in cooperation with their customers, including in the commercial sector.

4.2.3 Technological development

- This scenario expects no technological leaps forward, but a steady moderate improvement of efficiency is assumed in all aspects of energy consumption.
- Control and automation technology will optimize the "user behaviour" aspect.
- ICT will become more efficient and "greener," serious "green IT" initiatives will be implemented on grounds of cost-effectiveness – especially for computer centres and IT service providers, as well as for the backbone infrastructure. Significant elements of efficiency enhancement will be offset by capacity increases and more intensified use (continuing the trend to date).
- Technical methods for using waste heat will become widespread at all temperature levels in the industry and service sector.
- In the residential and service sectors, heat pumps will continue to gain ground in the heating structure. Absorption/adsorption-based heat pumps will increasingly be used bivalently to heat and cool rooms.
- Current technical developments in lighting will continue, with further gains in efficiency. Improved fluorescent lamps will completely replace incandescent lamps, and will in turn gradually yield to LED technology. LED technology will begin in the high-end sector, the technical sector, and street lighting. The next

generation of OLED (organic LED) technology will start to become established towards the end of the period under study.

- Industry and services will improve efficiency in the use of power. The most efficient equipment will become standard, and also be used in complex installations, especially in cross-application technologies like motors, compressed air, pumping and cooling.

- The specific consumption of vehicles will be reduced further. However, there will be no distinct shift in preferences for vehicle classes. In the passenger car market, hybrid vehicles, plug-in hybrids and electric cars will gradually be introduced. The admixture of biofuels will be mandated.

- Great strides will be made in the development of renewable energy sources. Electricity generated from thin-film solar cells will continue to become cheaper; the yields of wind farms will become more reliable as short-term forecasting improves; biomass processes will become somewhat more efficient; more biogas will be fed into the natural gas network.

4.3 Results

4.3.1 Energy consumption of the residential sector

4.3.1.1 Final energy consumption of space heating

More than 77% of the 2005 final energy consumption of the residential sector, adjusted for weather, was used for space heating. The following influencing factors were taken into account in calculating energy consumption for space heating:

- The quantity of housing and apartments and heated living space,

- The energy performance standards of residential buildings, expressed as demand in heat capacity (in watts/m2) or specific energy consumption (in kWh/m2/yr),

- Residents' behaviour,

- The performance standard of heating systems, expressed as the ratio of useful energy to final energy (technical efficiency in percent).

The duration of actual demand in heat capacity is determined by the residents' behaviour and the local number of heating degree days. The general warming caused by climate change of 1.75ºC by 2050 will cause the annual number of heating degree days, adjusted for weather, to decrease by 18.4%, and thus result in a lower duration of use of heating systems annually. Multiplying the demand in heat capacity by the actual hours of use yields the specific heating demand as a measure of energy demand (kWh/m^2).[2]

The official statistics for new-build and demolitions, together with additional detailed information, were used to derive the current inventory of living space by building type and heating system for 2005 (Table 4.3-1).

Table 4.3-1: Reference scenario: Existing living space in mid-2005, million m²

Reference scenario		District heating	Oil	Gas	Coal	Electricity	Heat pumps	Wood	Solar	Total
Single and two family buildings		51	794	903	36	105	15	31	1	1,937
Three-family and multi-unit buildings/ non-residential building		269	335	698	29	79	3	13	0	1,428
Total		321	1,129	1,602	65	184	18	44	2	3,364
of which:	empty	13	47	65	4	9	1	3	0	141
	occupied	307	1,082	1,537	60	175	18	41	2	3,223

Source: Federal Statistical Office, Prognos (own calculations)

4.3.1.2 Development of living space and heating systems

Based on the physically existing living space in 2005 and the assumed change in socio-economic base conditions (population, residential, age structure, income; see Sec. 3.1), living space is projected to expand by a total of 9% from 2005 to 2050 (Table 4.3-1). The maximum will appear in 2032; after that, living space will slowly shrink as a consequence of demographic developments.

The changes in heating systems for new homes, according to the reference scenario, is shown in Table 4.3-2.

In the calculations the replacement of heating systems for existing buildings and new buildings is treated separately, as the structure of fuel use for space heating differs between existing and new systems as well as for building types.

All in all, the trend away from oil and coal based heating systems and away from electric resistance heating will continue. Oil-heated living space is projected to decrease 23% by 2050, to about 829 million m^2; space heated with electric resistance heaters will decrease by 66%.

Living space heated with natural gas will continue to expand initially, but that trend reverses around 2030. All in all, gas-heated living space will be 9% greater in 2050

2 Projections of heat capacity or heating energy demand for the existing housing stock use either net usable floor space or living space as the quantity component, making distinctions for various types of buildings. Here it should be noted that net useful floor space and living space differ by some 5 to 15%. For that reason, the explicit requirements for heating energy demand under the Energy Saving Regulation (EnEV) cannot be applied directly to living space used as a reference value. The results presented below are based on figures for living space (following the practice of the official statistics on buildings and housing).

than in 2005. This projection takes account of “new” gas technologies like gas heat pumps and mini or micro gas turbines.

The greatest increase will be in heat pumps. Living space heated by these is projected to increase from 18 million m^2 in 2005 to nearly 286 million m^2 in 2050. Most of this increase will be in single-family homes and duplexes.

Table 4.3-2: Reference scenario: Heating structure of new residential construction 2005 – 2050, in % of new living space

		Reference scenario			
	2005	2020	2030	2040	2050
Single-family homes and duplexes					
District heating	3.9%	5.4%	6.4%	7.4%	8.4%
Oil	12.7%	3.1%	3.1%	3.1%	3.2%
Gas	74.2%	40.2%	33.6%	29.2%	26.6%
Coal	0.2%	0.0%	0.0%	0.0%	0.0%
Wood	2.9%	15.1%	16.1%	16.6%	16.6%
Electricity (n/incl. heat pumps)	1.5%	1.3%	1.3%	1.2%	1.2%
Electric heat pumps	4.3%	30.6%	30.4%	30.4%	30.4%
Solar	0.3%	4.3%	9.1%	12.0%	13.6%
Three-family and multi-unit buildings					
District heating	17.5%	20.0%	20.9%	22.0%	23.0%
Oil	5.3%	1.4%	1.5%	1.5%	1.4%
Gas	74.8%	61.3%	55.6%	52.2%	50.2%
Coal	0.2%	0.0%	0.0%	0.0%	0.0%
Wood	0.6%	5.7%	6.4%	6.4%	6.4%
Electricity (n/incl. heat pumps)	0.5%	0.5%	0.3%	0.2%	0.2%
Electric heat pumps	1.1%	8.1%	8.9%	8.9%	8.9%
Solar	0.0%	2.9%	6.4%	8.9%	9.8%
Non-residential buildings					
District heating	17.5%	20.2%	21.2%	22.4%	23.3%
Oil	5.3%	1.4%	1.4%	1.3%	1.3%
Gas	74.8%	61.3%	55.6%	52.2%	50.2%
Coal	0.2%	0.0%	0.0%	0.0%	0.0%
Wood	0.6%	5.5%	6.0%	6.0%	6.3%
Electricity (n/incl. heat pumps)	0.5%	0.6%	0.5%	0.5%	0.4%
Electric heat pumps	1.1%	8.2%	9.0%	9.1%	9.0%
Solar	0.0%	2.9%	6.2%	8.5%	9.5%
All buildings					
District heating	7.1%	8.9%	9.7%	10.6%	11.7%
Oil	11.0%	2.7%	2.8%	2.8%	2.8%
Gas	74.3%	45.2%	38.5%	34.3%	31.8%
Coal	0.2%	0.0%	0.0%	0.0%	0.0%
Wood	2.4%	12.8%	13.9%	14.3%	14.4%
Electricity (n/incl. heat pumps)	1.2%	1.1%	1.1%	1.0%	1.0%
Electric heat pumps	3.5%	25.2%	25.6%	25.7%	25.6%
Solar	0.2%	4.0%	8.5%	11.3%	12.8%

Source: Prognos 2009

Living space heated with district heating will increase by 118 million m^2 during the period under study; wood-based space heating will increase by 109 million m^2, and solar-based space heating will increase by 68 million m^2.

In spite of the stagnation or decrease in the oil- and gas-heated living space, gas and oil will remain the most important energy sources for space heating. More than 70% of living space will still be heated with these fuels in 2050 (Table 4.3-4). This is because of these energy sources' large initial share in 2005 and the slow diffusion of alternative energy sources, as a consequence of long renewal and replacement cycles.

Table 4.3-3: Reference scenario: Heating structure of existing living space 2005 – 2050, in million m^2

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
All homes					
District heating	307	358	391	410	425
Oil	1,082	1,010	959	895	829
Gas	1,537	1,733	1,765	1,732	1,677
Coal	60	35	32	31	29
Wood	41	73	103	129	150
Electricity (n/incl. heat pumps)	175	147	119	89	59
Heat pumps	18	114	181	238	286
Solar	2	15	32	51	70
Total housing stock	3,223	3,485	3,583	3,576	3,525
Of which: single-family and duplex					
District heating	49	72	86	98	108
Oil	761	716	687	651	612
Gas	867	1,012	1,049	1,052	1,039
Coal	33	20	18	18	17
Wood	29	58	84	107	127
Electricity (n/incl. heat pumps)	100	84	69	53	36
Heat pumps	15	97	155	204	246
Solar	1	11	23	37	50
All single-family and duplex	1,856	2,069	2,171	2,220	2,235

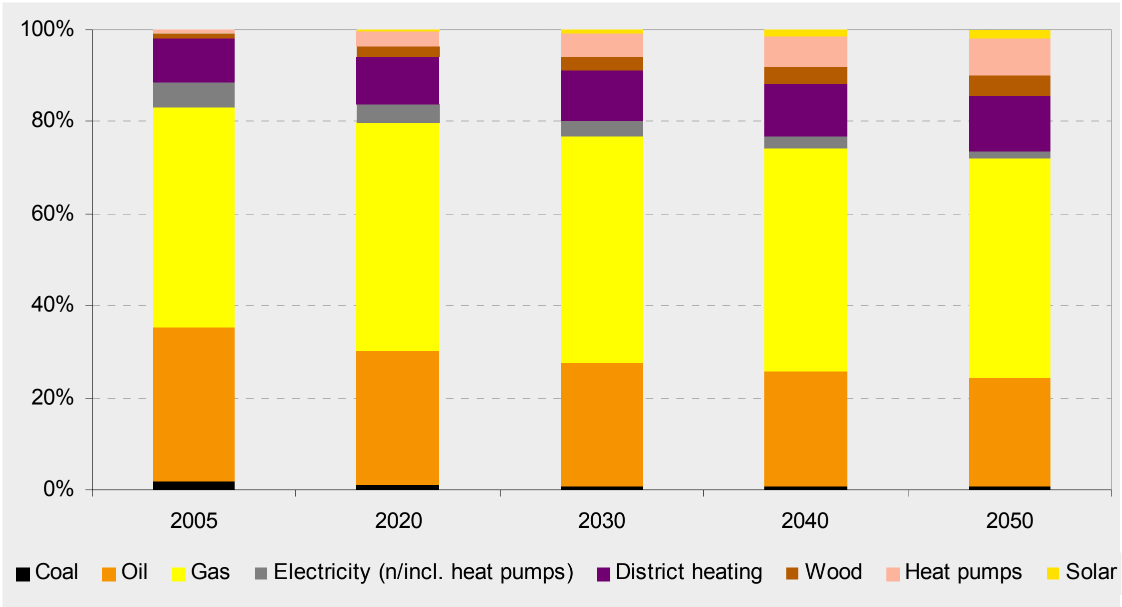
Source: Prognos 2009

Table 4.3-4: Reference scenario: Heating structure of existing living space 2005 – 2050, in %

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
District heating	9.5%	10.3%	10.9%	11.5%	12.1%
Oil	33.6%	29.0%	26.8%	25.0%	23.5%
Gas	47.7%	49.7%	49.3%	48.4%	47.6%
Coal	1.9%	1.0%	0.9%	0.9%	0.8%
Wood	1.3%	2.1%	2.9%	3.6%	4.3%
Electricity (n/incl. heat pumps)	5.4%	4.2%	3.3%	2.5%	1.7%
Heat pumps	0.5%	3.3%	5.1%	6.7%	8.1%
Solar	0.1%	0.4%	0.9%	1.4%	2.0%
All living space	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Prognos 2009

Figure 4.3-1: Reference scenario: Heating structure of existing living space 2005 – 2050, in % (occupied housing)



Source: Prognos 2009

4.3.1.3 Energy performance standard of living space and heating systems

The energy performance standard of a building is expressed in its specific heat capacity, which is determined by the shape of the building, the construction materials employed, maintenance condition, and any upgrade measures. Additionally, subjective factors, such as residents' ventilation behaviour or the desired interior temperature, also play a role in thermal energy demand.

New buildings and changes in the housing stock are significant for changes in the average thermal energy demand. Energy upgrades of building shells and the replacement of old heating systems, in some cases changing energy sources at the same time, can reduce thermal energy demand. The reference scenario assumes that upgrade rates will remain stable, and that annual construction of new space will decrease from 25 million m^2 in 2005 to about 9 million m^2 in 2050. For that reason, energy-saving refurbishment will become increasingly important over the period being studied.

For new buidlings, the reference scenario assumes a further significant reduction in heat capacity, in part because of the implementation of the planned German Energy Saving Ordinance (Energieeinsparverordnung, EnEV) in 2009 and a further tightening of the EnEV in 2015. The regulations will be tightened still further every five years to 2050 (decreasing from 25% to 5%), until the passive house standard is achieved in new buildings, equivalent to an annual thermal energy demand of 15 kWh/m^2.

Upgrade efficiency, defined here as the percentage of energy improvement per upgrade case, depends on the initial condition of the unrenovated building, the scope of upgrades, and the date of the upgrade. For the scope of upgrades, it is assumed that on average a heat capacity will be achieved that is 30% greater than the heat capacity in new buildings (referred to the date of the upgrade). The later an upgrade is made, accordingly, the greater the upgrade efficiency and the reduction of thermal energy demand.

The frequency of upgrades depends primarily on the building's age and type. The reference scenario retains the upgrade cycles that have been observed historically: single-family homes and duplexes less than 10 years old are generally not upgraded; the annual upgrade rate rises from 0.1% to 1.1% for homes between 10 and 35 years old, and remains at the same level after that. Multi-unit buildings are upgraded more often. Their annual upgrade rate is already 0.1% for buildings only 5 years old or more; it rises with building age to reach a maximum of about 1.4% p.a. at 25 years or so, and then declines slightly for older buildings.

Table 4.3-5: Reference scenario: Frequency of energy-saving refurbishment depending on building age, in % per year

Building age	Reference scenario									
	2001-2005	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Single-family homes and duplexes										
till 1918	1.5%	1.4%	1.3%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1919-1948	1.5%	1.4%	1.3%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1949-1968	1.5%	1.4%	1.3%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1969-1978	0.7%	1.0%	1.2%	1.2%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1979-1987	0.5%	0.4%	0.5%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
1987-1991	0.2%	0.4%	0.3%	0.4%	0.8%	1.1%	1.1%	1.1%	1.1%	1.1%
1992-1995	0.0%	0.1%	0.2%	0.2%	0.2%	0.5%	1.1%	1.1%	1.1%	1.1%
1996-1997	0.0%	0.2%	0.2%	0.2%	0.2%	0.5%	1.1%	1.1%	1.1%	1.1%
1998-2000	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.5%	1.1%	1.1%	1.1%
2001-2005		0.0%	0.1%	0.2%	0.2%	0.2%	0.5%	1.1%	1.1%	1.1%
2006-2010			0.0%	0.1%	0.2%	0.2%	0.2%	0.5%	1.1%	1.1%
2011-2015				0.0%	0.1%	0.2%	0.2%	0.2%	0.5%	1.1%
2016-2020					0.0%	0.1%	0.2%	0.2%	0.2%	0.5%
2021-2025						0.0%	0.1%	0.2%	0.2%	0.2%
2026-2030							0.0%	0.1%	0.2%	0.2%
2031-2035								0.0%	0.1%	0.2%
2036-2040									0.0%	0.1%
2041-2046										0.0%
Multi-unit and non-residential buildings										
till 1918	1.6%	1.5%	1.4%	1.3%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
1919-1948	1.6%	1.5%	1.4%	1.3%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
1949-1968	1.6%	1.5%	1.4%	1.3%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
1969-1978	1.6%	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%	1.2%	1.2%
1979-1987	1.5%	1.5%	1.4%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.2%
1987-1991	1.1%	1.3%	1.4%	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%	1.3%
1992-1995	0.1%	0.7%	1.3%	1.3%	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%
1996-1997	0.1%	0.7%	1.3%	1.3%	1.4%	1.3%	1.3%	1.3%	1.3%	1.3%
1998-2000	0.0%	0.1%	0.7%	1.3%	1.3%	1.4%	1.3%	1.3%	1.3%	1.3%
2001-2005		0.1%	0.7%	1.3%	1.3%	1.4%	1.4%	1.3%	1.3%	1.3%
2006-2010			0.1%	0.7%	1.3%	1.3%	1.4%	1.4%	1.3%	1.3%
2011-2015				0.1%	0.7%	1.3%	1.3%	1.4%	1.4%	1.3%
2016-2020					0.1%	0.7%	1.3%	1.3%	1.4%	1.4%
2021-2025						0.1%	0.7%	1.3%	1.3%	1.4%
2026-2030							0.1%	0.7%	1.3%	1.3%
2031-2035								0.1%	0.7%	1.3%
2036-2040									0.1%	0.7%
2041-2046										0.1%

Source: Prognos 2009

The energy performance standard of heating systems is expressed by the annual utilisation ratio, and represents a total efficiency of the heating system averaged over the year. The annual utilisation ratio represents the ratio between useful energy consumption (thermal energy demand) and final energy consumption. It also includes standby and distribution losses from the heating system, which as a rule come to between 3 and 8%.

Efficiencies greater than 100% for natural gas and oil heaters can be explained by the use of condensing boiler systems. Condensing boilers can achieve efficiencies of more than 100% (referred to the lower heating value) because these boilers retrieve the latent heat of the water in the flue gas by condensation.

Table 4.3-6 shows the development of the average utilisation ratio for the existing stock of systems, the mean specific thermal energy demand, and the specific final energy consumption resulting from the combination of the two. All in all, the specific thermal energy demand is projected to decrease 49% over the period under study, equivalent to an average annual efficiency increase of 1.6%. The specific final energy consumption will decrease 58% (–2% p.a.)

Table 4.3-6: Reference scenario: Mean specific thermal energy demand, utilisation ratio and final energy consumption by existing residential building stock, 2005 – 2050

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Thermal energy demand (MJ/m2)	473	385	328	280	236
Utilisation ratio (%)	83	92	97	100	102
Final energy consumption (MJ/m2)	573	417	337	280	231

Source: Prognos 2009

The final energy consumption for space heating is obtained by relating living space to specific final energy consumption (Table 4.3-7). The levels shown are weather-neutral figures that permit a better estimation of development trends. Global warming – the continuous increase of 1.75ºC in mean annual temperature by 2050 – is taken into account in the weather-adjusted consumption figures.

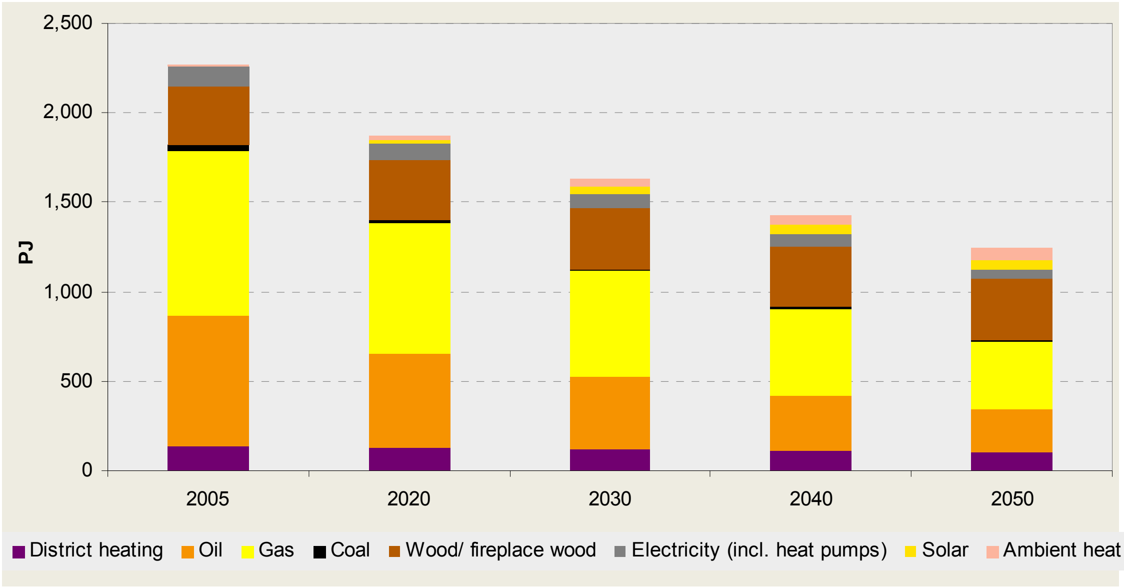
Table 4.3-7: Reference scenario: Final energy consumption for space heating 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
District heating	137	132	124	112	99
Oil	730	519	403	313	241
Gas	919	733	589	480	383
Coal	38	19	14	12	9
Wood/ firewood	326	333	339	342	342
Electricity (incl. heat pumps)	113	97	81	67	54
Solar	1	12	38	49	53
Ambient heat	4	24	44	54	61
Total	2,268	1,869	1,632	1,429	1,242

Source: Prognos 2009

The final energy consumption for space heating steadily declines from 2005 to 2050. Because of the expansion of living space, final energy consumption decreases less steeply on the whole than specific consumption. At the end of the period under study, final energy consumption will be 45% below the initial value.

Figure 4.3-2: Reference scenario: Final energy consumption for space heating 2005 – 2050, in PJ



Source: Prognos 2009

Heating oil and natural gas will become less important, but will still remain quantitatively the most important energy sources even in 2050. At the end of the period under study, they will account for some 60% of final energy consumption for space heating. Fossil natural gas will be replaced in part by biogas. Biogas's share of gas consumption will be approx. 10%.

4.3.1.4 Final energy consumption of water heating

The households served by a conventional central hot water system are calculated on the basis of housing stock, as a function of energy source and heating system.

Currently, centrally heated homes usually use the same energy source to heat water as for space heating. On that basis, it is assumed that homes with central hot water will represent a stagnating or declining share of the central heating inventory of conventional heating systems (oil, natural gas, coal and district heating). This determines the proportion of households and of the population that is supplied with hot water via a central system.

In the remaining residential sector, hot water is supplied by conventional decentralised systems, central heat pumps, or solar water heating systems. The projection of the structure of water heating for the population is based on the following assumptions:

- Old water heating systems based on coal, wood and decentralised oil and natural gas systems will disappear almost entirely.
- Electric water heaters will become less important, with a share declining from 26% to 19%.

- Solar heating systems and process water heat pumps will gain market share. The share of the residential population served with hot water from solar installations will rise from 4% to 37%, and the share using heat pumps will rise from 1.5% to 9%.

- The share of central hot water systems (coupled and uncoupled) will rise following the same trend as central heating, and will be about 10% percentage points higher in 2050 than in 2005.

Table 4.3-8: Reference scenario: Structure of hot water supply for the German population 2005 – 2050, in million persons

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Hot water from Central systems coupled to heating					
District heating	7.0	6.2	5.9	3.9	3.2
Oil	16.9	12.6	10.7	10.0	8.0
Gas	27.7	24.6	22.2	12.8	13.7
Coal	0.3	0.2	0.1	0.2	0.1
Wood	0.2	0.4	0.5	0.1	0.1
Central, non-coupled systems					
Solar*	2.6	8.0	13.9	22.3	26.8
Heat pumps	1.0	3.7	4.7	6.4	6.7
Decentralised systems					
Electricity	21.2	22.2	20.5	20.3	13.9
Gas	4.1	1.7	0.0	0.0	0.0
Total persons served	81.0	79.6	78.5	76.1	72.4
No own hot water heating	1.4	0.2	0.0	0.0	0.0

** Converted to full supply* *Source: Prognos 2009*

The calculation is based on the assumption that the specific hot water consumption per capita will rise in the period under study. For reasons of comfort, hitherto per capita consumption for central hot water systems – which also include heat pumps and solar installations – has been higher than with decentralised hot water systems. Water consumption is likely to even out by 2050. For central heating systems, hot water consumption per capita will increase from 45 litres to 50 litres per day, assuming a temperature difference of 35ºC; for decentralised electric or gas systems it will rise from 42 litres to 50 litres.

Increasing efficiency of individual installations, together with the shift towards higher-efficiency systems (solar collectors and heat pumps) will result in a higher average utilisation ratio for water heating (Table 4.3-9). By 2050, the average utilisation ratio for water heating is projected to rise to 100%; in 2005 it was 74%.

Table 4.3-9: Reference scenario: Utilisation ratio of hot water supply 2005 – 2050, in %

		Reference scenario			
	2005	2020	2030	2040	2050
Central systems coupled to heating					
District heating	78	81	83	84	86
Oil	63	72	77	81	84
Gas	69	81	87	91	95
Coal	52	56	58	61	64
Wood	57	63	64	66	67
Central, non-coupled systems					
Solar*	100	100	100	100	100
Heat pumps	206	221	231	241	251
Decentralised systems					
Electricity	92	92	92	92	92
Gas	73	77	79	79	79
Total hot water supply	74	86	92	97	100

** Converted to full supply* *Source: Prognos 2009*

The reference scenario assumes that in the long term, the hot water needed for washing machines and dishwashers will be provided in part from a central hot water system, not from electric heaters within the appliances themselves.[3] This implies a shift in energy consumption away from electric appliances and towards water heating.

The effects of higher utilisation ratios and a declining population, which will reduce consumption, will outweigh the effects of increasing per capita consumption, which would increase consumption. Consequently the final energy consumption for water heating will decline to the end of the period under study (Table 4.3-10) by a total of 16%. While energy consumption to heat water with gas, oil, district heating and coal will decrease significantly, environmental energy in the form of solar radiation and environmental heat (heat pumps) will see greater use.

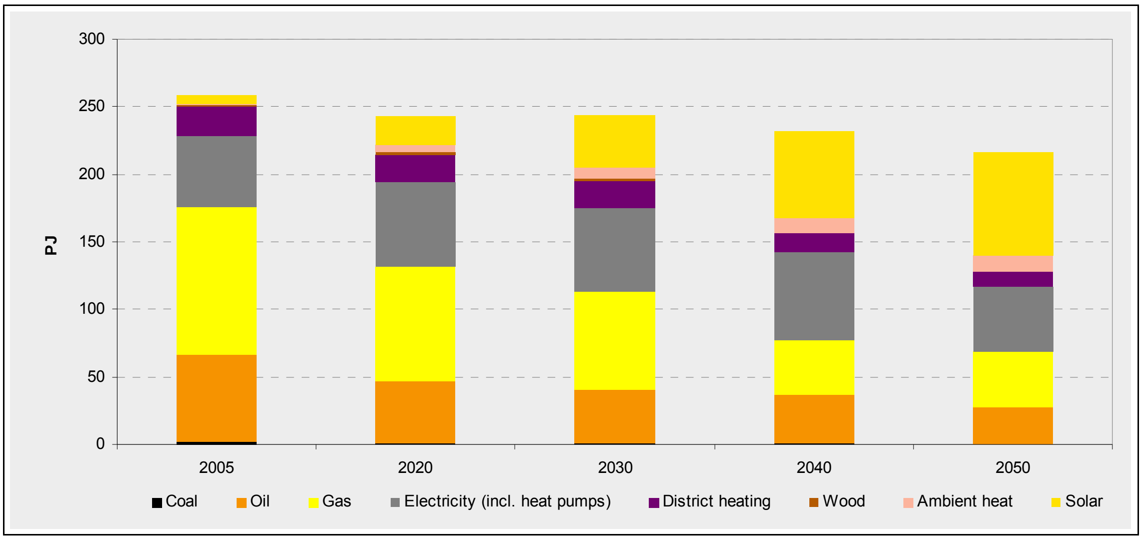
Table 4.3-10: Reference scenario: Final energy consumption of water heating 2005 – 2050, in PJ

		Reference scenario			
	2005	2020	2030	2040	2050
District heating	21.8	20.1	20.2	13.4	10.7
Oil	64.8	45.9	39.7	35.4	27.0
Gas	109.1	85.3	72.6	40.7	41.3
Coal	1.5	0.8	0.6	1.1	0.2
Wood	0.9	1.6	2.2	0.4	0.3
Electricity (incl. heat pumps)	53.0	62.7	61.7	65.6	48.5
Subtotal	251.0	216.4	197.2	156.7	128.2
Solar	6.3	20.9	39.5	64.6	76.5
Ambient heat	1.3	5.3	7.6	10.9	11.5
Total final energy consumption	258.6	242.5	244.3	232.2	216.2

Source: Prognos 2009

3 This quantity of water is not yet taken into account in the daily per capita consumption of 45 to 50 litres.

Figure 4.3-3: Reference scenario: Final energy consumption of water heating 2005 – 2050, in PJ



Source: Prognos 2009

4.3.1.5 Final energy consumption of cooking

Cooking plays a minor role in the final energy consumption of the residential sector, with a share of about 2%. Energy consumption for cooking is largely affected by the numbers of cooking stoves in households, the structure of the inventory of stoves (electric, gas, coal, wood stoves), and the specific consumptions for the individual stove types.

Because of demographic change, and the associated increase in small households, the intensity of stove usage will decrease. This change will be supported by the increasing importance of eating out or takeaway food, and the delivery of prepared meals to households of seniors. To this is added the factor that cooking functions are increasingly shifting from the stove to small appliances (microwaves, grills) that are counted as electric appliances (see further below).

The trend towards electric stoves will continue. Coal and wood stoves will vanish from the market. Gas stoves will remain an attractive niche application. As a consequence of these changes, energy consumption for cooking in 2050, at 32 PJ, will be about 45% less than in 2005 (Table 4.3-11).

Table 4.3-11: Reference scenario: Final energy consumption of cooking, 2005 – 2050

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Percent of households with stoves	99.0%	98.0%	97.0%	96.0%	95.0%
Electric stove	80.2%	84.6%	86.4%	88.0%	88.6%
Gas stove	18.9%	15.2%	13.5%	12.0%	11.4%
Wood or coal stove	0.8%	0.1%	0.0%	0.0%	0.0%
Appliances used (million)					
Electric stove	31.2	33.5	34.1	34.4	32.8
Gas stove	7.4	6.0	5.3	4.7	4.2
Wood or coal stove	0.3	0.1	0.0	0.0	0.0
Specific consumption in kWh per appliance per year					
Electric stove	383.2	328.7	285.3	251.3	230.7
Gas stove	576.4	479.8	408.1	352.3	317.1
Wood or coal stove	622.8	620.2	594.6	550.5	531.4
Final energy consumption in PJ					
Electric stove	43.0	39.6	35.0	31.1	27.2
Gas stove	15.3	10.4	7.8	6.0	4.8
Wood or coal stove	0.7	0.1	0.0	0.0	0.0
Total final energy consumption	59.0	50.1	42.9	37.1	32.1

Source: Prognos 2009

4.3.1.6 Power consumption of electrical appliances

The electrical appliances used in households includes what are known as “white goods” (large appliances like refrigerators, washing machines, dryers, dishwashers), entertainment equipment, information and communication (ICT) equipment, lighting, air conditioners, and other small appliances. Almost all devices have substantial potential for increasing their technical energy efficiency (Table 4.3-12).

During the period under consideration, the inventory of electrical appliances – whose service life as a rule is between 10 and 20 years – will be replaced several times. To take due account of the market penetration of new technologies, high-consumption large appliances like refrigerators, freezers, washing machines, dishwashers and televisions are projected using cohort models.

In refrigerators, an ongoing spread of magnetic refrigerators is assumed. Additionally, a limited amount of “waterless” washing machines will be introduced, thus eliminating the need for dryers and washer-dryers. The sharp decline in specific consumption for lighting is explained primarily by the ban on conventional incandescent bulbs. Consequently more efficient lighting will be used across the board.

The trend towards multifunctional ICT devices will continue. Since these devices see more intensive use than single-function devices, the influence of this structural change on energy consumption will remain small.

Table 4.3-12: Reference scenario: Development of equipment component in specific consumption, 2005 – 2050, in kWh per appliance per year (= mean consumption per existing unit of equipment per year)

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Light	281	125	105	42	33
Refrigerator	256	199	145	122	114
Refrigerator-freezer	329	237	156	114	95
Freezer	299	225	170	141	127
Washing machine	223	171	143	128	117
Washer-dryer	613	495	422	379	348
Dryer	298	235	204	183	166
Dishwasher	243	202	184	169	156
Colour TV	162	207	150	97	83
Radio / sound system	51	48	46	44	42
Video / DVD player	40	8	8	8	8
Electric iron	25	24	23	22	20
Vacuum cleaner	24	23	22	21	20
Coffee maker	85	85	68	68	68
Toaster	25	24	23	22	20
Hair dryer	25	24	23	22	20
Extraction hood (cooker)	45	43	41	39	37
Microwave	35	33	32	30	29
PC (incl. peripherals)	196	84	62	62	62
Communal area lighting, etc.	28	21	20	17	17

Source: Prognos 2009

In addition to technical progress, the number of electric devices in operation is also of critical importance for power consumption of the residential sector. This quantity component is determined by the number of households and what electrical equipment they have, also taking second units into account. Generally the scenario assumes that households will have increasing amounts of electrical equipment (Table 4.3-14).

The warmer climate will increase demand for building cooling. For that reason, the number of air conditioners will rise substantially during the period under study. In 2050, 45% of living space will be air conditioned; the specific cooling power will rise from 25 W/m^2 to 40 W/m^2.

Table 4.3-13: Reference scenario: Percentage of the residential sector with electric appliances (first appliances), 2005 – 2050, in %

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Light	100	100	100	100	100
Refrigerator	68	62	60	52	47
Refrigerator-freezer	32	38	40	48	53
Freezer	59	64	66	68	72
Washing machine	88	81	72	53	38
Washer-dryer	8	16	27	47	62
Dryer	38	41	40	33	25
Dishwasher	59	75	80	82	85
Colour TV	94	94	94	94	94
Radio / sound system	100	100	100	100	100
Video / DVD player	83	92	96	100	100
Electric iron	98	99	99	99	99
Vacuum cleaner	99	99	99	99	99
Coffee maker	95	98	100	100	100
Toaster	90	94	96	98	99
Hair dryer	81	84	87	89	93
Extraction hood (cooker)	59	66	69	70	73
Microwave	65	84	94	97	100
PC (incl. peripherals)	68	100	100	100	100

Source: Prognos 2009

Table 4.3-14: Reference scenario: Quantity components of electric appliances relevant for consumption, 2005 – 2050, in million

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Light	39	40	41	41	39
Refrigerator	31	29	27	22	18
Refrigerator-freezer	13	16	17	21	22
Freezer	26	29	30	31	31
Washing machine	35	33	29	22	15
Washer-dryer	3	7	11	19	24
Dryer	15	17	16	13	10
Dishwasher	23	30	33	33	33
Colour TV	58	63	65	67	66
Radio / sound system	39	40	41	41	39
Video / DVD player	35	41	43	45	43
Electric iron	38	40	40	40	39
Vacuum cleaner	39	40	40	40	39
Coffee maker	37	40	41	41	39
Toaster	35	38	39	40	38
Hair dryer	32	34	35	36	36
Extraction hood (cooker)	23	27	28	29	28
Microwave	26	34	38	40	39
PC (incl. peripherals)	41	99	111	118	118

Source: Prognos 2009

All in all, although the (unweighted) average number of devices will rise 18%, power consumption of electric devices will decrease 21%, and will be 18 TWh less in 2050 than in 2005 (Table 4.3-15). The consumption by individual groups of appliances will develop differently. Power consumption for cooling and freezing will decrease the most. The decrease of 11.5 TWh in consumption represents a drop of nearly 60% (Figure 4.3-4). The largest relative savings, at roughly 85%, are in lighting (–10 TWh). Power consumption for washing and drying will decrease 6 TWh by 2050 (–35%). These figures take into account that a rising share of hot water needed for washing machines and dishwashers will be provided by central heating systems. Consumption by ICT devices will decrease 4 TWh; power demand for small devices and other applications will decrease 1.3 TWh.

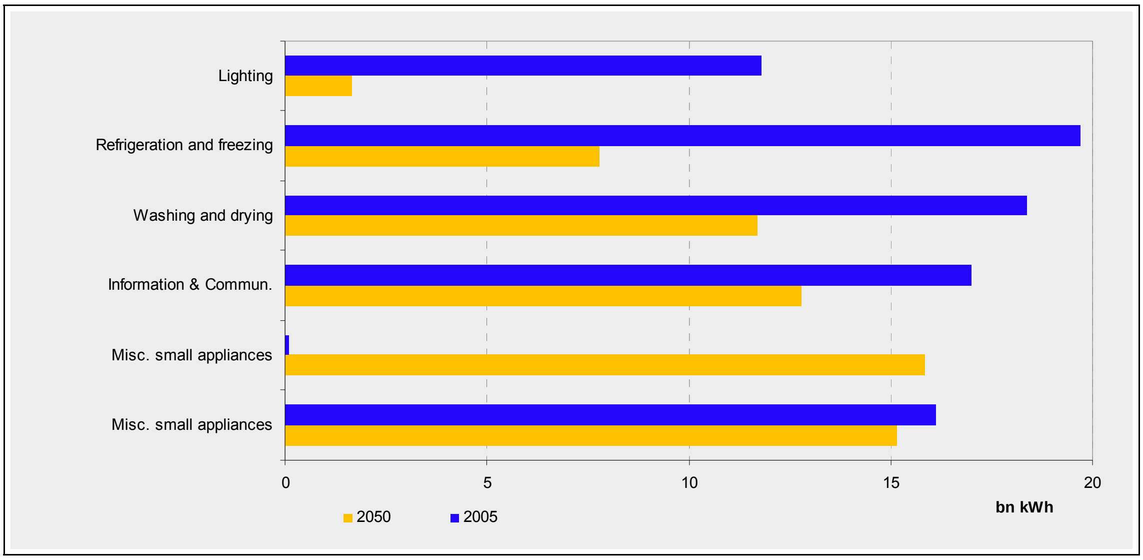
The decrease in power consumption of electrical equipment will be partially countered by the expansion of air conditioning. In 2050, some 15% of the power drawn by the residential sector will be used for this purpose (15.9 TWh).

Table 4.3-15: Reference scenario: Final energy consumption for electric appliances in the residential sector, 2005 – 2050, in billion kWh

		Reference scenario			
	2005	2020	2030	2040	2050
Light	11.2	5.2	4.4	1.8	1.3
Refrigerator	7.6	5.3	3.7	2.5	2.0
Refrigerator-freezer	4.2	3.7	2.6	2.3	2.0
Freezer	7.9	6.5	5.0	4.3	3.8
Washing machine	7.1	4.3	2.2	1.4	0.9
Washer-dryer	1.8	2.9	4.0	6.0	7.0
Dryer	4.1	3.4	2.8	2.0	1.3
Dishwasher	5.3	4.7	2.9	2.7	2.5
TV	7.0	9.8	7.5	5.1	4.4
Radio / sound system	1.9	1.8	1.7	1.6	1.5
Video / DVD player	1.3	0.3	0.3	0.3	0.3
Electric iron	0.9	0.8	0.8	0.7	0.7
Vacuum cleaner	0.9	0.9	0.8	0.8	0.7
Coffee maker	3.1	3.2	2.6	2.6	2.4
Toaster	0.9	0.9	0.8	0.8	0.7
Hair dryer	0.8	0.8	0.7	0.7	0.7
Extraction hood (cooker)	1.0	1.1	1.1	1.0	1.0
Microwave	0.9	1.1	1.1	1.1	1.0
PC (incl. peripherals)	6.8	6.7	5.7	6.3	6.6
Communal area lighting, etc.	0.6	0.5	0.4	0.4	0.3
Air conditioning	0.0	2.6	7.1	11.1	15.9
Other consumption	7.7	9.0	10.0	9.1	7.9
Total final energy consumption	83.0	75.4	68.4	64.5	64.9

Source: Prognos 2009

Figure 4.3-4: Reference scenario: Final energy consumption of electric appliances in the residential sector by type of use, 2005 and 2050, in billion kWh



Source: Prognos 2009

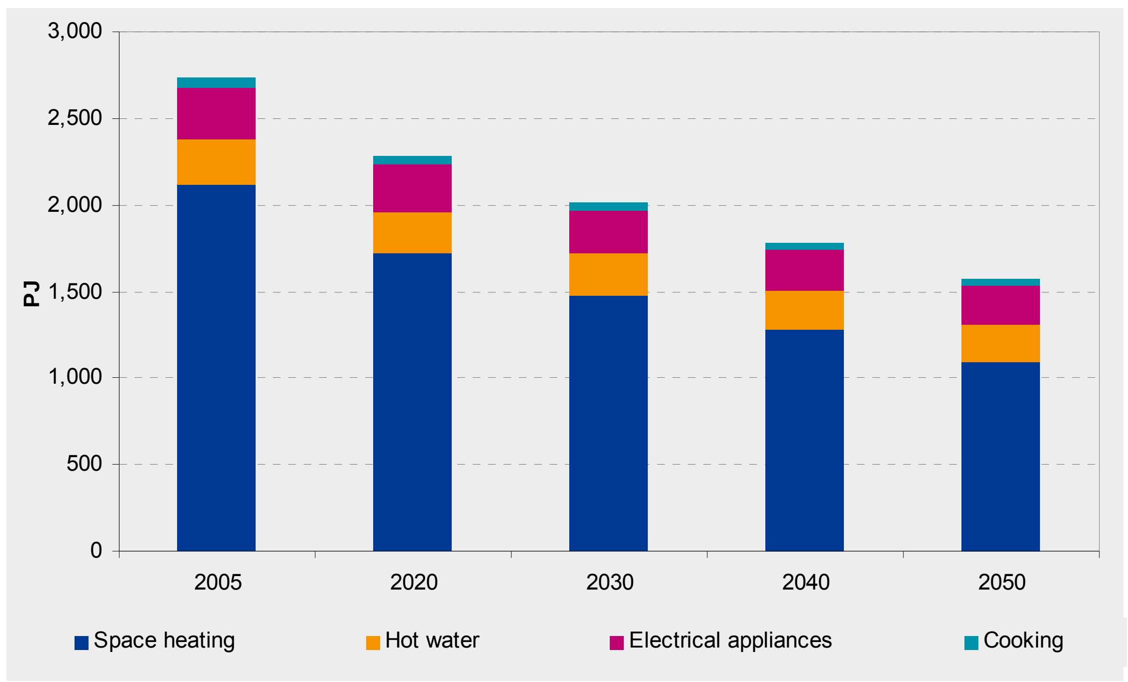
4.3.1.7 Final energy consumption

Energy consumption by residential is dominated by space heating. This use accounted for about 77.5% of total energy consumption in 2005. Water heating and electrical equipment used about 10% each. Cooking, at 2%, played only a minor role in energy consumption (Figure 4.3-5).

During the period under consideration, the various uses' shares of total consumption will shift slightly. The share of space heating will decrease to just under 70%, while the share for water heating will rise to 14% and the share for electrical equipment will rise to 15%. The share for cooking will not change significantly (Table 4.3-16).

In contrast to the use structure, the quantity consumed will change significantly during the period. In the reference scenario, the energy consumption by residential will decrease from 2,735 PJ in 2005 to 1,569 PJ in 2050 (–42%).

Figure 4.3-5: Reference scenario: Final energy consumption in the residential sector by type of use (space heating, hot water, cooking, electric appliances), 2005 – 2050, in PJ



Source: Prognos 2009

Table 4.3-16: Reference scenario: Final energy consumption of electric appliances in the residential sector by type of use, 2005 – 2050, in PJ and %

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Type of use					
Space heating	2,118	1,718	1,479	1,275	1,087
Hot water	259	243	244	232	216
Cooking	59	50	43	37	32
Electrical appliances	299	271	246	232	234
Total final energy consumption	2,735	2,282	2,013	1,777	1,569
Share in %					
Space heating	77.5%	75.3%	73.5%	71.8%	69.3%
Hot water	9.5%	10.6%	12.1%	13.1%	13.8%
Cooking	2.2%	2.2%	2.1%	2.1%	2.0%
Electrical appliances	10.9%	11.9%	12.2%	13.1%	14.9%

Source: Prognos 2009

The various energy sources develop differently (Table 4.3-17). Consumption of fossil fuels will decrease significantly. Heating oil consumption will decrease by 66%, gas consumption will decrease 63%, and coal consumption will decrease by 77%. Nevertheless the fossil fuels oil, natural gas and coal will still have a share of about 42% of consumption in 2050. There will also be decreases in the use of district heating (–31%) and electricity (–28%).

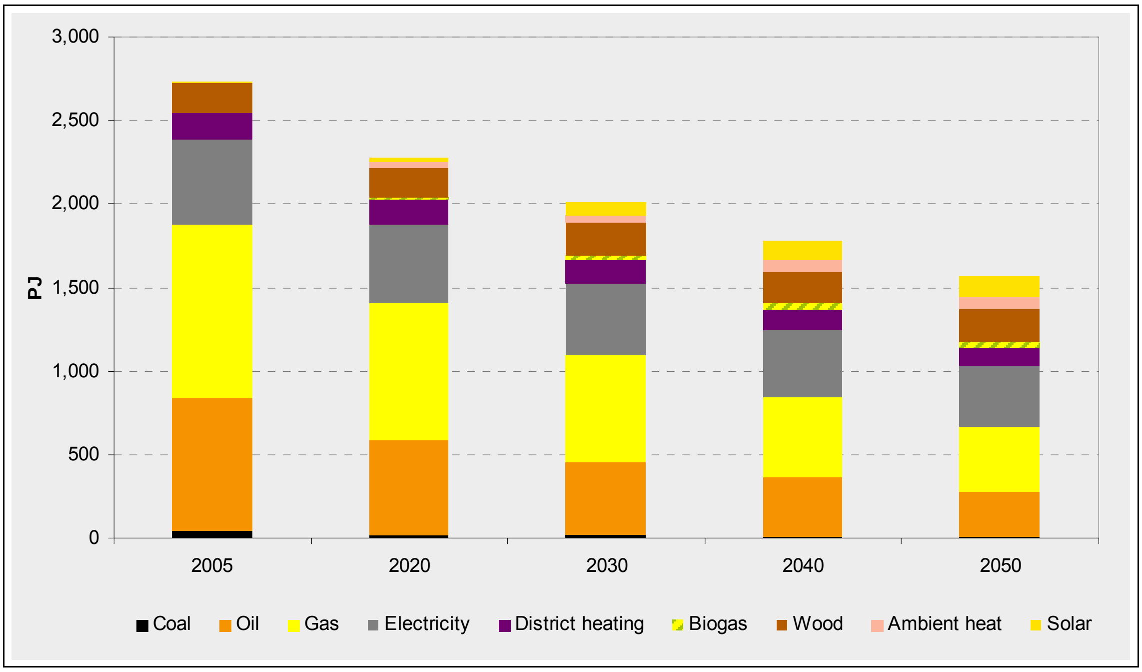
By contrast, the use of renewable energy sources will increase. Wood consumption will rise 6%, to 188 PJ. The use of environmental heat will rise by a factor of 11, solar heat will rise by a factor of 18, and biogas use will rise to 40 PJ. In 2050, renewable energy sources will cover 27% of household energy demand.

Table 4.3-17: Reference scenario: Final energy consumption in the residential sector, 2005 – 2050, by energy source, in PJ and %

		Reference scenario			
	2005	2020	2030	2040	2050
Energy source in PJ					
District heating	158	153	144	126	110
Oil	795	565	442	348	268
Gas	1,043	819	638	489	389
Coal	40	19	15	13	9
Wood	178	184	188	189	188
Electricity	508	470	424	396	364
Ambient heat	6	29	52	65	73
Solar	7	33	78	114	129
Biogas	0	9	32	38	40
Total final energy consumption	2,735	2,282	2,013	1,777	1,569
Structure in %					
District heating	5.8%	6.7%	7.2%	7.1%	7.0%
Oil	29.1%	24.8%	22.0%	19.6%	17.1%
Gas	38.1%	35.9%	31.7%	27.5%	24.8%
Coal	1.5%	0.9%	0.8%	0.7%	0.6%
Wood	6.5%	8.1%	9.4%	10.6%	12.0%
Electricity	18.6%	20.6%	21.1%	22.3%	23.2%
Ambient heat	0.2%	1.3%	2.6%	3.7%	4.6%
Solar	0.3%	1.5%	3.9%	6.4%	8.2%
Biogas	0.0%	0.4%	1.6%	2.1%	2.5%

Source: Prognos 2009

Figure 4.3-6: Reference scenario: Final energy consumption in the residential sector by energy source, 1990 – 2050, in PJ



Source: Prognos 2009

4.3.2 Energy consumption by the service sector

4.3.2.1 Framework data

Energy consumption in the commerce, retail and service sector (called the service sector below) is broken down by segments and is oriented to the development of associated segment-specific leading indicators. These indicators are typically the number of persons employed in the segment, and gross value added. These were projected using the Prognos macro model, as explained in Chapter 3 (see Appendix G).

Gross value added in 2050 will be 46% above the 2005 level. This is associated with a further structural change. Banking and insurance, transport and communications, other private services – already strong segments – as well as healthcare will see gross value added grow by as much as 72%. In some cases, growth in service segments will be accelerated by outsourcing of activities from the industry sector. For example, "other private services" include industry-related services and specialised research. By contrast, growth in agriculture and gardening, small industrial and craft businesses, the construction industry, and public administration will be far below average. The same will apply to employment in these segments.

Despite growing gross value added, the number of persons employed will decrease by about 10% between 2005 and 2050. This development will parallel the structural change and the advance of automation. The number of persons employed in agriculture and gardening, small industrial and crafts businesses, the construction industry, and public administration will decrease by as much as 45%. By contrast, employment in healthcare will increase 15%.

Table 4.3-18: Reference scenario: Framework data for service sector, 2005 – 2050

		Reference scenario			
	2005	2020	2030	2040	2050
Persons employed (in 1,000)					
Agriculture, gardening	853	702	611	533	464
Small industrial / crafts	1,673	1,331	1,188	1,061	953
Construction	2,185	1,968	1,834	1,686	1,597
Retail	5,903	5,628	5,345	5,081	4,813
Banking / insurance	1,239	1,127	1,082	1,037	1,005
Transport, telecommunications	2,118	2,187	2,179	2,175	2,132
Other private services	9,675	11,089	10,478	9,834	9,574
Healthcare	4,036	4,830	4,655	4,504	4,625
Education	2,281	2,521	2,403	2,298	2,282
Government, social insurance	2,298	2,059	1,857	1,676	1,534
Defence	373	350	350	350	350
All segments	32,634	33,792	31,982	30,235	29,329
Gross value added (EUR bn)					
Agriculture, gardening	23	23	23	23	23
Small industrial / crafts	68	77	80	82	86
Construction	76	71	69	66	65
Retail	215	234	252	268	294
Banking / insurance	69	85	90	95	107
Transport, telecommunications	114	145	159	173	196
Other private services	598	704	776	853	963
Healthcare	141	178	192	209	233
Education	84	91	92	93	97
Government, social insurance	99	111	108	107	108
Defence	16	19	20	22	25
All segments	1,503	1,736	1,861	1,991	2,196

Source: Prognos 2009

Apart from the leading indicators for quantity components, changes in specific energy consumption will also be significant. Consumption will differ as a function of energy source and individual types of use. Further factors in determining energy consumption for space heating are floor space, broken down by segment, and the office or non-residential of the energy performance standard buildings.

The individual segments differ substantially in their predominant types of use of energy (Table 4.3-19). As a consequence, the specific energy consumption varies (Figure 4.3-7).

Energy demand for space heating plays a dominant role in education and healthcare. Since specific consumption for space heating will decrease as much as 70% by 2050, specific consumption in these segments as a whole will decrease more than average. The development of the energy performance standard of office or non-residential buildings roughly approximates that in the household sector. In other words, the specific space heating demand per unit of floor space will decrease sharply on average. Since old buildings in the service and industry sectors are often torn down and replaced with new ones rather than being upgraded, turnover in the inventory of buildings here will be somewhat faster, and space heating demand in some segments will fall faster than for residential buildings.

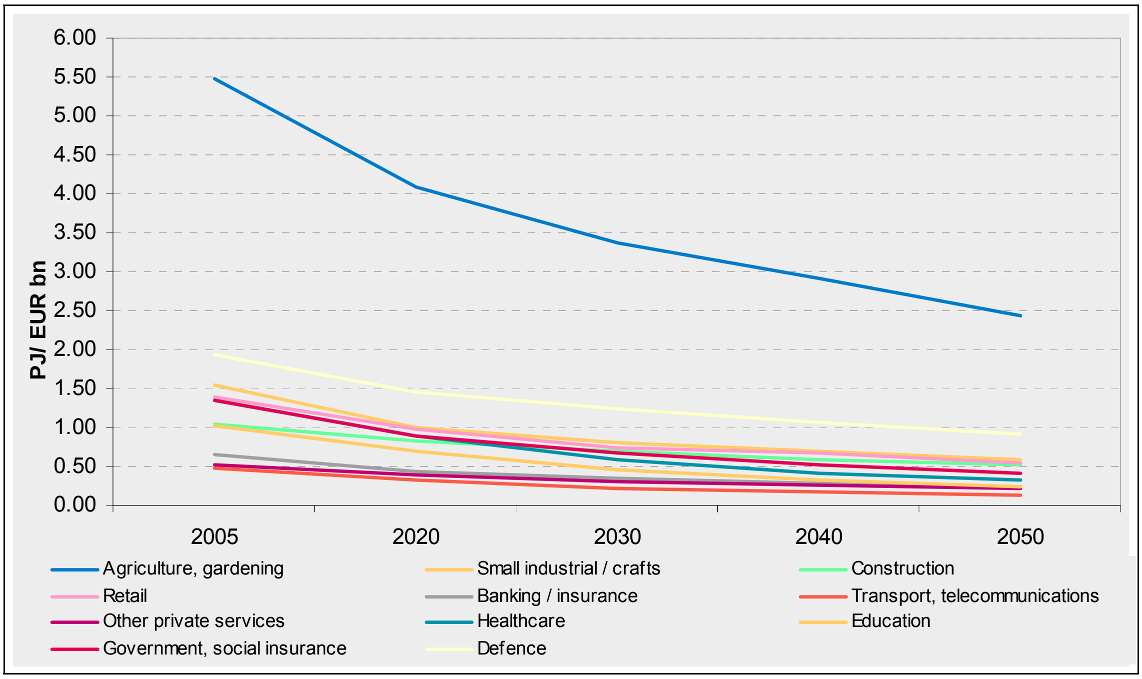
In agriculture and gardening, small industrial and crafts businesses, the construction industry, and defence, energy is used primarily for process heat and to generate force (mechanical work, including drive mechanisms). Specific consumption for these applications will not decrease as rapidly as for space heating. The highest specific consumption in 2005 was in the agricultural and defence segments. We assume that the force applications for mechanical drives there will see improvements in efficiency similar to those in the transport sector.

Table 4.3-19: Reference scenario: Specific consumption (energy consumption / gross value added) in service sector, absolute (in PJ/EUR bn) and indexed, 2005 – 2050, model results, temperature-adjusted

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Specific consumption					
Agriculture, gardening	5.48	4.09	3.38	2.92	2.44
Small industrial / crafts	1.54	1.00	0.80	0.69	0.58
Construction	1.04	0.83	0.69	0.60	0.53
Retail	1.39	0.98	0.75	0.67	0.55
Banking / insurance	0.65	0.43	0.34	0.29	0.24
Transport, telecommunications	0.49	0.32	0.22	0.17	0.13
Other private services	0.53	0.39	0.30	0.26	0.22
Healthcare	1.34	0.89	0.59	0.41	0.33
Education	1.02	0.70	0.45	0.32	0.25
Government, social insurance	1.34	0.90	0.67	0.52	0.42
Defence	1.93	1.46	1.24	1.07	0.91
Normalised specific consumption					
Agriculture, gardening	100	75	62	53	45
Small industrial / crafts	100	65	52	45	38
Construction	100	80	66	57	51
Retail	100	71	54	48	39
Banking / insurance	100	66	52	45	37
Transport, telecommunications	100	66	46	34	26
Other private services	100	75	58	49	42
Healthcare	100	67	44	31	25
Education	100	69	45	31	24
Government, social insurance	100	67	50	39	31
Defence	100	75	64	55	47

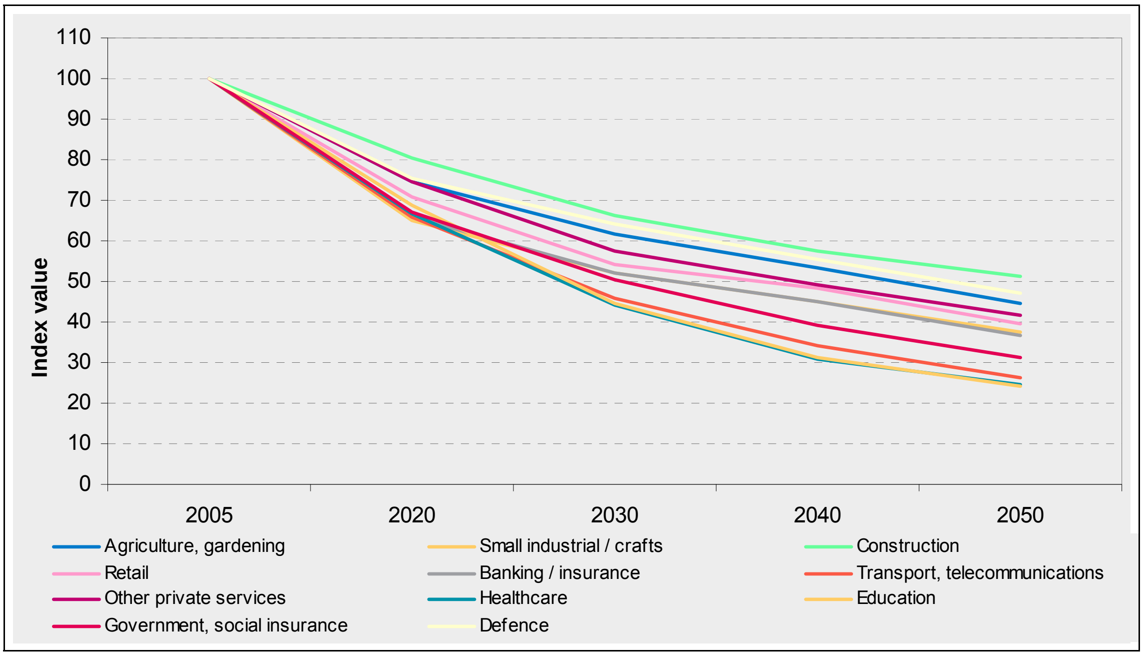
Source: Prognos 2009

Figure 4.3-7: Reference scenario: Specific final energy consumption in service sector by segment, 2005 – 2050, in PJ/EUR bn



Source: Prognos 2009

Figure 4.3-8: Reference scenario: Specific final energy consumption in service sector by segment, 2005 – 2050, indexed to 2005



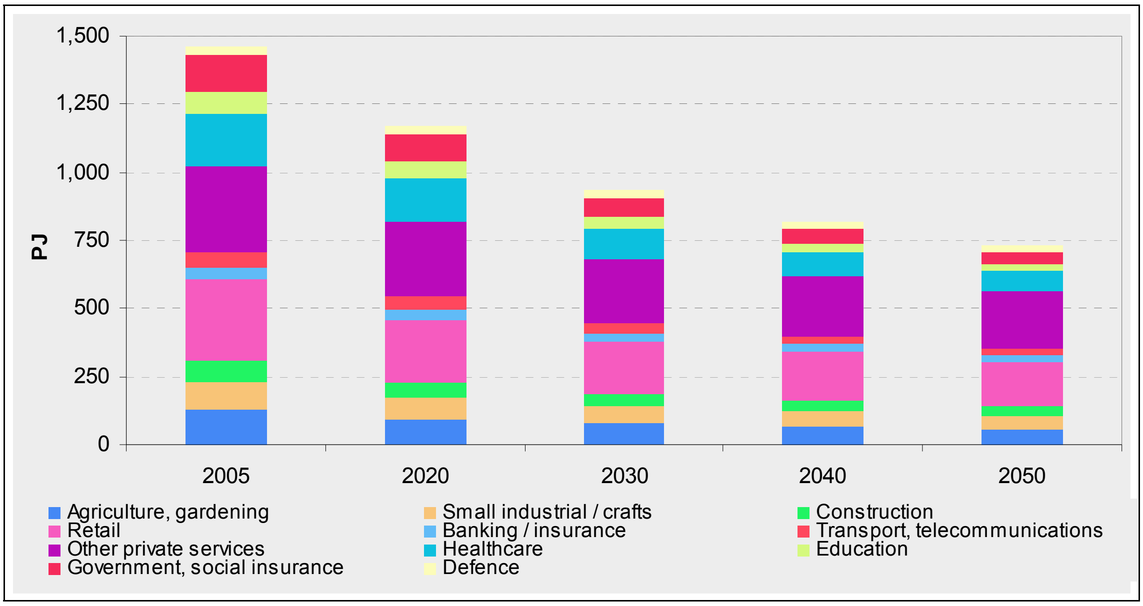
Source: Prognos 2009

4.3.2.2 Final energy consumption

In the reference scenario, final energy consumption in the service sector will decrease 50% between 2005 and 2050, from 1,462 PJ to 726 PJ. This is equivalent to an average annual decrease of approx. 1.6% (Figure 4.3-9).

This declining trend is evident in all the segments combined under the service sector, and results from the sometimes contrary effects of growth in driver quantities (gross value added) and changes in efficiency. A more detailed consideration shows that savings are below average in banking and insurance, other private services, and retail. The main reason here is these segments' especially dynamic economic growth. The declines in energy consumption are clearest in education and in public administration. A substantial reduction in energy consumption in these segments results from low segment growth (change in gross value added) and from the great significance for most of them of space heating, office equipment and air conditioning – all of which are presumed to have substantial efficiency increases in the reference scenario.

Figure 4.3-9: Reference scenario: Final energy consumption in service sector by segment, 2005 – 2050, in PJ



Source: Prognos 2009

There are sometimes substantial shifts among individual energy sources. Electricity's share is projected to increase to represent more than 60% of energy demand in 2050, 30 percentage points more than in 2005. Gas will cover 20% of demand in 2050, compared to more than 35% in 2005. The shares of district heating and petroleum (heating oil and motor fuels) will decrease by more than half. Coal will vanish almost entirely. Liquid petroleum products will be replaced almost entirely by natural gas for producing process heat. In this sector, natural gas will increasingly also be used to generate electricity in combined heat and power operation.

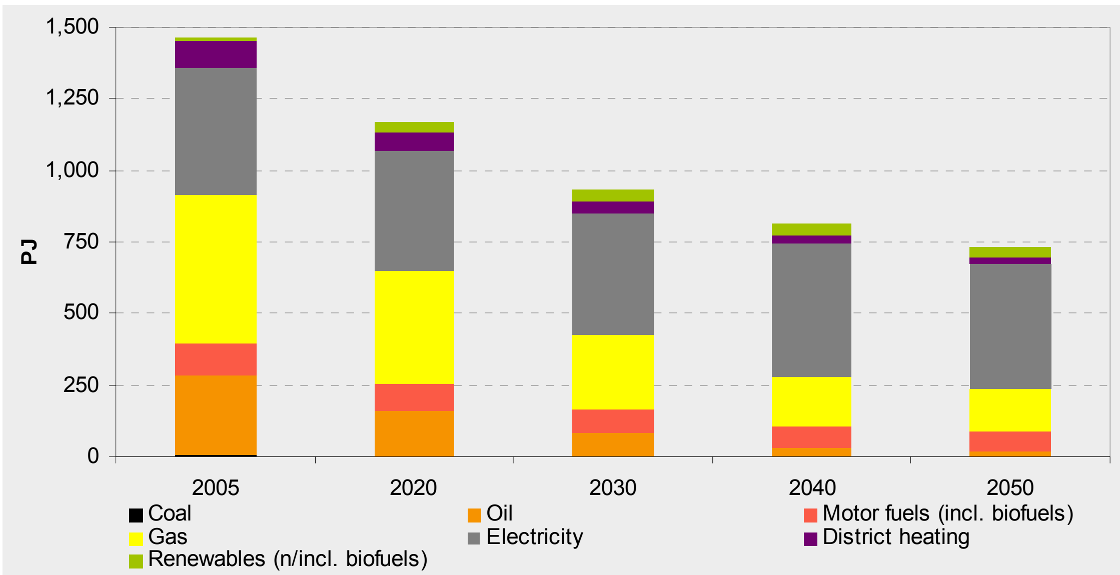
The share of renewables will increase substantially, while remaining low in absolute terms. This is in part because a typical area where renewable energy sources can be used at low cost is space heating, where savings will have already been achieved by efficiency measures. Biogas, and especially biogenic residues, can be used to generate process heat. A further share will be covered by ambient heat or waste heat, which can be recycled with heat pumps or heat transformers for further heating or cooling uses.

Table 4.3-20: Reference scenario: Final energy consumption in service sector, 2005 – 2050, by segment, type of use and energy source, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Segment					
Agriculture, gardening	127	95	78	67	57
Small industrial / crafts	104	77	63	56	50
Construction	79	59	47	39	35
Retail	298	230	189	180	160
Banking / insurance	45	36	30	28	25
Transport, telecommunications	55	47	35	29	25
Other private services	315	277	236	222	211
Healthcare	189	158	114	86	76
Education	85	63	42	30	24
Government, social insurance	133	100	73	56	45
Defence	32	27	25	24	22
All segments	1,462	1,169	933	815	731
Type of use					
Space heating	664	415	189	53	7
Process heat	310	310	301	292	291
Cooling and ventilation	65	85	137	213	215
Lighting	148	119	97	80	66
Office equipment	56	52	45	36	28
Mechanical force	220	189	165	142	124
All types of use	1,462	1,169	933	815	731
Energy source					
Coal	5	0	0	0	0
Oil	279	159	80	30	20
Gas	515	394	256	171	147
Electricity	443	415	426	465	439
District heating	96	69	43	28	22
Renewables (n/incl. biofuels)	10	34	41	44	35
Motor fuels (incl. biofuels)	114	98	87	76	67
All energy sources	1,462	1,169	933	815	731

Source: Prognos 2009

Figure 4.3-10: Reference scenario: Final energy consumption in service sector by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

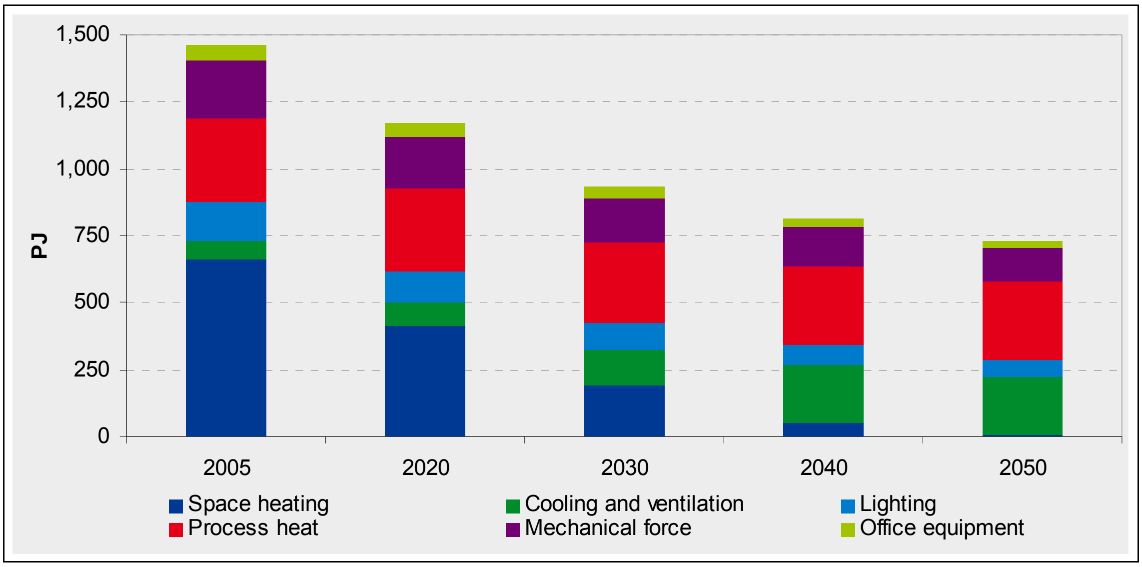
4.3.2.3 Final energy consumption by type of use

The shares of types of use in total consumption shift substantially during the period under study. The share for space heating will decline to nearly zero. By contrast, the shares for cooling and ventilation and for process heat will increase substantially. The shares for lighting and office equipment do not change significantly (Table 4.3-20). In parallel with the use structure, consumption quantities will also change significantly during the period.

By 2050, energy consumption for space heating will decline to nearly zero. The principal reasons here are the extreme reduction in mean final energy demand per square meter of heated space (approx. –70%), the decrease in building area in general (approx. –15%), and global warming, which by 2050 will result in a further decrease of about 20% in mean final energy demand for heating per square meter of living space.

The specific energy demand of the installations used to generate process heat is projected to decrease an average of between 24% (electricity) and 35% (combustibles) during the period under consideration. Technical improvements in systems for generating heat and steam will largely parallel progress in industry. These assumptions include heavier use of waste heat and general improvements in processes and equipment.

Figure 4.3-11: Reference scenario: Final energy consumption in service sector by type of use, 2005 – 2050, in PJ



Source: Prognos 2009

A substantial increase in energy consumption for cooling and ventilation (+300%) can be expected between 2005 and 2050. The reason is the increase of installed appliances for air conditioning in buildings. It is assumed that all new office/non-residential buildings will be routinely equipped with air conditioning systems. This trend will be amplified by global warming.

Lighting uses, which account for about 10% of the final energy demand of the service sector, will need about half as much energy in 2050 as in 2005. This is because of the extensive realisation of potential for savings here. Among the options that might be used here are reflector grid lamps, electronic ballasts, and dimming as a function of daylight. Moreover, broader use of daylight for room lighting can also save electricity. Here it must be borne in mind that the original situation for lighting in the service sector was significantly more efficient than in the household sector, since fluorescent lamps are the preferred lighting here. The relative savings from the use of even more efficient technology are therefore less than in the case of an original situation that still includes incandescent bulbs.

There are also significant opportunities to reduce specific energy consumption by office equipment. More recent generations of units often consume over 60% less than their predecessor models. Power consumption of desktop computers, for example, can be lowered to the level of portable devices. Additionally, appropriate segments (ICT) will make greater use of “green IT” applications for cost-efficiency reasons. By 2050, final energy demand for this use will decrease by half.

As a rule, motor fuels and electricity are used to deliver force – i.e., to generate mechanical work. The change in the specific consumption of diesel engines, which are widely used, will parallel developments in the transport sector. In the case of electric motors, which are used for example to run conveyor systems, pumps, and compressed-air systems, higher specific savings are possible (up to 80% in some cases), but these will not necessarily always be realised in each case. Energy demand will decrease 40% by 2050 in the reference scenario.

4.3.3 Energy consumption by the industry sector

4.3.3.1 Framework data

Energy consumption in industry is derived at the industry segment level from the combination of a quantity component and an efficiency component.

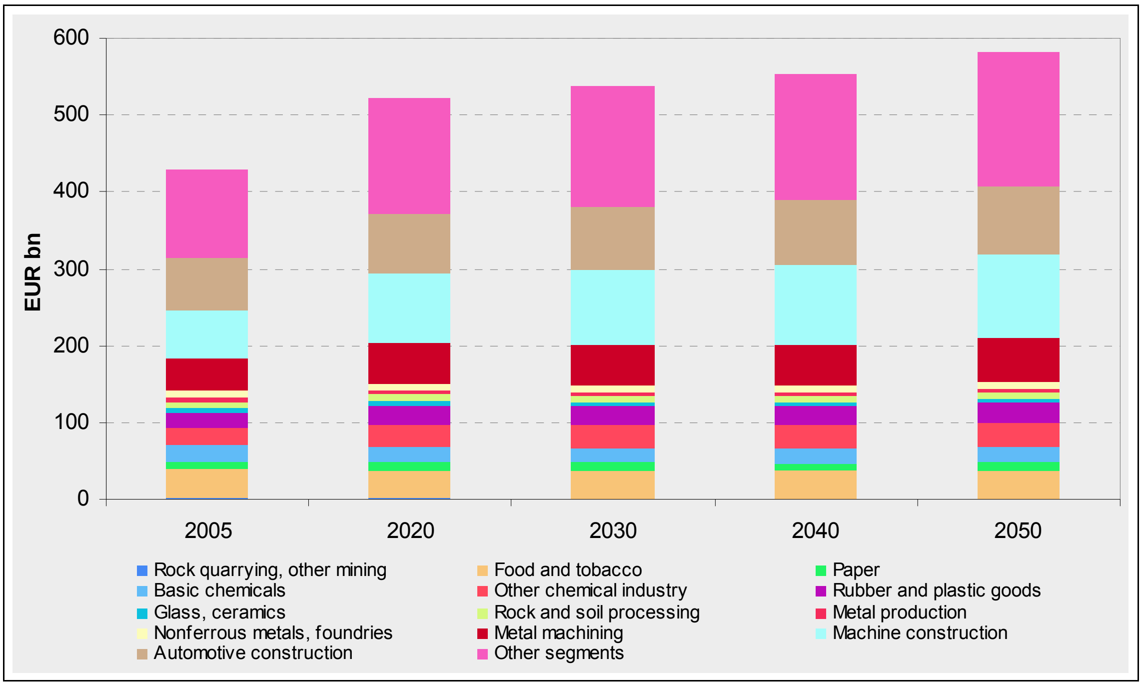
Table 4.3-21: Reference scenario: Industrial production 2005 – 2050 (categories from energy balance sheet), EUR bn, in 2000 prices

		Reference scenario			
	2005	2020	2030	2040	2050
Rock quarrying, other mining	1.9	1.3	1.1	1.0	0.9
Food and tobacco	37.3	37.0	36.3	35.7	37.0
Paper	10.4	11.1	10.6	10.5	10.7
Basic chemicals	20.7	20.1	19.1	19.0	19.8
Other chemical industry	23.0	29.0	29.7	30.4	32.0
Rubber and plastic goods	20.6	24.0	24.2	24.5	25.5
Glass, ceramics	5.2	6.3	5.9	5.7	5.7
Rock and soil processing	8.0	7.9	7.8	7.7	8.0
Metal production	6.0	5.9	4.9	4.4	4.4
Non-ferrous metals, foundries	8.3	8.9	8.8	8.8	8.9
Metal machining	41.3	51.5	53.1	54.6	57.3
Machine construction	64.0	91.9	97.9	102.4	108.7
Automotive construction	68.0	77.8	80.7	84.3	89.3
Other segments	115.5	149.6	158.1	164.5	173.2
All segments	430.3	522.0	538.1	553.4	581.3

Source: Prognos 2009

The quantity component, expressed as a value for industrial production or output, will rise approx. 35% from 2005 to 2050. This is equivalent to an annual growth rate of less than 0.7%. As in the service sector, for the reference scenario this production development, differentiated by segments, is calculated using the Prognos macro model with moderate "world development." Here production in the energy-intensive segments largely declines. By contrast, non-energy-intensive segments grow, thus continuing the trend to date. All in all, the assumption is that primarily high-value, knowledge-intensive products will be produced in highly developed industrialised nations, and thus the "value density" of products will rise. A typical example is high-grade special steels, which are optimised for specific requirements and therefore have a substantially higher value and price per physical unit of product (mass in metric tons) than conventional steels do. Another example is vehicles, in which "high-quality" brands command higher production levels for approx. the same amount of material input (and in correlation, also the same amount of energy input). Some industrial value added will migrate to the service sector by way of outsourcing and changes in the organisation of value chains and processes (e.g., IT, communications, contracted research, marketing, building operations, etc.).

Figure 4.3-12: Reference scenario: Industrial production 2005 – 2050 (categories from energy balance sheet), EUR bn, in 2000 prices



Source: Prognos 2009

The individual industry segments contribute very differently to this sector's production output. Currently – and this will hold true in the future as well – the largest contributions come from machine construction and manufacturing (with the strongest growth in both absolute and relative terms), automotive construction, metalworking, other chemicals and plastics, and the food and tobacco industry. The segments summarised under "other industries" each have lower production output levels individually than the "smallest" segment shown here, stone and soil quarrying.

The efficiency component in most segments is reflected by the energy intensity – broken down between combustibles and electricity – referred to each segment's value produced. A further decrease in energy intensity in the various industry segments can be expected during the period under consideration. However, the decrease will tend to level off or weaken over time, since unless entirely new production methods are introduced, the technical potential for savings will decrease. One example is the use of high-efficiency heat generators, which is already common practice today and limits the potential for further improvements in this area. Similar considerations apply for other types of applications. The basic materials industries are in some cases approaching the physical and technical limits of energy efficiency improvements. In general, it can be assumed that in the energy-intensive industries, the relative and absolute potential for energy savings in conventional processes is also limited by the fact that optimisation here is already being continuously kept up for cost reasons. In contrast to the non-energy-intensive segments and most service segments, here the cost of energy represents more than 5% to 10% of production cost. For that reason, a number of investments in savings are economically attractive here, and are regularly carried out.

Table 4.3-22: Reference scenario: Specific fuel consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

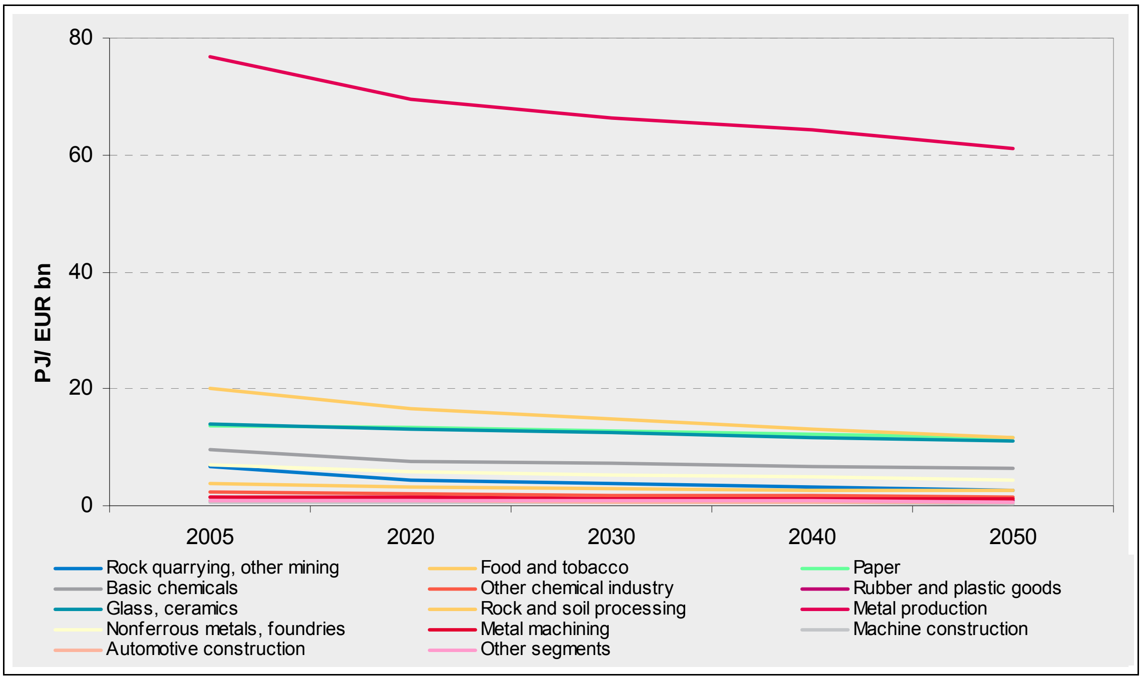
		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	6.6	4.3	3.7	3.1	2.5
Food and tobacco	3.8	3.3	3.0	2.7	2.5
Paper	13.6	13.3	12.8	12.2	11.7
Basic chemicals	9.7	7.6	7.2	6.8	6.4
Other chemical industry	2.2	2.0	1.8	1.7	1.5
Rubber and plastic goods	1.5	1.2	1.1	1.0	1.0
Glass, ceramics	14.1	13.2	12.5	11.7	11.0
Rock and soil processing	19.9	16.5	14.8	13.1	11.7
Metal production	76.7	69.6	66.4	64.2	61.1
Non-ferrous metals, foundries	7.0	5.8	5.3	4.9	4.5
Metal machining	1.4	1.3	1.2	1.2	1.1
Machine construction	0.7	0.6	0.5	0.5	0.4
Automotive construction	0.8	0.7	0.7	0.6	0.6
Other segments	1.0	0.8	0.8	0.7	0.7
All segments	3.7	2.8	2.5	2.2	2.0

Source: Prognos 2009

Despite these limitations, a reduction in the intensity of fuel and electricity use in industry is foreseeable. Contributions here will come not only from segment-specific technical developments, but also from improvements in energy efficiency in processes and applications that are used across many sectors of the economy (cross-application technologies) (Table 4.3-22, Table 4.3-23).

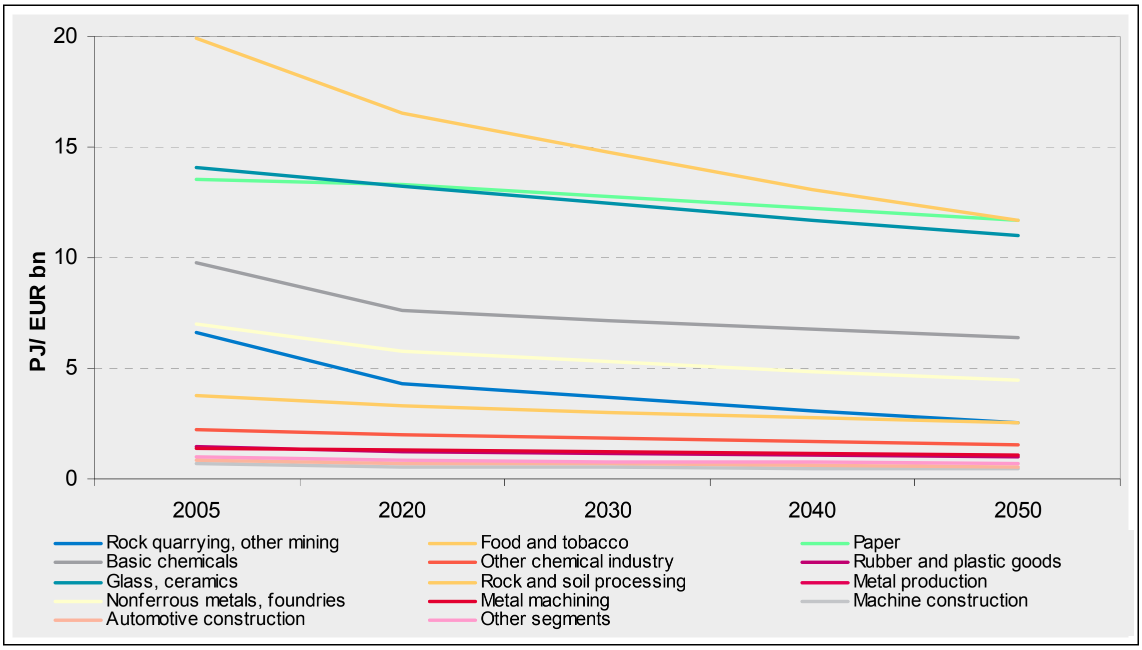
Metal production has by far the highest specific demand for fuel. It is followed by paper, basic chemicals, glass and ceramics, stone and soil quarrying and processing, and non-ferrous metals/foundries, with medium specific fuel consumption. All other segments are at the lower end (Figure 4.3-13, Figure 4.3-14, Figure 4.3-15).

Figure 4.3-13: Reference scenario: Specific fuel consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn



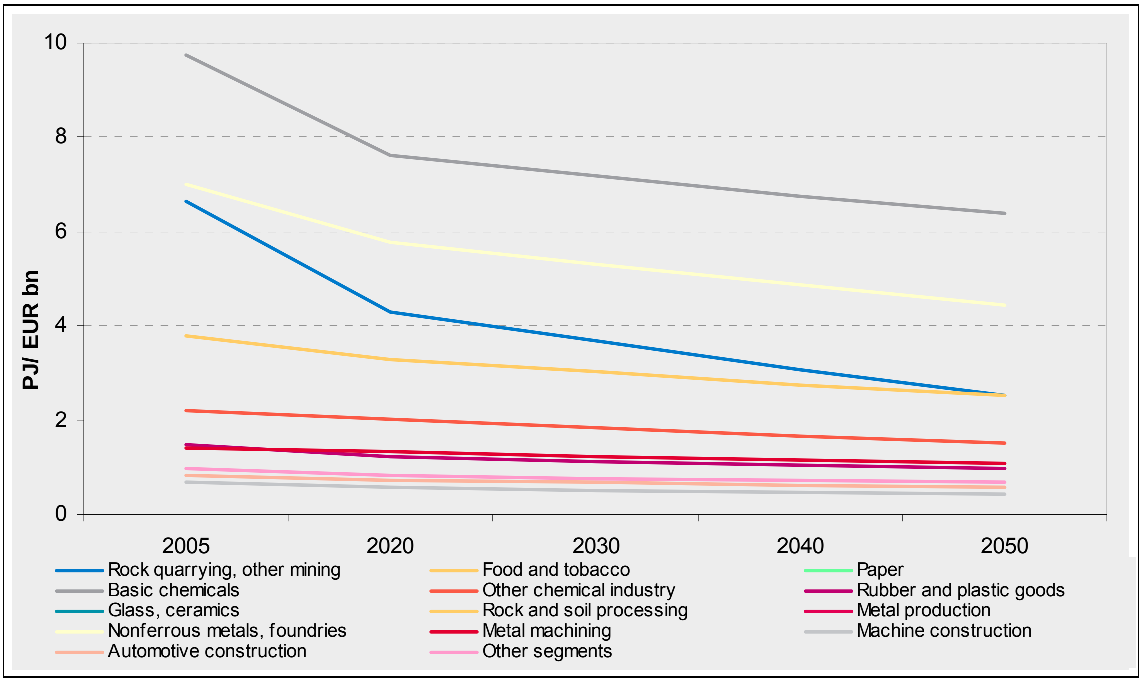
Source: Prognos 2009

Figure 4.3-14: Reference scenario: Specific fuel consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn, excluding metal production



Source: Prognos 2009

Figure 4.3-15: Reference scenario: Specific fuel consumption for industry (categories from energy balance sheet), 2005 – 2050, in PJ/EUR bn, non energy-intensive segments



Source: Prognos 2009

In specific power consumption, there are options for savings in uses for mechanical energy, lighting, and information and communication. Using energy-efficient electric motors, compressed-air systems, pumps (cross-application technologies), lighting fixtures, and PCs with their peripherals, helps reduce specific power consumption. However, the increasing electrification of previously fuel-based production modes will limit the reduction in specific power consumption by 2050 to a total of 33%.

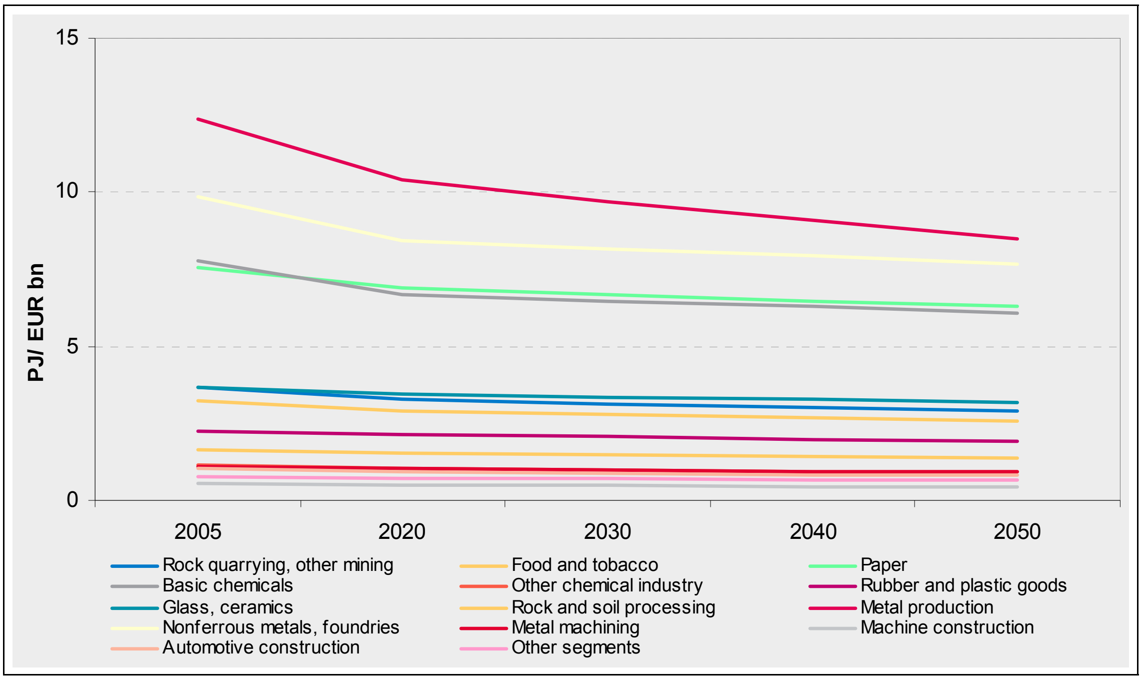
The segments with the highest specific power consumptions are metal production (electric furnace steel), non-ferrous metals/foundries, basic chemicals and the paper industry; stone and soil quarrying has a medium specific power consumption. All other segments (including metalworking, machine construction and automotive construction) are significantly lower by comparison (Figure 4.3-16, Figure 4.3-17, Table 4.3-24).

Table 4.3-23: Reference scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

		Reference scenario			
	2005	2020	2030	2040	2050
Rock quarrying, other mining	3.7	3.3	3.1	3.0	2.9
Food and tobacco	1.6	1.5	1.5	1.4	1.4
Paper	7.5	6.9	6.7	6.5	6.3
Basic chemicals	7.8	6.7	6.5	6.3	6.1
Other chemical industry	1.2	1.0	1.0	0.9	0.9
Rubber and plastic goods	2.2	2.1	2.1	2.0	1.9
Glass, ceramics	3.7	3.5	3.4	3.3	3.2
Rock and soil processing	3.2	2.9	2.8	2.7	2.6
Metal production	12.4	10.4	9.7	9.1	8.5
Non-ferrous metals, foundries	9.8	8.4	8.2	7.9	7.7
Metal machining	1.1	1.0	1.0	0.9	0.9
Machine construction	0.6	0.5	0.5	0.5	0.4
Automotive construction	1.0	0.9	0.9	0.8	0.8
Other segments	0.8	0.7	0.7	0.7	0.6
All segments	1.9	1.6	1.4	1.4	1.3

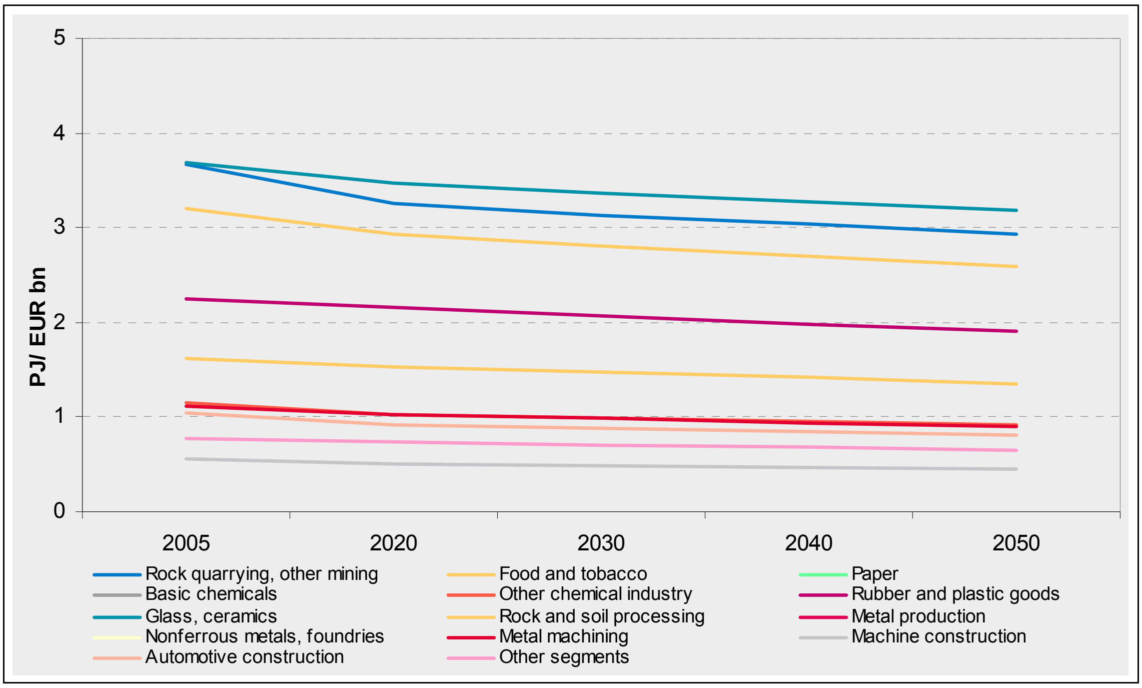
Source: Prognos 2009

Figure 4.3-16: Reference scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn



Source: Prognos 2009

Figure 4.3-17: Reference scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn, excluding electricity-intensive segments



Source: Prognos 2009

All in all, the specific energy consumption by industry in the Reference scenario will decline 42% by 2050 (Table 4.3-24).

Table 4.3-24: Reference scenario: Specific energy consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

		Reference scenario			
	2005	2020	2030	2040	2050
Rock quarrying, other mining	10.3	7.5	6.8	6.1	5.5
Food and tobacco	5.4	4.8	4.5	4.2	3.9
Paper	21.1	20.2	19.4	18.7	18.0
Basic chemicals	17.5	14.3	13.6	13.0	12.5
Other chemical industry	3.4	3.1	2.8	2.6	2.4
Rubber and plastic goods	3.7	3.4	3.2	3.0	2.9
Glass, ceramics	17.8	16.7	15.8	15.0	14.2
Rock and soil processing	23.1	19.5	17.6	15.8	14.2
Metal production	89.0	80.0	76.1	73.3	69.6
Non-ferrous metals, foundries	16.8	14.2	13.5	12.8	12.1
Metal machining	2.5	2.4	2.2	2.1	2.0
Machine construction	1.2	1.1	1.0	0.9	0.9
Automotive construction	1.9	1.7	1.6	1.5	1.4
Other segments	1.8	1.6	1.5	1.4	1.3
All segments	5.6	4.4	3.9	3.5	3.3

Source: Prognos 2009

4.3.3.2 Final energy consumption

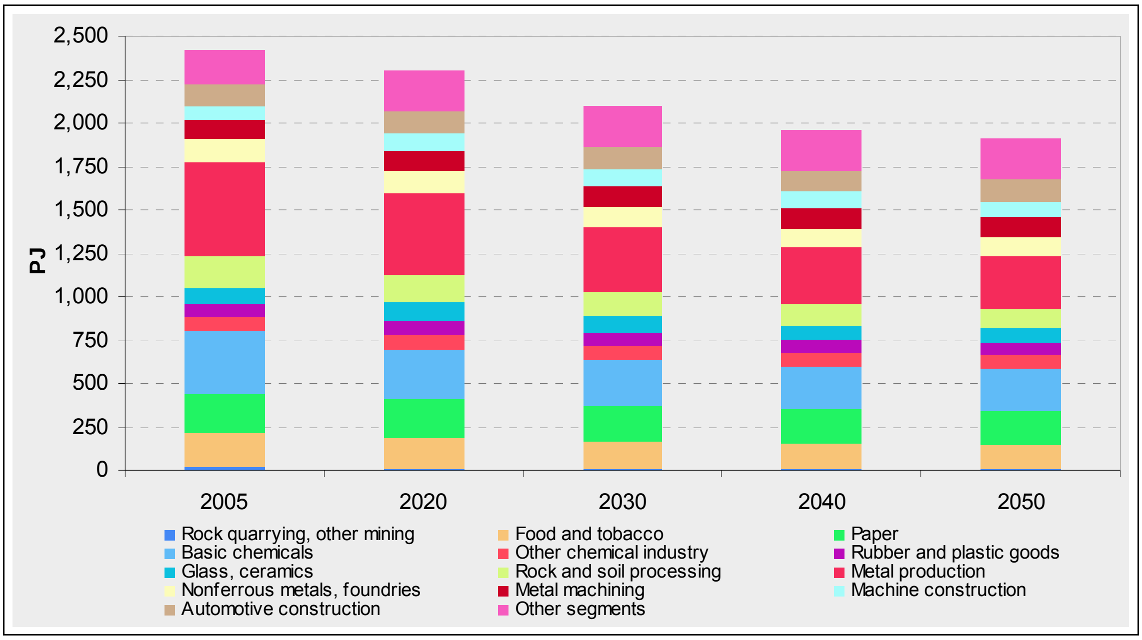
Final energy consumption in the industrial sector will decrease 21% between 2005 and 2050, as a consequence of the mostly contrary effects of segment growth and efficiency enhancement.

Table 4.3-25: Reference scenario: Final energy consumption for industry, 2005 – 2050 (categories from energy balance sheet), by segment, in PJ/EUR bn

		Reference scenario			
	2005	2020	2030	2040	2050
Rock quarrying, other mining	19	9	7	6	5
Food and tobacco	201	179	163	149	143
Paper	220	223	205	196	193
Basic chemicals	362	287	260	247	246
Other chemical industry	77	89	84	80	78
Rubber and plastic goods	77	81	77	74	73
Glass, ceramics	92	105	94	85	81
Rock and soil processing	185	154	136	122	113
Metal production	537	468	373	325	303
Non-ferrous metals, foundries	140	127	119	112	108
Metal machining	104	122	118	114	113
Machine construction	79	98	98	96	95
Automotive construction	127	128	125	124	123
Other segments	203	232	234	232	234
All segments	2,424	2,301	2,094	1,961	1,909

Source: Prognos 2009

Figure 4.3-18: Reference scenario: Final energy consumption for industry, by segment, 2005 – 2050, in PJ



Source: Prognos 2009

A more detailed consideration shows that savings in stone and soil quarrying, other mining, and metal production will be far above average. The primary reason for this is the slow growth in production in these segments. Energy consumption will increase

20% in machine construction and as much as 15% in the other branches. The increase in energy consumption here will be caused by a significant expansion in production (value produced +70% and +50%, respectively) (Table 4.3-25, Figure 4.3-18).

In some cases there are structural shifts between the individual energy sources (Table 4.3-26, Figure 4.3-19). Electricity's share will increase, representing 39% of energy demand in 2050. Thus electricity and gases will become the most important energy sources for industry, together covering approx. 80% of energy demand. The principal reason is the systematic shift of process heat to be based on natural gas, which has advantages in terms of handling, and also has a lower relative price disadvantage than coal and oil in energy-intensive industries because of the CO_2 cost. In less energy-intensive industries, it will also be used increasingly in combined heat and power operations.

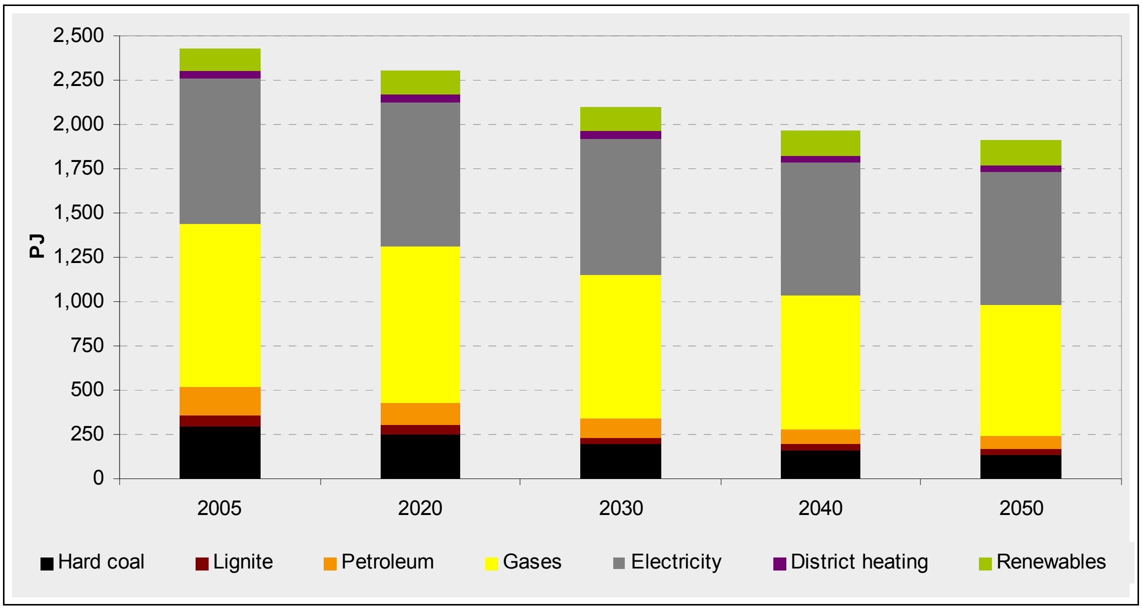
Renewable energy sources will continue to gain in importance. In 2050 they will cover 8% of energy demand. Considerations analogous to the service sector apply here: potential uses for renewable energy sources with low energy density (solar thermal energy, ambient heat) are limited in the industrial sector. Space heating, their potential primary application, plays only a minor role in this sector. They may come into consideration as heat sources for heat pumps for preheating and cooling purposes; biogenic residues may have a larger role in process heat production. But it is assumed that these residues will be used more to produce motor fuels.

Table 4.3-26: Reference scenario: Final energy consumption for industry, by energy source, 2005 – 2050, in PJ

			Reference scenario			
		2005	**2020**	**2030**	**2040**	**2050**
Hard coal		296	252	193	158	137
Lignite		59	48	41	35	32
Petroleum		162	132	107	87	72
of which:	Heating oil, light	77	63	54	45	38
	Heating oil, heavy	67	55	42	33	27
	Other petroleum products	19	14	11	9	7
Gases		921	883	807	759	742
of which:	Natural gases	800	780	724	687	674
	LPG, refinery gas	11	13	11	9	8
	Coke oven gas	33	27	22	19	18
	Furnace gas	77	63	50	44	42
Renewables		118	129	132	137	144
Electricity		823	814	773	748	746
District heating		45	43	40	37	35
Total final energy consumption		2,424	2,301	2,094	1,961	1,909

Source: Prognos 2009

Figure 4.3-19: Reference scenario: Final energy consumption for industry, by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

4.3.3.3 Final energy consumption by type of use

Energy consumption in industry is also projected on a differentiated basis by type of use. For space heating, development follows the same lines as the service sector. Since economic development in industry will be significantly slower than in the service sector, the service sector's comparatively high building replacement rates will not be achieved here. Moreover, in the industrial sector, rooms are often heated with low-temperature waste heat from processes, so that for reasons of climate protection as well, it is less urgent to economize on the need for space heating by performing (expensive) work on the building shell. By 2050, energy consumption for this purpose will decrease 42%.

During the period under study, there will be hardly any shifts among types of use. Process heat will still account for the dominant share, decreasing slightly from 67% in 2005 to 65% in 2050. But mechanical energy's share of total consumption will increase 4 percentage points. The share used for space heating will decrease 3 percentage points (Table 4.3-27, Figure 4.3-20).

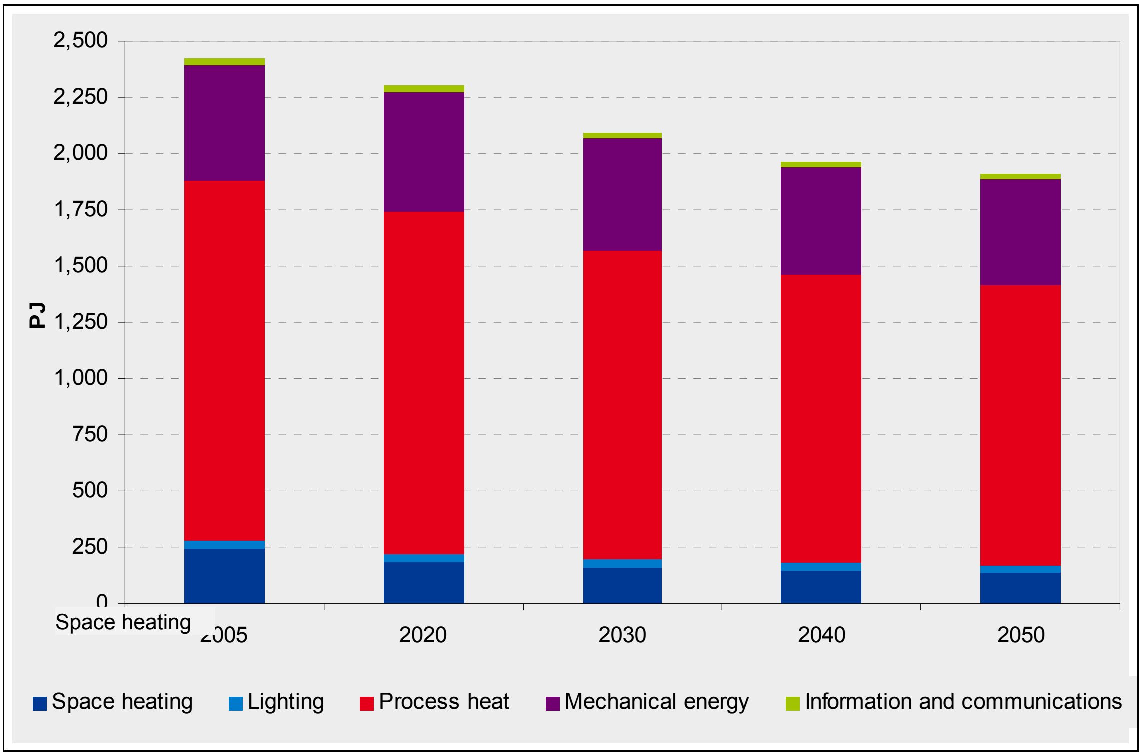
The specific energy demand of the installations used to generate process heat will decrease by an average of roughly 24% by 2050. Efficiency gains may be achieved, for example, by using electronic process control systems, retrieving heat, reducing flue gas losses, applying new process designs, and replacing fuel-fired furnaces with electric furnaces.

Table 4.3-27: Reference scenario: Final energy consumption for industry, by type of use, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Space heating	240	182	162	147	138
Process heat	1,597	1,524	1,376	1,283	1,248
Mechanical energy	516	527	496	475	469
Information and communications	33	31	27	24	23
Lighting	39	37	34	31	30
Total final energy consumption	2,424	2,301	2,094	1,961	1,909

Source: Prognos 2009

Figure 4.3-20: Reference scenario: Final energy consumption for industry, by type of use, 2005 – 2050, in PJ



Source: Prognos 2009

The specific energy demand for delivering force will decrease by as much as 30%. This change in efficiency will be accomplished by retrieving mechanical process energy, adapting installations to actual needs, taking steps to improve mechanical efficiency, and dimensioning motors and drive equipment appropriately for needs. About one-quarter less energy will be needed for lighting purposes in 2050 than in 2005. Possibilities here include using compact fluorescent lamps and LEDs to replace incandescent lamps, fluorescent tubes, and halogen lamps. There are also substantial possibilities for reducing specific consumption in information and communication equipment. Power consumption of desktop computers, for example, can be lowered to the level of portable devices. By 2050, final energy demand for this use will decrease by 31%.

4.3.4 Energy consumption by the transport sector

4.3.4.1 Basic assumptions

The scenarios for the transport sector were prepared in cooperation with ProgTrans AG, of Basel, and are based on the socio-economic framework data (see Chapter 3).

The reference scenario assumes a weak trend towards centralization, and a significant increase in mobility of the elderly as a function of four factors: holding a driver's license, the general trend of "subjectively perceived age," structure of travel purposes, and vehicles per capita. The proportion of older persons with a driver's license will be in line with the levels among persons now between the ages of 18 and 60, and thus will be distinctly higher than among the same age groups today. This change will be reinforced as driver's license ownership comes into closer balance among women and men. "Subjectively perceived age" refers to what happens when the mobility behaviour already known from today is combined with remaining life expectancy, and thus implies a transfer of "younger" behaviour patterns to older generations. Based on this it is projected that older groups will also have greater leisure mobility, even if the retirement age is raised to 67. At the same time, leisure transport will extensively remain a function of passenger cars. Vehicles per capita will show an effect similar to driver's license ownership: "younger" levels of vehicles per capita will spread to older groups in terms of both age and sex.

In freight transport, the reference scenario assumes a conservative continuation of past developments: there will be no interruptions in trends, no reversals of economic links, and no completely new technologies. The infrastructure supply as well is expected to continue along the same trends.

In technical development, essentially the trends apparent today are expected to continue. The combustion engine will remain the principal drive technology for road vehicles. The energy efficiency of this technology will continue to improve moderately, more substantially in passenger cars than in heavy goods vehicles, which are already optimised for saving fuel and costs. But improvements and new developments in drive technology, such as hybrid drives, gas drives and pure electric vehicles, will not replace pure combustion engines, although they will gradually spread in the market. Fuel cell drives will not be widely implemented.

For motor fuels, a strategy of admixture of biofuels (up to 25%) into conventional fuels is assumed.

4.3.4.2 Development of framework data for the transport sector

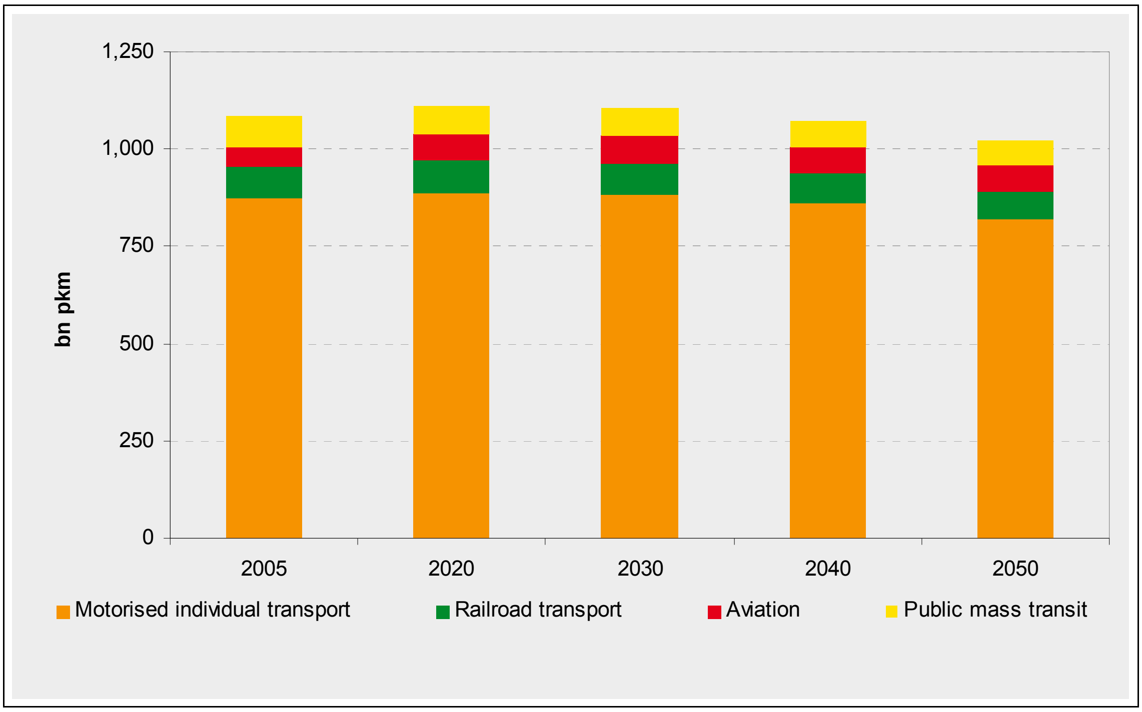
In **passenger transport,** transport volume, as measured in passenger kilometres, will remain almost stable until 2030, then decline slightly, until it is 6.5% lower in 2050 than in 2005 (Table 4.3-28). The individual modes of transport will develop differently. Mass transit will decrease the most (–18.0%), while aviation will increase nearly 25%. Passenger cars will decrease 6.5%; rail transport will decrease 3.6%. These changes will not significantly alter the shares held by the various mode in total passenger transport volume; passenger cars, at 80%, will remain the dominant means. This is due in part to demographic development and the associated shifts in trip purposes – which will be friendly to car use (more leisure and shopping travel) – as well as more cars per capita.

Table 4.3-28: Reference scenario: Passenger transport volume, by mode, 2005 – 2050, in billion passenger kilometres

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Motorised individual transport	876	889	884	860	819
Passenger cars	857	871	867	845	805
Two-wheeled	19	18	17	16	14
Rail transport	77	81	81	78	74
Local transport by rail	43	44	43	42	40
Long-distance transport by rail	34	37	37	36	34
Public mass transit	79	74	70	68	64
Trams, urban rapid railways, underground	15	16	15	15	14
Buses	63	58	55	53	50
Aviation	53	68	69	68	66
Total passenger transport volume	1,084	1,111	1,104	1,075	1,023
Share in %					
Motorized individual transport	80.8	80.0	80.0	80.0	80.0
Rail transport	7.1	7.3	7.3	7.3	7.2
Public mass transit	7.2	6.6	6.4	6.3	6.3
Aviation	4.9	6.1	6.3	6.4	6.4

Source: ProgTrans / Prognos 2009

Figure 4.3-21: Reference scenario: Passenger transport volume, by mode of transport, 2005 – 2050, in billion passenger kilometres



Source: ProgTrans / Prognos

In absolute terms as well, the stagnating share of passenger cars reflects declining passenger transport volume, which will at least reduce pressure on roads and thus make somewhat more space, in the most literal sense. The price competition between passenger cars and public transit will cause the available mass transit to thin out and concentrate increasingly on areas of greater intensity.

Freight transport will be determined primarily by the development of economic output and foreign trade. Freight transport volume, measured in ton-kilometres, will increase nearly 83% in the period under study (Table 4.3-29). Thus the expansion of freight transport volume will be substantially greater than GDP growth, which will come to 33% during the same period. Rail transport will have above-average growth of nearly 116%, while inland navigation will remain behind the average at 23%. Freight transport by road will increase 85%, and air cargo transport by nearly 250%, albeit starting from a very low level.

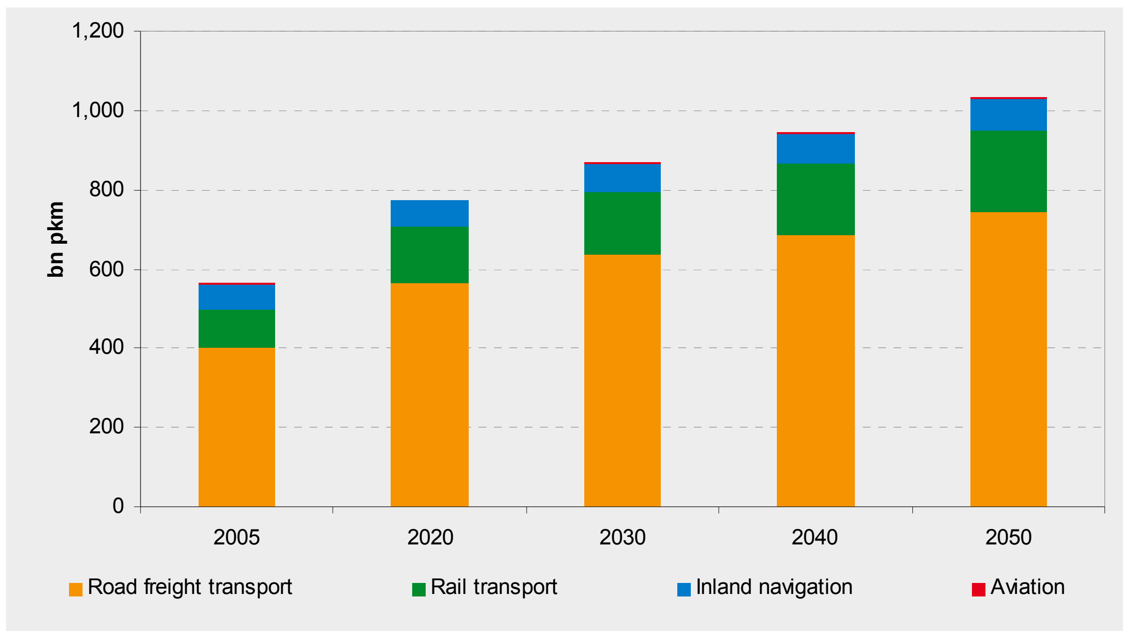
Table 4.3-29: Reference scenario: Freight transport volume, 2005 – 2050, by mode of transport, in billion (metric) ton-kilometres

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Freight transport by road	403	565	634	684	744
German heavy goods vehicles/road tractors	272	365	406	441	533
Long-distance transport	196	285	326	360	452
Local/regional transport	75	80	80	80	81
Foreign heavy goods vehicles/road tractors	131	199	228	243	211
Rail transport	**95**	**141**	**162**	**182**	**206**
Inland navigation	**64**	**67**	**72**	**75**	**79**
Aviation	**1**	**2**	**2**	**3**	**4**
Total freight transport volume	**563**	**775**	**869**	**944**	**1,033**
Share in %					
Road transport	71.5	72.9	72.9	72.4	72.1
Rail transport	16.9	18.2	18.6	19.3	19.9
Inland navigation	11.4	8.7	8.3	8.0	7.6
Aviation	0.2	0.2	0.2	0.3	0.4

Source: ProgTrans / Prognos

The transport sector is dominated by road transport, with a share of around 72% of total freight transport volume. This dominance will persist throughout the period under study, although the segment of “stone, soils and construction materials,” which is important for freight transport by road, will grow less than the average. Rail transport will make slight gains (+3 percentage points) at the expense of inland navigation (–3.7 percentage points).

Figure 4.3-22: Reference scenario: Freight transport volume, by mode of transport, 2005 – 2050, in billion (metric) ton-kilometres



Source: ProgTrans / Prognos 2009

4.3.4.3 Final energy consumption of road transport

Energy consumption for road transport is determined primarily by passenger cars and freight transport by road. It additionally includes consumption by buses and two-wheeled vehicles, but in terms of quantity this is of little significance and is not discussed separately here.

In motorised passenger transport, the slight decline in passenger kilometres travelled and the declining specific consumption of vehicles over time will result in an overall decrease in consumption (Table 4.3-30). All in all, the inventory of vehicles will increase a slight 1%, primarily as a consequence of higher mobility among the elderly. Smaller residential and the assumed further trend towards individualised living will result in a slightly lower mean occupancy of passenger cars. Consequently transport volume will be covered using a larger total number of vehicles.

In terms of automotive technology, the “diesel trend” that has been observable for the past few years is expected to continue to 2025. At that point the number of diesel cars will be 87% higher than in 2005. After 2025 the figure will decrease 61% (Table 4.3-30). From 2025 onwards, more than 2 million hybrid cars will be in use, and will take away significant market share from both all-gasoline and all-diesel vehicles. By 2050 they will make up 23% of the vehicles in use, and will thus be approx. on a par with diesel vehicles. Plug-in hybrids and electric vehicles will then have a share of 13% of total vehicles in use. Gas (natural gas and biogas) vehicles will have a role primarily in local fleets.

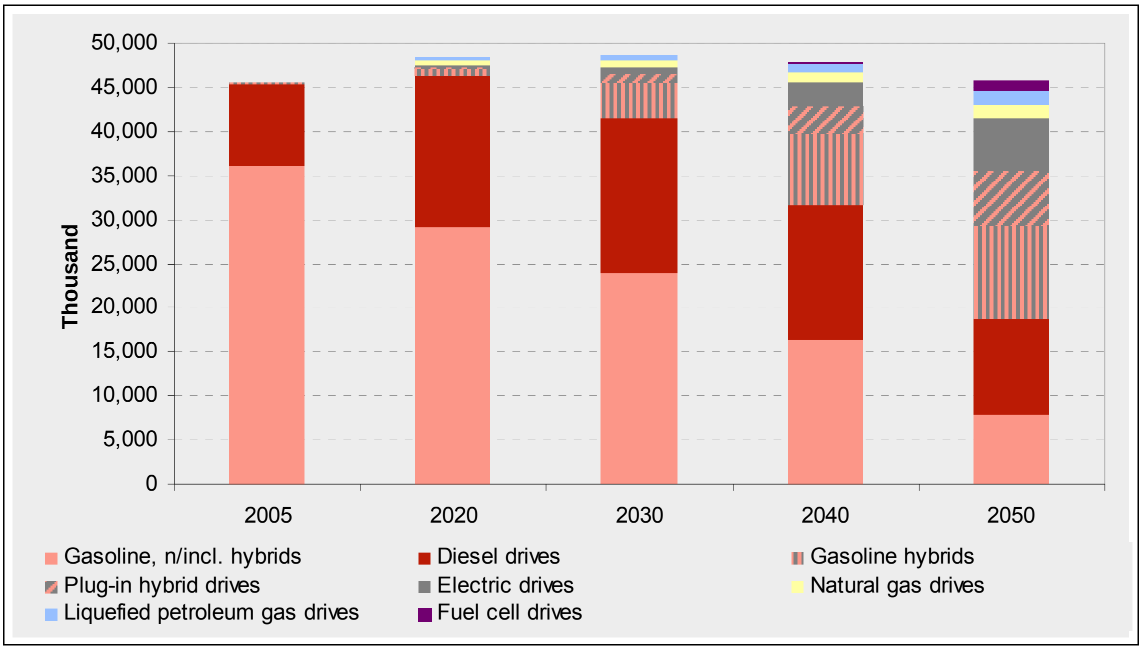
Table 4.3-30: Reference scenario: Determinants for energy consumption by passenger cars and station wagons, averaged for the entire existing vehicle fleet, 2005 – 2050

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Total vehicles in use (000)	**45,521**	**48,491**	**48,739**	**47,835**	**45,828**
Gasoline, n/incl. hybrids	36,050	29,078	24,025	16,382	7,915
Gasoline hybrids	25	784	4,057	8,197	10,593
Diesel drives	9,392	17,314	17,560	15,239	10,823
Natural gas drives	20	493	815	1,091	1,640
Liquefied petroleum gas drives	32	457	710	1,064	1,570
Electric drives	2	158	624	2,659	6,020
Plug-in hybrid drives	0	204	944	3,070	6,113
Fuel cell drives	0	2	3	132	1,154
Annual kilometres travelled (000 vkm/vehicle)	**12.8**	**12.4**	**12.4**	**12.4**	**12.3**
Gasoline, n/incl. hybrids	10.9	9.4	9.9	10.8	11.6
Gasoline hybrids	8.1	8.4	9.8	10.8	11.6
Diesel drives	19.9	17.6	16.5	15.4	14.4
Natural gas drives	15.7	16.6	16.5	15.4	14.4
Liquefied petroleum gas drives	15.7	16.6	16.5	15.4	14.4
Electric drives	3.2	4.6	7.3	10.2	11.5
Plug-in hybrid drives	0.0	4.6	7.3	10.2	11.5
Fuel cell drives	1.5	2.7	3.9	5.3	6.8
Total kilometres travelled (bn vkm)	**581.7**	**602.0**	**605.5**	**591.3**	**564.7**
Gasoline, n/incl. hybrids	393.9	272.9	238.3	176.4	91.8
Gasoline hybrids	0.2	6.5	39.8	88.3	122.8
Diesel drives	186.7	305.1	290.6	234.6	156.0
Natural gas drives	0.3	8.2	13.5	16.8	23.6
Liquefied petroleum gas drives	0.5	7.6	11.8	16.4	22.6
Electric drives	0.0	0.7	4.6	27.0	69.4
Plug-in hybrid drives	0.0	0.9	6.9	31.2	70.5
Fuel cell drives	0.0	0.0	0.0	0.7	7.9
Specific consumption					
Cars (gasoline, diesel, hybrid; L/100 km)	7.8	6.0	5.2	4.9	4.6
Gasoline, n/incl. hybrids (L/100 km)	8.3	6.7	5.8	5.4	5.0
Gasoline hybrids (L/100 km)	6.2	5.0	4.4	4.0	3.8
Diesel drives (L/100 km)	6.8	5.4	4.9	4.7	4.5
Natural gas drives (kg/100 km)	5.6	4.5	3.9	3.7	3.4
Liquefied petroleum gas drives (kg/100 km)	6.1	4.9	4.3	4.0	3.7
Electric drives (kWh/100 km)	20.6	17.0	15.0	14.2	14.0
Plug-in hybrid drives (kWh/100 km)		24.5	21.5	20.1	19.2
Fuel cells (kg H2/100 km)	1.8	1.4	1.2	1.2	1.1
Occupancy (pkm/vkm)	**1.5**	**1.4**	**1.4**	**1.4**	**1.4**

Source: ProgTrans / Prognos 2009

Specific consumption, averaged across the entire existing fleet at a given time, will decrease during the period from 2005 to 2050 by about 40% each for gasoline, hybrid and gas vehicles, about 34% for diesel vehicles, and 32% for all-electric vehicles.

Figure 4.3-23: Reference scenario: Existing vehicle fleet of passenger cars and station wagons by type of drive, 2005 – 2050, in thousand



Source: ProgTrans / Prognos 2009

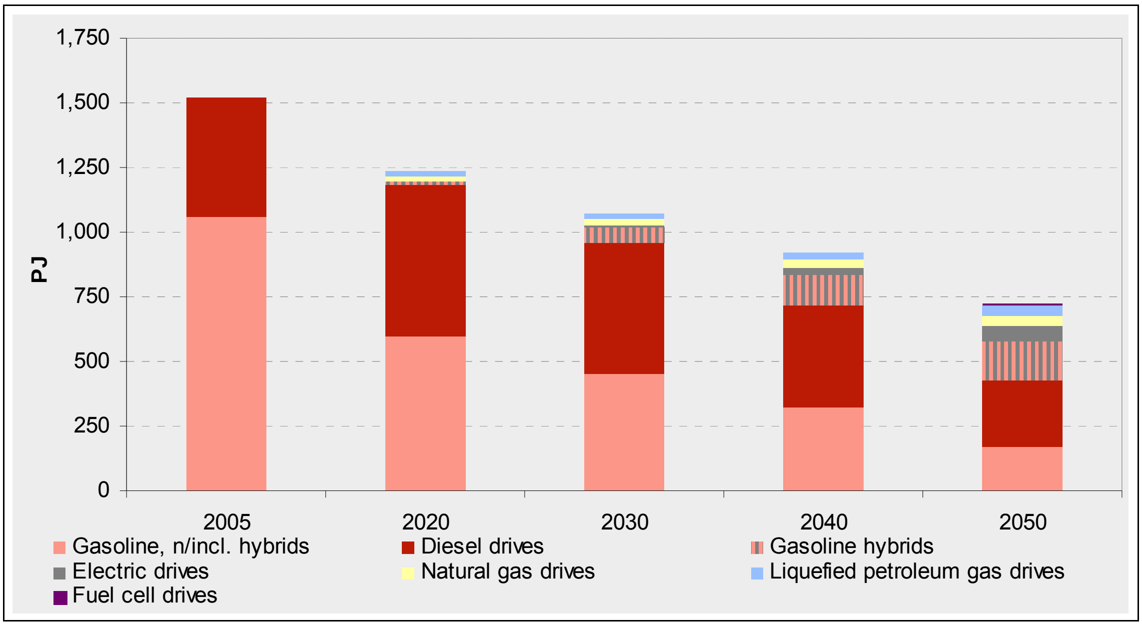
Thus energy consumption for cars and station wagons, which together account for about 95% of the consumption for passenger cars, will decrease 52%, all told, between 2005 and 2050 (gasoline including hybrids: –30%; diesel: –40%, each including biofuels). Gas and electricity will be increasingly important, but 80% of energy consumption for automotive drives will still be gasoline and diesel (Table 4.3-31). The reference scenario assumes that increasing proportions of biofuels will be mixed in with these fuels. However, for ease of understanding, biofuels are not shown separately here, and instead are shown in the discussion of final energy demand for road transport and for the transport sector as a whole.

Table 4.3-31: Reference scenario: Energy consumption by passenger cars and station wagons by type of drive, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids	1,062	598	456	322	174
Gasoline hybrids	0	11	57	116	150
Diesel drives	457	590	507	398	253
Natural gas drives	1	19	27	31	40
Liquefied petroleum gas drives	1	17	23	30	38
Electric drives	0	1	5	25	60
Fuel cell drives				1	10
Total energy consumption	1,521	1,235	1,074	923	726
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids		-3.4	-2.6	-3.4	-6.0
Gasoline hybrids		25.9	15.5	7.5	2.6
Diesel drives		-0.3	-1.6	-2.4	-4.4
Natural gas drives		10.1	1.8	1.5	2.7
Liquefied petroleum gas drives		4.4	2.1	2.6	2.5
Electric drives		-	16.3	17.3	9.1
Fuel cell drives		-	-	-	26.5
Total energy consumption		-1.6	-1.2	-1.5	-2.4

Source: ProgTrans / Prognos 2009

Figure 4.3-24: Reference scenario: Energy consumption by passenger cars and station wagons by type of drive, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

In motorised **freight transport**, the sharply rising transport volume is the dominant variable. The increased service will be provided with a growing number of vehicles (+24%) and improved utilisation of vehicle capacity (+64%) (Table 4.3-32). In terms of vehicle technology, in the Reference scenario we assume that few alternatives to slowly but steadily more economical diesel will reach maturity for the market. Gas and electric vehicles may find a niche in delivery heavy goods vehicles and in urban and local shipping. Fuel cell vehicles will be developed to the point of large-scale trials, but their energy consumption will not be visible yet on the PJ scale.

Table 4.3-32: Reference scenario: Determinants for energy consumption in freight transport by road, 2005 – 2050, averaged for the entire existing vehicle fleet, 2005 – 2050

		Reference scenario			
	2005	2020	2030	2040	2050
Total vehicles in use (000)	**4,424**	**4,872**	**5,108**	**5,272**	**5,496**
Gasoline drives	308	144	105	79	53
Diesel drives	4,107	4,648	4,880	5,026	5,228
Natural gas drives	6	62	93	125	160
Liquefied petroleum gas drives	2	12	19	26	33
Electric drives	2	7	12	16	21
Annual kilometres travelled (000 vkm/vehicle)	**19.3**	**20.2**	**20.0**	**19.9**	**19.8**
Gasoline drives	10.4	10.3	9.9	8.8	6.8
Diesel drives	20.0	20.6	20.5	20.4	20.3
Natural gas drives	10.9	11.7	11.6	11.4	11.3
Liquefied petroleum gas drives	9.5	11.1	11.1	11.1	11.0
Electric drives	8.6	8.8	8.8	8.7	8.6
Total kilometres travelled (bn vkm)	**85.5**	**98.2**	**102.3**	**105.2**	**109.0**
Gasoline drives	3.2	1.5	1.0	0.7	0.4
Diesel drives	82.2	95.8	99.8	102.6	106.3
Natural gas drives	0.1	0.7	1.1	1.4	1.8
Liquefied petroleum gas drives	0.0	0.1	0.2	0.3	0.4
Electric drives	0.0	0.1	0.1	0.1	0.2
Specific consumption (PJ/bn km)					
Gasoline drives (L/100 km)	13.7	11.7	10.7	10.6	11.0
Diesel drives (L/100 km)	23.5	20.4	19.4	18.4	18.0
Natural gas drives (kg/100 km)	15.8	14.2	13.3	12.9	12.8
Liquefied petroleum gas drives (kg/100 km)	16.6	15.4	14.5	14.1	14.0
Electric drives (kWh/100 km)	56.0	50.4	47.5	44.3	42.8
Mean load factor (tkm/vkm)	4.3	5.1	5.5	5.9	7.0

Source: ProgTrans / Prognos 2009

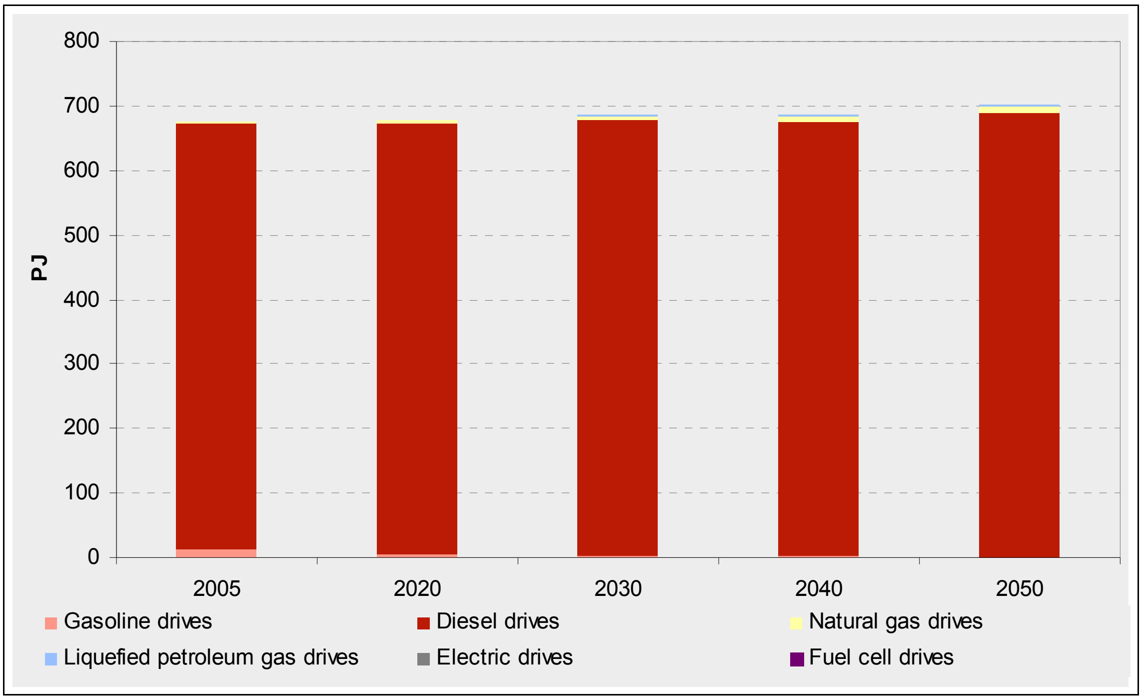
Specific consumption will improve an average of 22%. Consequently energy consumption for freight transport by road will increase 4% between 2005 and 2050 (Table 4.3-33, Figure 4.3-25).

Table 4.3-33: Reference scenario: Energy consumption of freight transport by road by type of drive, 2005 – 2050, in PJ

		Reference scenario			
	2005	2020	2030	2040	2050
Gasoline drives	13.8	5.4	3.5	2.4	1.3
Diesel drives	660.6	667.7	674.6	673.4	687.2
Natural gas drives	0.5	4.7	6.6	8.5	10.6
Liquefied petroleum gas drives	0.1	1.0	1.5	2.0	2.6
Electric drives	0.0	0.1	0.2	0.2	0.3
Fuel cell drives	0.0	0.0	0.0	0.0	0.0
Total energy consumption	675.0	678.9	686.4	686.6	702.0
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Gasoline drives		-6.0	-3.3	-3.8	-6.0
Diesel drives		0.2	-0.2	0.0	0.2
Natural gas drives		5.5	2.9	2.6	2.3
Liquefied petroleum gas drives		7.0	3.6	3.0	2.5
Electric drives		-	3.2	2.6	2.3
Fuel cell drives		-	-	-	-
Total energy consumption		0.2	-0.2	0.0	0.2

Source: ProgTrans / Prognos 2009

Figure 4.3-25: *Reference scenario: Energy consumption of freight transport by road by type of drive, 2005 – 2050, in PJ*



Source: ProgTrans / Prognos 2009

Almost all of this reduction will come from efficiency enhancements in diesel drives. Energy consumption of gasoline engines, as they vanish from the fleet, will roughly be compensated by the rising number of gas and electric vehicles.

For reasons of space and significance, developments in motorized two-wheeled vehicles and in public mass transit are not shown separately here. These are included below in the total energy consumption for road transport. Public mass transit (currently mainly buses, prospectively group taxis and small buses) contributed to diesel consumption in 2005; prospectively, the consumption there will also be distributed among the other energy sources.

To match energy consumption against the system used in the energy balance sheet, the calculated levels must be adjusted for “tank-up tourism.” This refers to the “import” of fuels, both by foreign vehicles and by tanking up outside the country, in border regions. This fuel import came to some 74.5 PJ of gasoline in 2005 that was bought across the border because of the price difference from neighbouring countries; it will gradually decrease to about 20 PJ. The situation for diesel is the reverse; in some cases, there is minor “exporting” here.

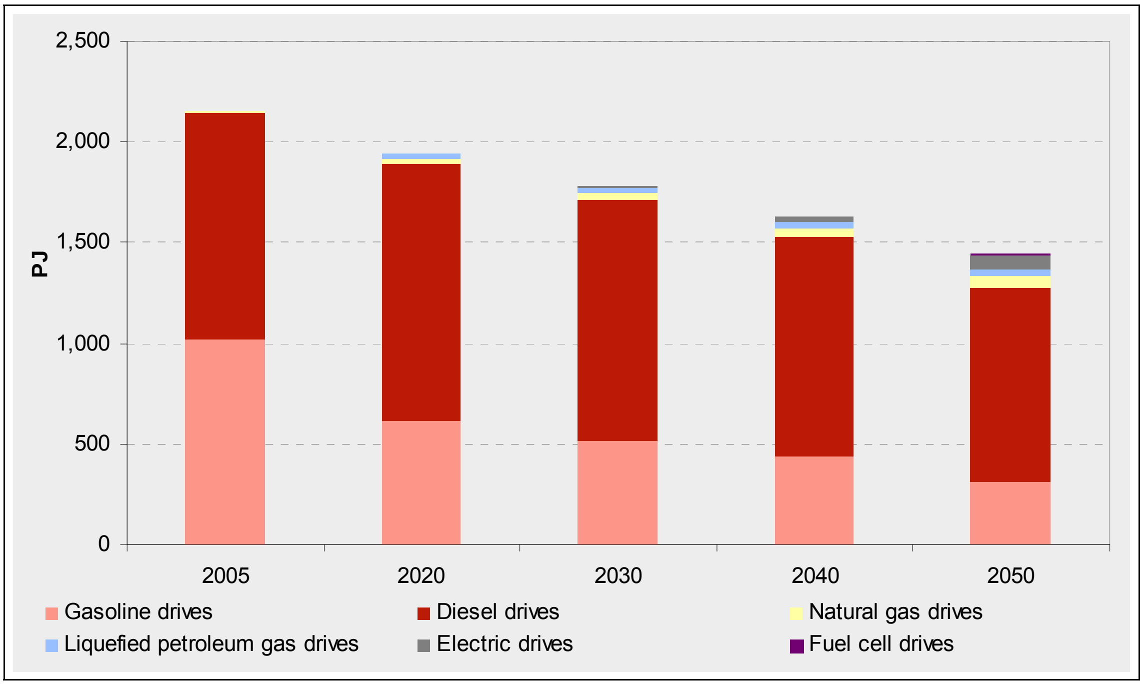
All in all, **final energy consumption of road transport** will present a continuous decrease, until in 2050 it is 33% below the initial level of 2005 (Table 4.3-34, Figure 4.3-26). Hybrid vehicles are subsumed under gasoline drive. The admixture of biofuels, and in some cases individual decisions to use pure biofuels, will increase the share of these fuels to nearly 25%. The large share of diesel power is primarily the consequence of freight transport.

Table 4.3-34: Reference scenario: Final energy consumption for road transport, 2005 – 2050, in PJ

		Reference scenario			
	2005	2020	2030	2040	2050
Gasoline drives	1,025	614	513	435	316
Diesel drives	1,124	1,281	1,204	1,094	962
Natural gas drives	2	24	34	41	52
Liquefied petroleum gas drives	2	18	25	32	41
Electric drives	0	1	5	25	60
Fuel cell drives	0	0	0	1	10
Total final energy consumption	2,152	1,939	1,782	1,628	1,442
For information only: Biofuel	69	181	251	300	317
Change in % p.a.		2020	2030	2040	2050
Gasoline drives		-3.2	-1.3	-1.6	-3.1
Diesel drives		0.0	-0.8	-1.0	-1.3
Natural gas drives		8.7	2.0	1.7	2.6
Liquefied petroleum gas drives		-	1.8	2.6	2.7
Electric drives		-	14.7	16.2	6.6
Fuel cell drives		-	5.8	62.2	16.4
Total final energy consumption		-1.0	-0.8	-0.9	-1.2

Source: ProgTrans / Prognos 2009

Figure 4.3-26: Reference scenario: Final energy consumption for road transport by type of drive, 2005 – 2050, in PJ



Source: ProgTrans / Prognos2009

4.3.4.4 Final energy consumption of rail transport

Rail transport includes not only transport by rail, but also transport via **rail mass transit**. This refers to such forms as underground rail lines, urban rapid railways and tramways. Because of declining population and the change in travel behaviour due to demographics, there will be a decline in both utilisation of capacity (about 1%) and kilometres travelled (about 6%) during the period under study. Thus passenger transport volume by rail mass transit will decrease 8%. Since specific consumption will decrease 13% at the same time, power consumption in 2050 will be nearly 19% lower than in 2005 (Table 4.3-35).

Table 4.3-35: Reference scenario: Determinants and energy consumption in rail mass transit (tram, urban rapid railways and underground rail lines), 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Transport volume (bn pkm)	15.3	15.7	15.4	14.9	14.1
Utilisation of capacity (pkm/vkm)	24.3	24.3	24.0	24.0	23.9
Kilometres travelled (million vkm)	629.1	644.1	640.2	620.1	588.8
Specific consumption (kWh/vkm)	2.9	2.7	2.6	2.6	2.5
Consumption (electricity, PJ)	**6.6**	**6.2**	**6.0**	**5.7**	**5.3**

Source: ProgTrans / Prognos 2009

Rail transport is more significant for the development of final energy consumption. Transport volume in **rail passenger transport**, measured in passenger kilometres, will decrease nearly 4% during the period under consideration. The decrease results primarily from changes in local mass transit, where transport volume will decrease 8%. Long-distance transport volume will rise until 2030, and then decrease back to approx. the original value by 2050 (+2%).

In energy consumption for rail passenger transport, rising technical efficiency will result in a decrease for both local and long-distance transport. Energy consumption will decrease 17.6% between 2005 and 2050, to somewhat more than 30 PJ. Of this figure, about 70% will be in electricity. The remainder will be diesel, including biofuels (Table 4.3-36).

Table 4.3-36: *Reference scenario: Determinants and energy consumption for rail passenger transport, 2005 – 2050, in PJ*

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Local travel					
Transport volume (bn pkm)					
Electric traction	31.5	34.5	34.1	32.9	31.1
Diesel traction	11.6	9.5	9.3	9.0	8.5
Total transport volume	43.1	44.0	43.5	41.9	39.6
Specific consumption (kJ/pkm)					
Electric traction	486	445	445	445	445
Diesel traction	1,038	1,015	1,015	1,015	1,015
Total specific consumption	636	568	568	568	568
Energy consumption (PJ)					
Electricity	15.3	15.4	15.2	14.6	13.8
Diesel (incl. biofuel)	12.1	9.6	9.5	9.1	8.7
Total energy consumption	27.4	25.0	24.7	23.8	22.5
Long-distance travel					
Transport volume (bn pkm)					
Electric traction	32.9	36.0	36.7	35.6	33.7
Diesel traction	0.8	0.7	0.7	0.7	0.7
Total transport volume	33.7	36.7	37.4	36.3	34.4
Specific consumption (kJ/pkm)					
Electric traction	261	220	217	214	212
Diesel traction	715	674	674	674	674
Total specific consumption	272	228	225	222	221
Energy consumption (PJ)					
Electricity	8.6	7.9	7.9	7.6	7.2
Diesel (incl. biofuel)	0.6	0.5	0.5	0.5	0.5
Total energy consumption	9.2	8.4	8.4	8.1	7.6
Total passenger transport					
Energy consumption (PJ)					
Electricity	23.9	23.3	23.1	22.2	21.0
Diesel (incl. biofuel)	12.7	10.1	10.0	9.6	9.1
Total energy consumption	36.5	33.3	33.1	31.8	30.1

Source: ProgTrans / Prognos 2009

In **freight transport by rail**, transport volume will expand some 116%. A 30% improvement in vehicle efficiency will partially compensate for the energy consumption consequences of higher transport volume. During the period under study, energy consumption for rail freight transport will increase nearly 52%, to more than 25 PJ. Diesel will decrease in significance; its share will decline from 22% to 14% (Table 4.3-37).

Local services – including shunting, loading and operating stationary railroad installations – will see consumption grow by roughly the same amount. Electricity alone will be used for this purpose by 2050.

Table 4.3-37: Reference scenario: Determinants and energy consumption for rail freight transport, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Transport volume (bn tkm)					
Electric traction	83	130	151	171	195
Diesel traction	13	11	11	11	11
Total transport volume	95	141	162	182	206
Specific consumption (kJ/tkm)					
Electric traction	143	122	119	115	112
Diesel traction	368	323	318	313	308
Total specific consumption	173	138	132	127	122
Energy consumption (PJ)					
Electricity	11.8	15.9	17.9	19.7	21.7
Diesel (incl. biofuel)	4.7	3.5	3.5	3.4	3.4
Total specific consumption	16.5	19.5	21.4	23.1	25.1
Local services					
Energy consumption (PJ)					
Electricity	16.1	18.4	19.6	21.1	22.7
Diesel (incl. biofuel)	1.5	0.6	0.4	0.2	0.0
Total energy consumption	17.5	19.0	20.0	21.3	22.7

Source: ProgTrans / Prognos

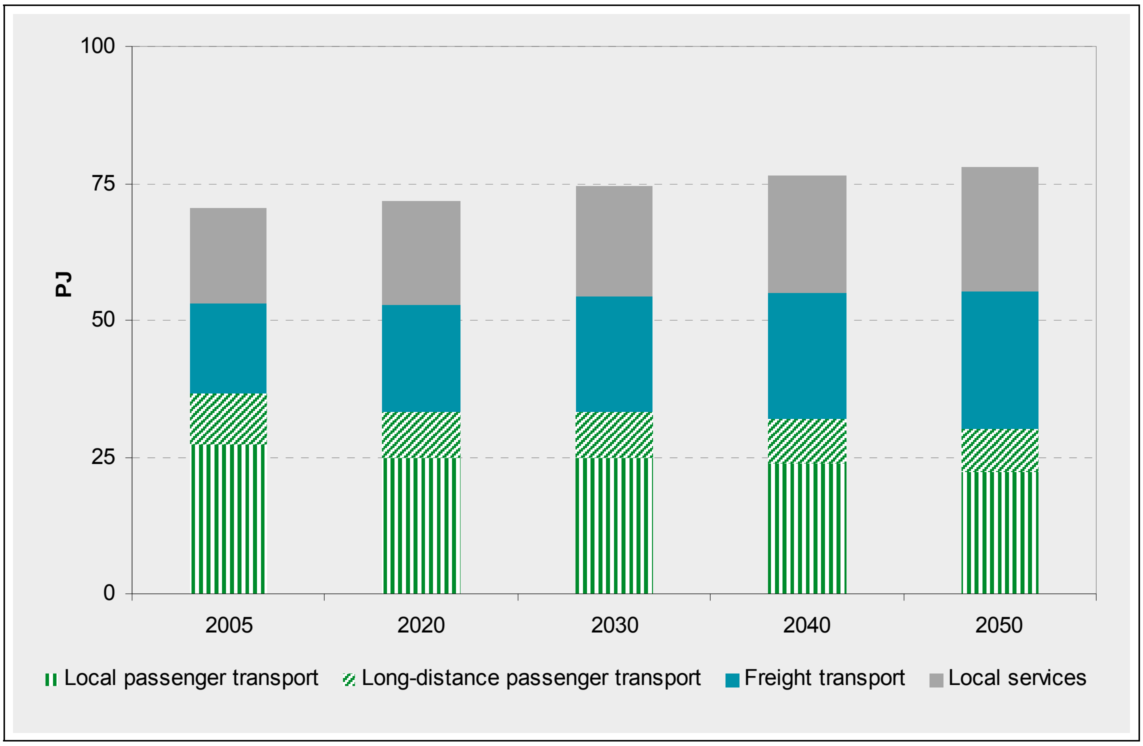
All in all, final energy consumption for rail transport is projected to increase 10.4%; in 2050 it will be 78 PJ (Table 4.3-38, Figure 4.3-27). The importance of electricity will increase; its share of consumption will grow from 76% in 2005 to 84% in 2050. These figures do not take account of consumption by rail mass transit, which is treated as road transport in accordance with the official categories.

Table 4.3-38: Reference scenario: Total energy consumption for rail transport, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Electricity	52	58	61	63	65
Diesel (incl. biofuel)	19	14	14	13	13
All rail transport	71	72	74	76	78
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Electricity		0.5	0.5	0.4	0.4
Diesel (incl. biofuel)		-0.5	-0.2	-0.5	-0.7
All rail transport		0.3	0.4	0.2	0.2
Local passenger transport	27.4	25.0	24.7	23.8	22.5
Long-distance passenger transport	9.2	8.4	8.4	8.1	7.6
Freight transport	16.5	19.5	21.4	23.1	25.1
Local services	17.5	19.0	20.0	21.3	22.7
All rail transport	70.6	71.8	74.5	76.3	78.0
Memo item: Public mass transit	6.6	6.2	6.0	5.7	5.3

Source: ProgTrans / Prognos 2009

Figure 4.3-27: Reference scenario: Energy consumption for rail transport by type of use, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

4.3.4.5 Energy consumption by inland navigation and aviation

Within the transport sector, energy consumption for inland navigation is of secondary importance. Its share of freight transport volume in 2005 was 11.4%. Since the importance of mass freight transport will decline in relative terms as a part of structural change, this share will decrease to 7.5% in 2050.

Assuming a 23% expansion of transport volume, rising technical efficiency (+26%) and a long-term return to rising domestic fuel tanking-up ratios, energy consumption for inland navigation will rise 17% by 2050, to more than 15 PJ (Table 4.3-39).

Table 4.3-39: Reference scenario: Determinants of energy consumption in inland navigation, 2005 – 2050

		Reference scenario			
	2005	2020	2030	2040	2050
Transport volume (bn tkm)	64	67	72	75	79
Specific consumption (kJ/tkm)	172	145	137	130	127
Consumption (diesel incl. biofuels, PJ)	13	14	14	15	15

Source: ProgTrans / Prognos 2009

Aviation accounted for about 13% of total 2005 energy consumption in the transport sector. This share will rise to nearly 18.5% by 2050. The reason is the still-dynamic growth of passenger transport, as well as air cargo, which is relatively insignificant in terms of quantity. Despite a significant decrease in specific consumption (–37%), therefore, consumption for aviation will increase slightly by 1.6% by 2050.

Table 4.3-40: Reference scenario: Determinants of energy consumption in aviation, 2005 - 2050

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Passenger transport volume (bn pkm)	52.6	67.6	69.3	68.3	65.7
Freight transport volume (bn tkm)	1.0	1.7	2.0	2.8	3.6
Specific consumption (PJ/bn pkm-equivalent[1])	5.5	4.6	4.2	3.8	3.4
Consumption (aviation fuel, PJ)	344.5	393.8	374.3	365.2	349.9

[1)] *1 tkm=10 pkm*

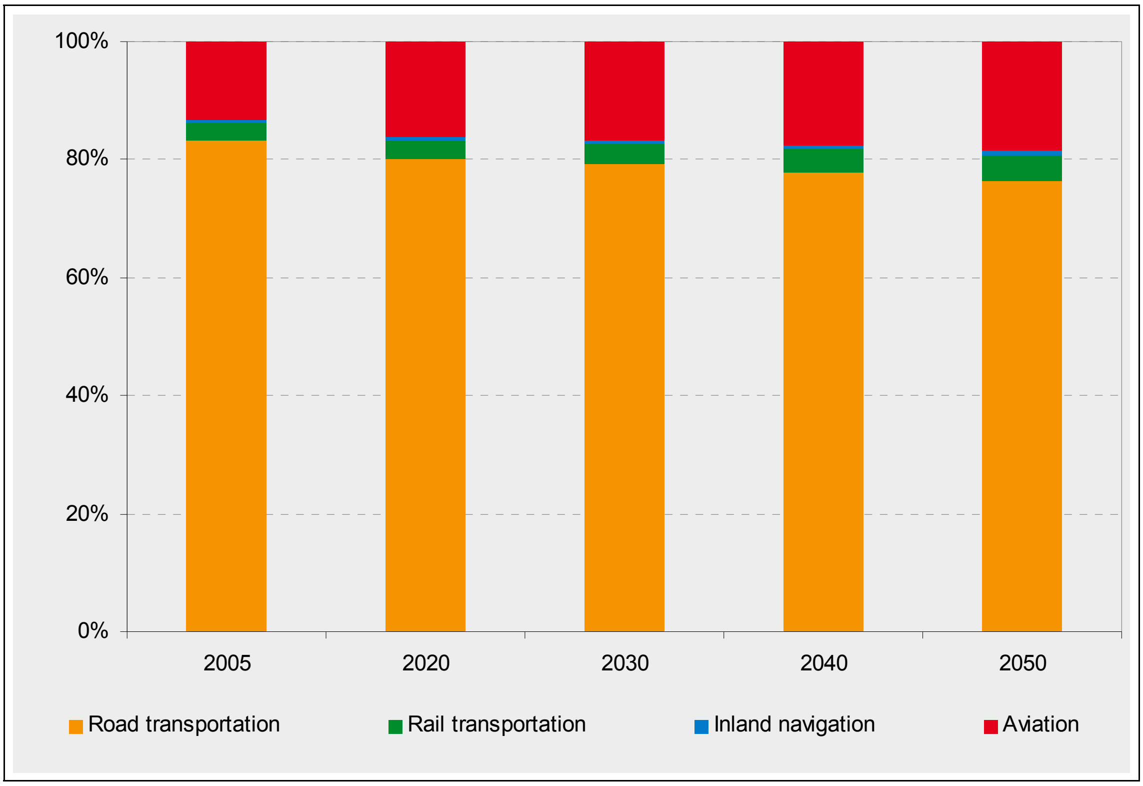
Source: ProgTrans / Prognos 2009

4.3.4.6 Final energy consumption: Total and by energy source

Energy consumption in the transport sector, more than 83% of which was attributed to road transport in 2005, will decrease 27% in the period under consideration. The observed past growth trend in energy consumption for the transport sector will reverse before 2010. The long-term decrease in energy consumption is a consequence of steadily rising energy productivity, expressed here as kilometres travelled and volumes carried per unit energy. This figure will double by 2050.

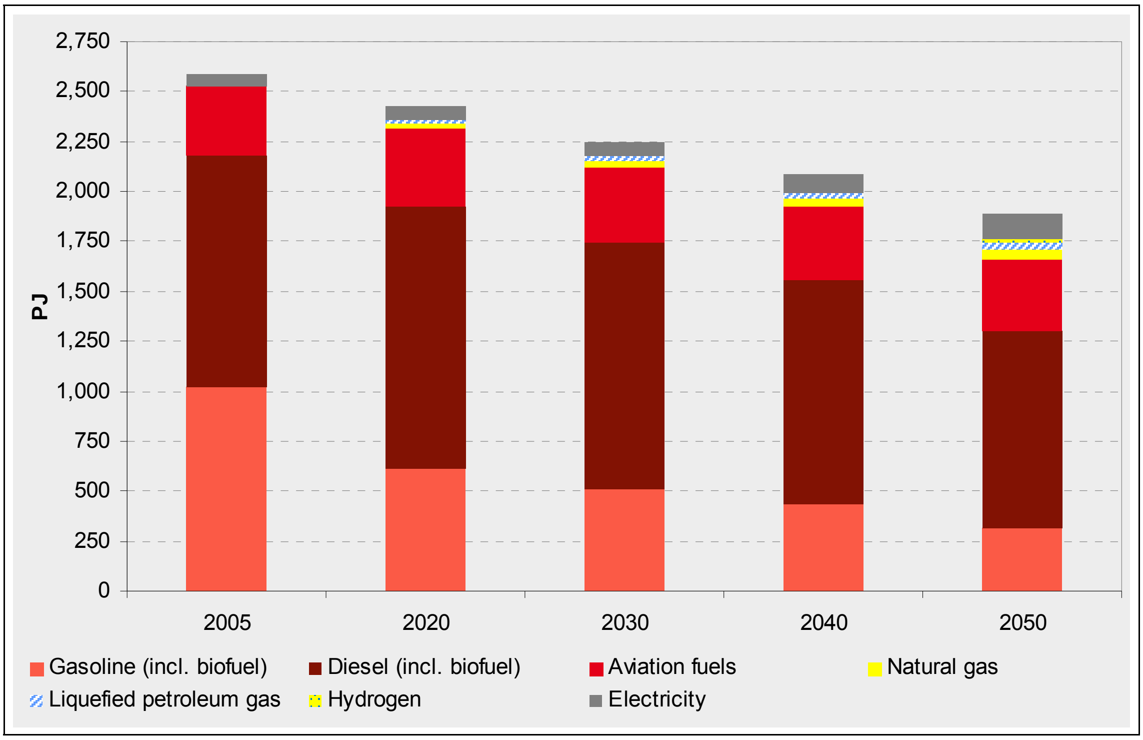
The various modes' shares of energy consumption will shift only slightly. The share consumed by road transport will decrease from 82% to 76%; the share of aviation will increase 5 percentage points to 18.5%; the share of rail transport will increase 1.5 percentage points to 4.4%. With a share of less than 1%, inland navigation will remain of little significance for energy consumption (Figure 4.3-28, Figure 4.3-29, Table 4.3-41).

Figure 4.3-28: Reference scenario: Share of mode of transport in energy consumption by the transport sector, 2005 – 2050



Source: ProgTrans / Prognos 2009

Figure 4.3-29: Reference scenario: Final energy consumption for transport, by energy source, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

Broken down by energy source, the changes sometimes vary significantly (Figure 4.3-29, Table 4.3-41). Gasoline consumption will decrease 69% by 2050, from 1,025 PJ to 316 PJ. The share of biofuel admixture will increase significantly, to about 70 PJ in 2050. Pure biofuel will rarely be used. Consumption of petroleum-based gasoline will decrease 76%.

Consumption of diesel fuel will initially continue to rise, but a decline in consumption will begin around 2015, and accelerate after 2030. Total diesel consumption will decrease 14%, to 990 PJ. The share of admixed biofuel will increase to about one-quarter of the amount consumed; pure biofuel will no longer be used after 2010. Consumption of petroleum-based diesel fuel will decrease 33%.

The decrease in the consumption of gasoline and diesel will result from the slight decrease in passenger kilometres travelled and the development of efficient vehicles. The admixture of biofuels will amplify the decrease in consumption of petroleum-based fuels.

Table 4.3-41: Reference scenario: Total final energy consumption for transport, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Road transport					
Gasoline	1,025	614	513	435	316
Gasoline substitutes from biomass	9	46	64	76	71
Gasoline from petroleum	1,015	568	449	359	245
Diesel	1,124	1,281	1,204	1,094	962
Diesel substitutes from biomass	60	135	187	224	245
Diesel from petroleum	1,064	1,147	1,017	869	717
Natural gas	2	24	34	41	52
Liquefied petroleum gas	2	18	25	32	41
Hydrogen	0	0	0	1	10
Electricity	0	1	5	25	60
Motor oil	1	0	0	0	0
All road transport	2,152	1,940	1,782	1,628	1,443
Rail transport					
Electricity	58	64	67	69	71
Diesel (incl. biofuel)	19	14	14	13	13
All rail transport	77	78	80	82	83
Inland navigation					
Diesel (incl. biofuel)	13	14	14	15	15
Aviation					
Aviation fuels	345	394	374	365	350
All transport	**2,587**	**2,426**	**2,251**	**2,090**	**1,891**
Gasoline (incl. biofuel)	1,025	614	513	435	316
Gasoline substitutes from biomass	9	46	64	76	71
Gasoline from petroleum	1,015	568	449	359	245
Diesel (incl. biofuel)	1,155	1,310	1,232	1,122	990
Diesel substitutes from biomass	62	138	191	230	252
Diesel from petroleum	1,093	1,172	1,041	892	738
Aviation fuels	345	394	374	365	350
Natural gas	2	24	34	41	52
Liquefied petroleum gas	2	18	25	32	41
Hydrogen	0	0	0	1	10
Electricity	58	65	72	94	131
Motor oil	0.6	0.5	0.4	0.3	0.3

Source: ProgTrans / Prognos 2009

Consumption of biofuels will increase by a factor of 4.5, from 71 PJ to 324 PJ. Demand for natural gas and liquid natural gas will also increase substantially. At a consumption of 93 PJ, gas will hold a share of just under 5%. Hydrogen consumption will remain insignificant (under 1%).

Electric power demand will increase about 124% between 2005 and 2050, to reach 131 PJ at the end of the period. Electric power demand will be determined primarily by rail transport. Electric drives will be increasingly significant in road transport; this consumption will come to 60 PJ by 2050.

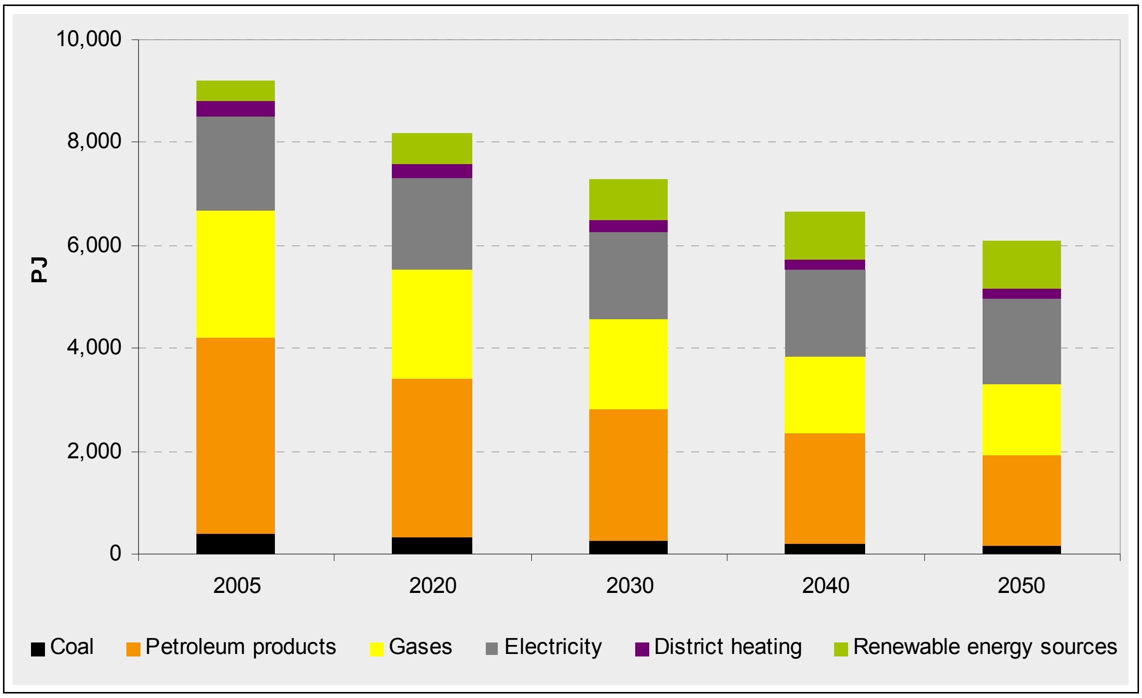
The use of aviation fuel(kerosene) will still grow slightly, to 394 PJ by 2015. Here too, consumption will decline from 2020 onwards. In 2050 it will be barely 2% higher than in 2005.

4.3.5 Total final energy consumption

Final energy consumption, broken down by energy source, will develop overall as shown in Table 4.3-42 and Table 4.3-43 and in Figure 4.3-30 and Figure 4.3-31.

By 2050, final energy consumption will have decreased steadily to 6,099 PJ (a 34% decrease against 2005), and thus by an average of 0.92% per year. Following fluctuations caused by the recent crises, the annual decrease will grow to 1.25% until 2020, and will then narrow to 0.75% by 2050.

Figure 4.3-30: Reference scenario: Final energy consumption by energy source group, 2005 – 2050, in PJ



Source: ProgTrans / Prognos

In addition to the decrease in total energy consumption, there will be a restructuring of the mix of energy sources.

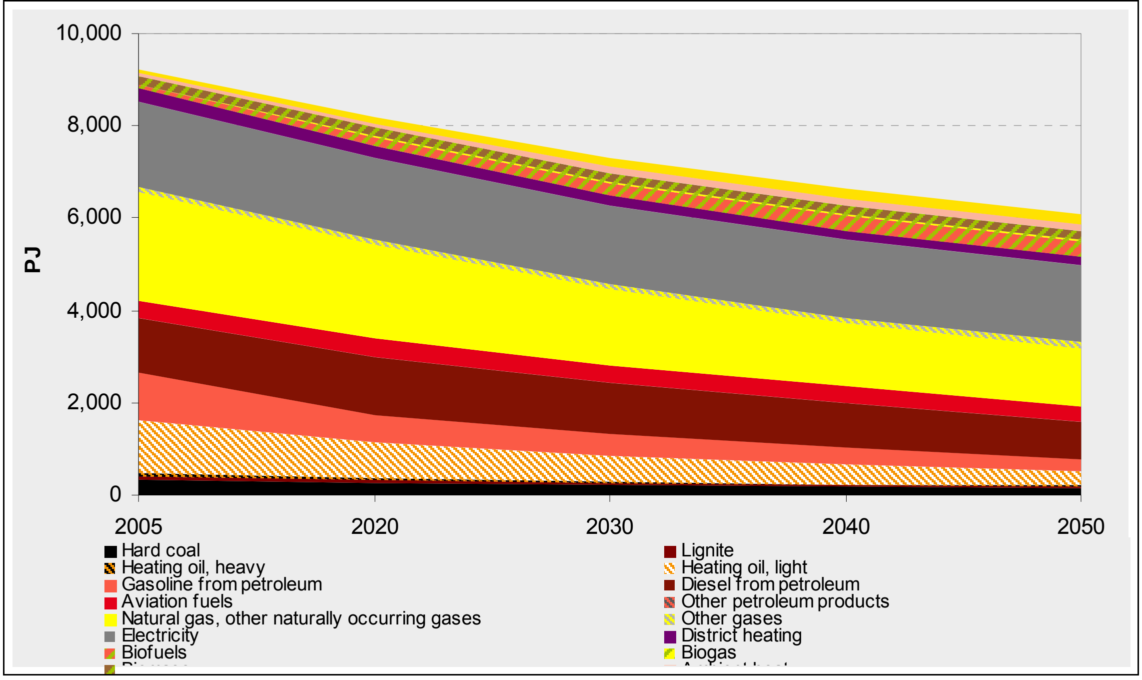
Sharp decreases in demand for conventional gasoline and light heating oil will cause the share of **petroleum products** in the mix to shrink by 12 percentage points, from 41% to 29%.

The market share of **conventional gases** will decrease by only 4 percentage points (from 27% to 23%).

In contrast to gas and petroleum products, the share of **electricity** in the mix will grow by 8% (from 20% to 28%). Electricity demand will decrease by 8% (from 1,868 PJ to 1,695 PJ).

The share of **renewable energy sources** will grow the most. The share of final energy furnished by renewable sources will quadruple between 2005 and 2050, to 16%. Compared to 2005 consumption, the growth will be 140%.

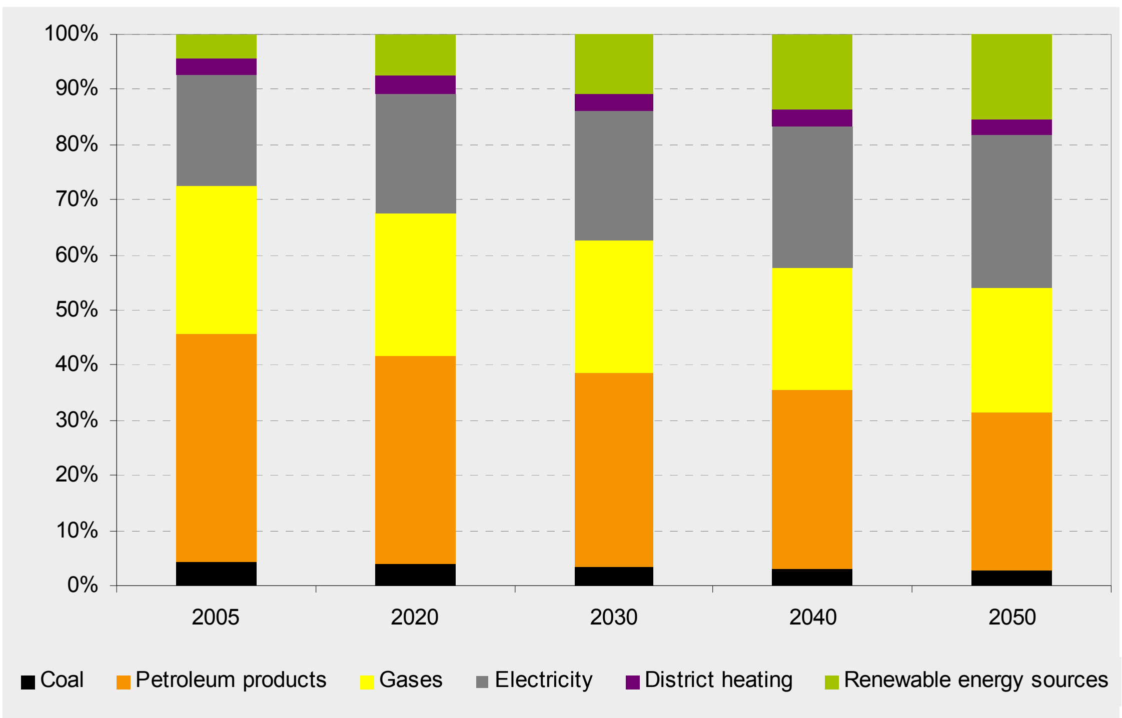
Figure 4.3-31: *Reference scenario: Final energy consumption, by energy source, 2005 – 2050, in PJ*



Source: ProgTrans / Prognos 2009

Direct **coal consumption** in demand sectors (not including power generation and other conversion) will decrease by 59%. Its share of final energy consumption in 2050 will be 2.9%.

Figure 4.3-32: *Reference scenario: Structure of energy sources in final energy consumption, 2005 – 2050, in %*

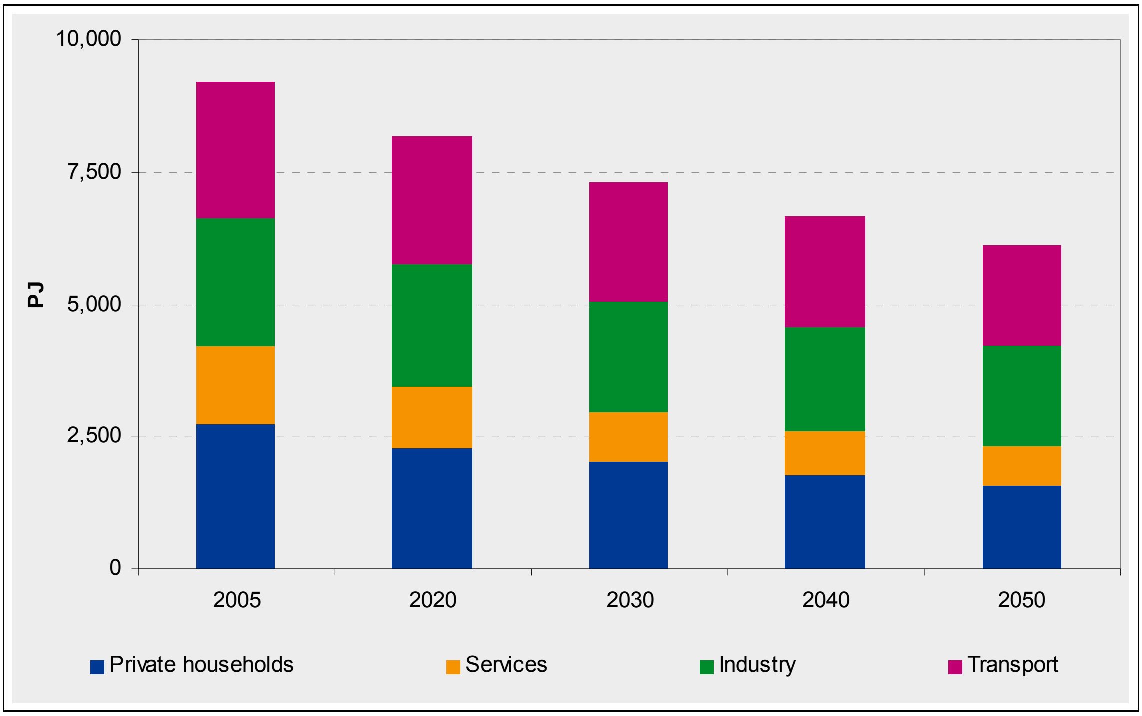


Source: ProgTrans / Prognos 2009

Decreasing demand for heat will reduce **district heating**'s share of energy consumption to 2.7%.

The largest absolute contribution to saving energy will come from the residential sector, with a saving of about 43% in 2050 compared to 2005. The primary reason here is the reduction of space heating, combined with the technological trend towards efficient use of electricity in major household appliances. The service sector will save 50%. This is because of the reduction in space heating and savings from such areas as office equipment in particular, green IT, and also because of virtualization and efficiency gains due to control and regulation processes.

Figure 4.3-33: Reference scenario: Final energy consumption, by sector, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

The savings in the industrial sector are the smallest, at 516 PJ (21%). Here physical conditions limit the potential for savings in process heat and mechanical force generation, unless fundamental process innovations are assumed. To some degree, the savings are offset by production growth. In the transport sector, especially because of a rise in freight transport volume that will offset great efficiency gains in the vehicle sector, 27% will be saved from 2005 to 2050 (Figure 4.3-33).

Table 4.3-42: Reference scenario: Final energy consumption, by energy source and consuming sector, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
By energy source					
Coal	**400**	**319**	**249**	**206**	**179**
Hard coal	341	272	208	170	146
Lignite	59	48	41	35	32
Petroleum products	**3,798**	**3,079**	**2,568**	**2,143**	**1,743**
Heating oil, light	1,151	787	576	423	325
Heating oil, heavy	67	55	42	33	27
Gasoline from petroleum	1,033	583	461	369	254
Diesel from petroleum	1,202	1,260	1,114	952	787
Aviation fuels	345	394	374	365	350
Other petroleum products	1	0	0	0	0
Gases	**2,482**	**2,139**	**1,760**	**1,493**	**1,382**
Natural gas, other naturally occurring gases	2,359	2,018	1,652	1,387	1,263
Other gases	123	121	108	106	119
incl.: Blast furnace gas	77	63	50	44	42
Renewable energy sources	**396**	**612**	**791**	**908**	**949**
Biomass	178	184	188	189	188
Ambient heat	68	104	130	147	155
Solar energy	73	122	173	213	226
Biofuels	77	193	268	321	340
Biogas	0	9	32	38	40
Electricity	**1,832**	**1,764**	**1,695**	**1,704**	**1,680**
District heating	**300**	**265**	**227**	**190**	**167**
Total final energy consumption	9,208	8,178	7,291	6,644	6,099
By consumer sector					
Residential	2,735	2,282	2,013	1,777	1,569
Services	1,462	1,169	933	815	731
Industry	2,424	2,301	2,094	1,961	1,909
Transport	2,587	2,426	2,251	2,090	1,891

Source: ProgTrans / Prognos

Table 4.3-43: Reference scenario: Structure of final energy consumption by energy source and consuming sector, 2005 – 2050, in %

		Reference scenario			
Structure in %	**2005**	**2020**	**2030**	**2040**	**2050**
By energy source					
Coal	**4.3**	**3.9**	**3.4**	**3.1**	**2.9**
Hard coal	3.7	3.3	2.9	2.6	2.4
Lignite	0.6	0.6	0.6	0.5	0.5
Petroleum products	**41.2**	**37.6**	**35.2**	**32.3**	**28.6**
Heating oil, light	12.5	9.6	7.9	6.4	5.3
Heating oil, heavy	0.7	0.7	0.6	0.5	0.4
Gasoline from petroleum	11.2	7.1	6.3	5.6	4.2
Diesel from petroleum	13.1	15.4	15.3	14.3	12.9
Aviation fuels	3.7	4.8	5.1	5.5	5.7
Other petroleum products	0.0	0.0	0.0	0.0	0.0
Gases	**27.0**	**26.2**	**24.1**	**22.5**	**22.7**
Natural gas, other naturally occurring gases	25.6	24.7	22.7	20.9	20.7
Other gases	1.3	1.5	1.5	1.6	2.0
incl.: Blast furnace gas	0.8	0.8	0.7	0.7	0.7
Renewable energy sources	**4.3**	**7.5**	**10.9**	**13.7**	**15.6**
Biomass	1.9	2.2	2.6	2.8	3.1
Ambient heat	0.7	1.3	1.8	2.2	2.5
Solar energy	0.8	1.5	2.4	3.2	3.7
Biofuels	0.8	2.4	3.7	4.8	5.6
Biogas	0.0	0.1	0.4	0.6	0.6
Electricity	**19.9**	**21.6**	**23.3**	**25.6**	**27.5**
District heating	**3.3**	**3.2**	**3.1**	**2.9**	**2.7**
Total final energy consumption	100.0	100.0	100.0	100.0	100.0
By energy source					
Residential	29.7	27.9	27.6	26.7	25.7
Services	15.9	14.3	12.8	12.3	12.0
Industry	26.3	28.1	28.7	29.5	31.3
Transport	28.1	29.7	30.9	31.5	31.0

Source: ProgTrans / Prognos

4.3.6 Power generation, other conversion sectors

4.3.6.1 Development of the power plant fleet in the “Reference without CCS” and “Reference with CCS“ options

Based on the order of obsolescence (Figure 2.2-5 in Sec. 2.2.2.2, p. 20), which describes the reduction of capacity in Germany’s power plant fleet due to aging, in these scenarios the plants in existence in the period to 2050 will develop primarily as a function of the market mechanisms that apply in the present. In this scenario, the primary goal is not to reduce CO_2 emissions. While the use of renewables will continue to expand, this development will lose considerable momentum over the long term.

It is unclear at present whether and when CCS technology can be implemented in Germany. Therefore, two options were calculated, with and without CCS technology.

In the reference option without CCS, the CCS technology does not achieve maturity for the market (or cannot be implemented, for example for reasons of safety or acceptance), and is not introduced into conventional power generation.

In the reference option with CCS, by contrast, the assumption is that by 2025 a technically mature version of this technology will be available, and will be cost-effective.

Both options operate with the same assumptions in terms of expansion paths for centralised and decentralised combined heat and power generation, and for renewables. Almost the only differences between the two options are in the structure of the fleet of conventional power plants and the associated CO_2 emissions, and in the full cost of power generation.

Electricity imports result as a residual quantity from the development of demand, the development of generation from renewable energy sources, the development of combined heat and power plants, and the construction of new conventional power plants in accordance with the merit order.

4.3.6.1.1 Combined heat and power

Power generation in centralised and decentralised combined heat and power plants will be heat-driven. In spite of decreasing demand for heat, this form of power generation increases slightly in the same way in both options, with and without CCS, as a result of the declining demand for heat and the rising amounts of equipment in the residential and in the service sector during the period from 2005 to 2050. It will rise to 77 TWh in 2020, and then decline to 74 TWh in the subsequent period to 2050. Installed capacity in the power plant model is categorised by energy source, primarily natural gas and biomass.

4.3.6.1.2 Expansion of renewable energy sources

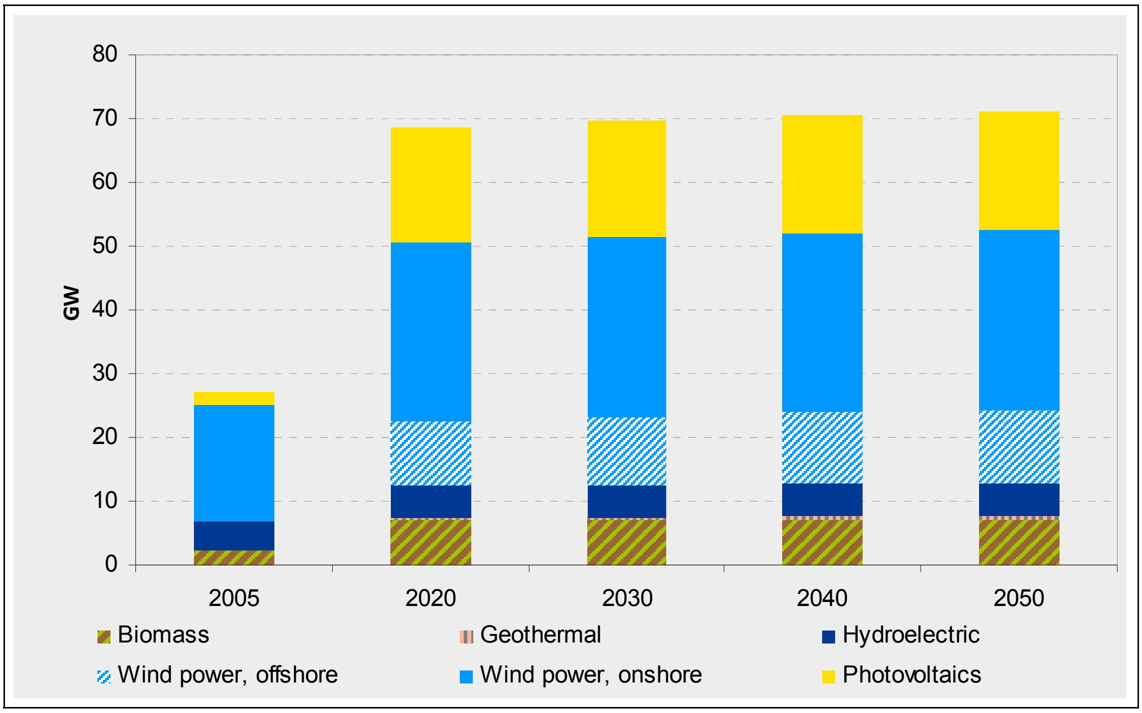
The reference scenario’s projection of fed-in power and installed capacity for individual renewable energy sources is based on the German Federal Environment Ministry’s guideline scenario for the expansion of renewable energy sources [Nitsch/DLR, 2008]. The path of expansion to 2020 presented there has been adopted unchanged, in accordance with current developments under the Renewable Energy Sources Act. During the rest of the period to 2050, the options with and without CCS diverge downward from the ambitious guideline scenario, for the following main reasons:

- Technical difficulties and the resulting delays are projected to slow both the expansion of offshore wind energy and the integration of renewable energy sources into the grid.
- Too little space will be made available for the expansion of onshore wind energy. Integration into the landscape will run up against limitations. Over the long term, gains will be limited to repowering existing installations.
- Political and organisational impediments will reduce the importation of electricity generated by renewables.
- In photovoltaic systems, the market will become saturated, and a continuation of subsidies will provide little further stimulus.
- Potential competition with food crops in land use will limit the quantity of biomass available for conversion to electricity. Levels achieved by 2020 can be maintained, but cannot be expanded significantly by 2050. The political environment will not be suitable for resolving the above problems.

In the reference option without CCS, installed capacity for power generation from renewable sources grows by a factor of more than two and a half between 2005 and 2050, or in total, from 27.1 GW to 71.0 GW. Details of this development:

- Hydroelectric capacity will gain 11%, from 4.6 GW to 5.1 GW;
- Wind power will increase by 116%, from 18.7 GW to 39.7 GW, 11.4 GW of this in offshore installations alone;
- Photovoltaic capacity will increase nine-fold, from 1.9 GW to 18.5 GW;
- Biomass capacity will expand by 228%, from 2.2 GW to 7.2 GW; and
- Geothermal energy will reach an installed capacity of 0.5 GW.

Figure 4.3-34: Reference options with and without CCS: Installed capacity of renewable energy sources, 2005 – 2050, in GW



Source: Prognos 2009

Secured capacity will also increase over the period of the study. But it will rise less, because new buildings will emphasise wind power and photovoltaic systems, whose fluctuating generation will ensure only a low firm contribution. In 2005, secured capacity from renewable energy sources came to approx. 6.0 GW. By 2050, it will increase by more than 120% in Germany, to some 13.3 GW. The importation of up to 10.2 TWh of renewable power will increase secured capacity in 2050 to 14.7 GW.

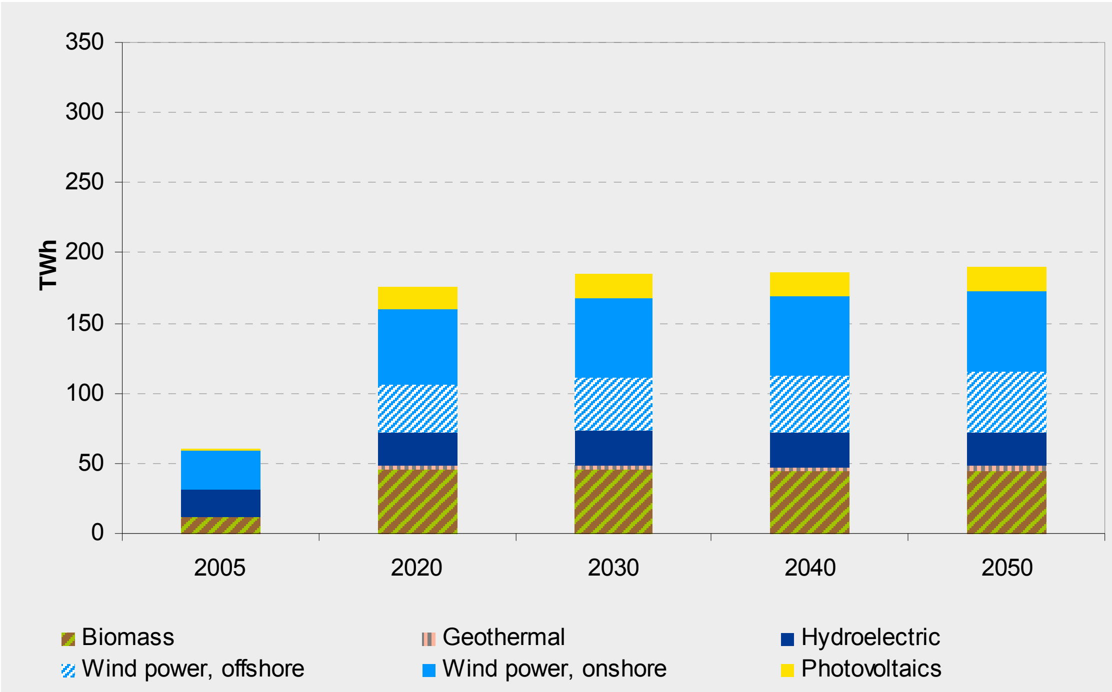
The pumped storage units installed today will be adequate to integrate renewables into the power supply and to cover peak loads. New capacity will not have to be built.

Power generated from renewable sources rises by a factor of 3.2 between 2005 and 2050 in both reference scenario options, with and without CCS, from 60 TWh to 190 TWh (see Figure 4.3-35). Details of this development:

- Hydroelectric power will increase 25%, from 20.0 TWh to 24.4 TWh;
- Power generated from the wind will increase by a factor of 3.7, from 27 TWh to 100 TWh;
- Photovoltaic power will increase by a factor of 14, from 1.2 TWh to 17.6 TWh;
- Biomass conversion to electricity will grow 280%, from 12.0 TWh to 44.7 TWh; and
- Geothermal energy will contribute 3.6 TWh of generated power by 2050.

Power generated from renewable sources will grow faster than installed capacity between 2020 and 2050 due to better utilisation of capacity (higher capacity factors).

Figure 4.3-35: Reference options with and without CCS: Net power generation from renewable energy sources, 2005 – 2050, in TWh



Source: Prognos 2009

4.3.6.1.3 Construction of new conventional power plants

In the reference scenarios both with and without CCS, construction of new conventional power plants will focus on ensuring coverage of annual peak loads on market-compatible terms. The power plants already under construction today (see Sec. 2.2.2.2, Figure 2.2-5, p. 20) are included below in the new power plant capacity constructed under both options.

In the reference scenario option without CCS, a total of 61.9 GW of new conventional power plant capacity is built between 2005 and 2050. Hard coal, at 24.7 GW of installed capacity, and lignite, at 23.2 GW, are about equal in new plant construction. Natural gas, at 14.0 GW, represents less than one-quarter of the new power plant capacity.

In the reference option with CCS, there is only slightly less new conventional power plant construction, for a total of 60.3 GW. However, CCS technology for hard coal and lignite occupies considerable ground towards the end of the period. A total of 20.7 MW of hard coal power plant capacity is constructed, 3.5 GW of this with CCS. Of the 25.5 GW in new lignite power plants, 9.0 GW is equipped with CCS. The new natural-gas power plant capacity built by 2050, at 14.1 GW, is roughly equivalent to the reference scenario option without CCS.

4.3.6.2 Results for reference scenario option without CCS

4.3.6.2.1 Energy

Net power consumption in the reference scenario option without CCS decreases by 6.3% between 2005 and 2050, to 530 TWh. The crucial factor here is the final energy consumption of electricity, which decreases by 9% to 472 TWh (see Sec. 4.3.5). Consumption in the conversion sector (refineries, district heat generation, lignite open pit mining, etc.) also decreases. Transport losses from the power grid (line losses) likewise decrease slightly because of the smaller volumes transported.
Imports of electricity, with a priority on renewable generation, increase. Based on this development, the necessary net power generated in Germany will decrease by 10.8% between 2005 and 2050, from 583 TWh to 520 TWh.

Table 4.3-44: Reference scenario without CCS: Net power consumption and generation, 2005 – 2050, in TWh

		Reference w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Final energy consumption – Electricity	517	492	474	478	472
Consumption for conversion	16	14	13	10	8
Line losses	29	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	22	24	25
Net power consumption	573	554	534	536	530
Net imports*	-9	0	5	8	10
Net power generation	583	554	530	529	520

** Priority in imports is on electricity from renewables from 2021 onwards* *Source: Prognos 2009*

Net power generation by the power plant fleet, including storage units, will decrease by a total of 10.8% by 2050 (for details of results see also Table 4.3-46).

- Power generation from hard coal will decrease slightly from 21.9% to 21% by 2050.

- Power generation from lignite will rise over the long term, primarily because lignite is little affected by rising fuel prices. Its share will increase from 26.6% to 31.9% by 2050.

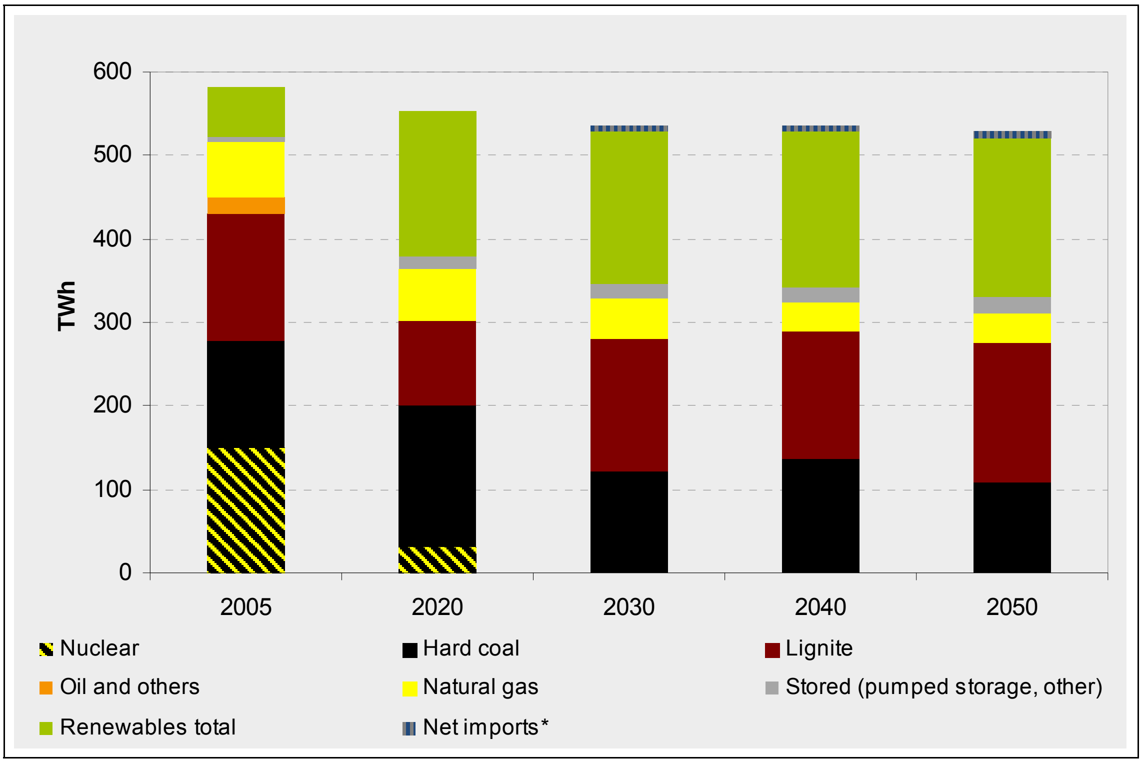
- Power generation from natural gas will decrease over the long term from 11.5% to 7.0%.

- Storage units will increasingly be used to balance the fluctuating feeds from renewable sources. While capacity remains the same, their contribution will rise from 1.3% to 3.5% by 2050.

- Renewables will more than triple their share of net power generation, from 10% in 2005 to 36.6% in 2050. Offshore wind power in particular will make a large contribution to this growth.

- Net imports will change; 10 TWh net will be imported in 2050, about 2% of net generation. It is assumed that the priority here will be on electricity generated from renewable sources.

Figure 4.3-36: Reference scenario without CCS: Net power generated by German power plant fleet, 2005 – 2050, in TWh



** Priority in imports is on renewably generated electricity from 2021 onwards* *Source: Prognos 2009*

4.3.6.2.2 Capacity

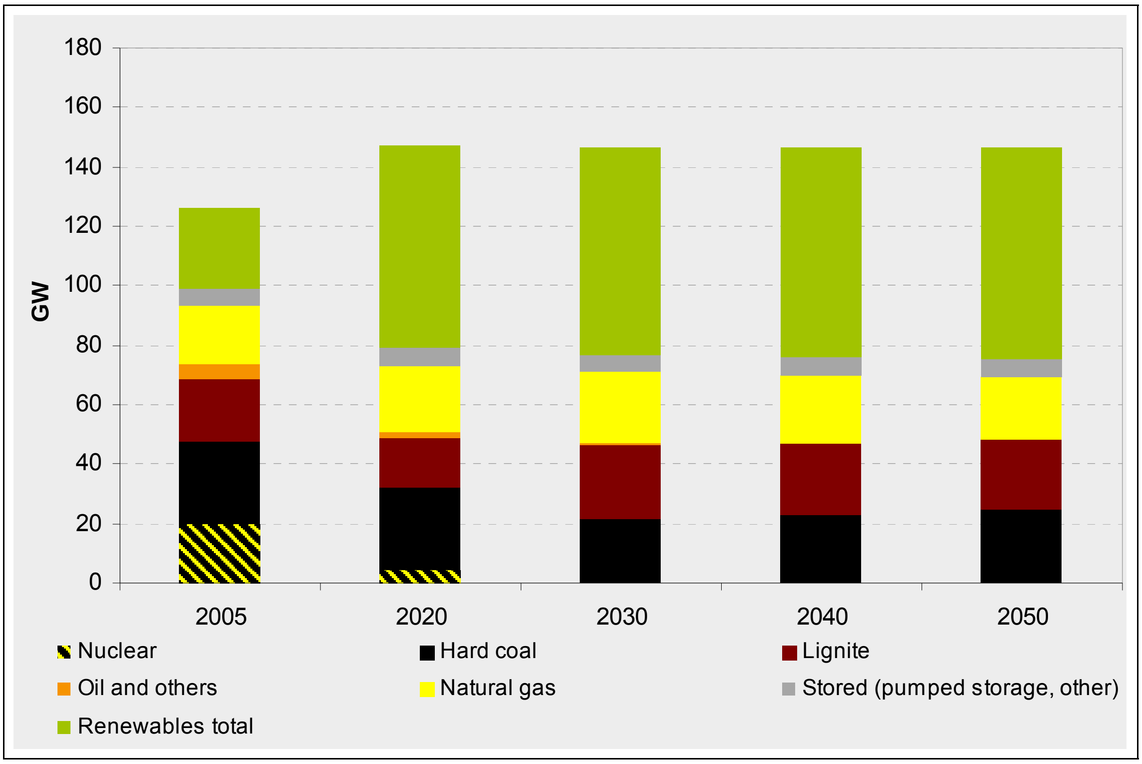
Declining net power consumption over the long term will decrease the annual peak load on the German power grid that must be covered by firm generating capacity based on renewables (with imports), storage, and conventional power plants (see Table 4.3-45). However, among renewables, the low secured capacity relative to annual power generated will have a negative effect on coverage of peak loads. Expansion of wind and photovoltaic power will mean that more balancing energy capacity, like gas turbines, must be added, which will achieve comparatively low capacity factors. This effect was taken into account in modelling the power plant fleet.

Table 4.3-45: Reference scenario without CCS: Peak load and secured capacity, 2005 – 2050, in GW

		Reference w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Peak load	84	76	74	75	74
Secured capacity	96	80	79	79	79
Renewables (incl. imports)	6	13	14	14	15
Conventional and stored	89	67	65	65	64

Source: Prognos 2009

Figure 4.3-37: Reference scenario without CCS: Installed capacity of the German power plant fleet, 2005 – 2050, in GW



Source: Prognos 2009

In the reference option without CCS, the installed net capacity of the German power plant fleet grows by about 10 % between 2005 and 2050, from a total of 129.9 GW to 145.8 GW. Since this option assumes that CCS technology will not become established, the power plant fleet in the long term only includes conventional power plants fuelled with hard coal, lignite, and natural gas, plus systems for generating power from renewable sources. All nuclear power plants leave the fleet after generating their respective remaining permitted power outputs, as do oil-fired power plants, which are not replaced with new ones because of cost (for the individual results see also Table 4.3-46). Details of developments from 2005 to 2050:

- Installed capacity of hard coal power plants will decrease from 20.2% to 16.9% by 2050.
- Lignite will maintain its share of roughly 16% of installed capacity over the long term.
- Installed capacity of natural gas power plants as a whole will decrease, despite the higher need for balancing energy from renewables. Newly built capacity will be more flexible to use. The share of natural gas in power generation will decrease from 15.6% to 14.5%.
- Storage capacity will remain roughly constant. For cost reasons, peak loads will be primarily covered by flexible natural gas power plants.
- The share of renewables in total capacity will expand steadily from 22.0% to 48.7%.

Table 4.3-46: Reference scenario without CCS: Net capacity, net power generated and annual capacity factors by input energy sources, 2005 – 2050

		Reference w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Net capacity in GW					
Nuclear	19.9	4.1	0.0	0.0	0.0
Hard coal	27.9	28.1	21.4	22.8	24.8
Hard coal w/ CCS		0.0	0.0	0.0	0.0
Lignite	20.8	16.8	25.0	24.3	23.2
Lignite w/ CCS		0.0	0.0	0.0	0.0
Natural gas	19.6	22.6	23.9	23.0	21.3
Oil and others	5.2	1.7	0.7	0.0	0.0
Stored (pumped storage, other)	5.4	5.7	5.9	6.2	6.4
Hydroelectric	4.6	5.1	5.1	5.1	5.1
Wind power, total	18.4	38.1	38.8	39.4	39.7
Wind power, onshore	18.4	28.1	28.1	28.2	28.3
Wind power, offshore		10.0	10.7	11.2	11.4
Photovoltaics	1.9	17.9	18.2	18.4	18.5
Biomass	2.2	7.1	7.2	7.2	7.2
Geothermal		0.3	0.3	0.4	0.5
Total net capacity	125.9	147.5	146.5	146.8	146.7
Net power generation in TWh					
Nuclear	151	30,2	0	0	0
Hard coal	128	169.6	120.9	136.7	109.1
Hard coal w/ CCS		0	0	0	0
Lignite	152.0	101.8	158.6	152.4	166.0
Lignite w/ CCS		0	0	0	0
Natural gas	67.0	61.5	49.1	35.8	36.3
Oil and others	18.1	0	0	0	0
Stored (pumped storage, other)	7.1	15.8	16.6	17.4	18.3
Hydroelectric	19.6	24.3	24.3	24.4	24.4
Wind power, total	27.2	87.2	95.0	97.6	99.8
Wind power, onshore	27.2	53.5	56.4	56.5	56.6
Wind power, offshore		33.7	38.6	41.1	43.1
Photovoltaics	1.2	15.5	16.6	17.1	17.6
Biomass	12.0	46.2	46.5	44.7	44.7
Geothermal		1.8	2.1	2.6	3.6
Total net power generation	583.2	554.0	529.7	528.7	520.0
Annual capacity factors in hrs/yr					
Nuclear	7,588	7,435	-	-	-
Hard coal	4,588	6,024	5,653	5,982	4,400
Hard coal w/ CCS	-	-	-	-	-
Lignite	7,308	6,067	6,342	6,271	7,168
Lignite w/ CCS	-	-	-	-	-
Natural gas	3,418	2,722	2,056	1,553	1,701
Oil and others	3,481	8	3	-	-
Stored (pumped storage, other)	1,315	2,786	2,808	2,834	2,866
Hydroelectric	4,261	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,452	2,475	2,514
Wind power, onshore	1,478	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000
Average	4,632	3,757	3,616	3,601	3,544

Source: Prognos 2009

The mean utilisation of capacity in the power plant fleet (annual capacity factor) will recede overall between 2005 and 2050. The reason is the shift towards renewable sources, especially wind energy, the phase-out of the use of nuclear energy, and the substantial decrease in the capacity factor for hard coal power plants. All other energy sources, and especially pumped storage power plants, will see an increase in their mean annual utilisation.

4.3.6.2.3 Fuel input and CO_2 emissions

The CO_2 emissions are calculated on the basis of fuel input broken down by energy source. Fuel input is derived from net power generation and the power plants' associated mean annual fuel utilisation ratios (annual utilisation ratios). Technical progress will raise the fuel utilisation ratio for all new conventional power plants, which will gradually become established throughout the fleet. Towards the end of the period under study, the annual utilisation ratios for hard coal and natural gas will recede somewhat. The reasons: higher start-up losses due to lower utilisation of capacity, in the case of hard coal, and the rising number of gas turbines, in the case of natural gas.

Fuel input will decrease by 39.2% between 2005 and 2050. The reason, apart from decreasing net power generation, is the rising share of renewable energy sources; with the exception of geothermal energy and biomass, these by definition have a "fuel" utilisation ratio of 100%.

The use of renewable energy sources for power generation is treated as CO_2-emission neutral, in accordance with the generally applicable definition. Fossil fuels – hard coal, lignite, natural gas, oil, and other combustibles – are relevant for the calculation of CO_2 emissions from power generation. The employed biomass contains a significant percentage of waste; hence it contributes to CO_2 emissions with a lower emission factor. The calculation is based on fuel input broken down by energy source, and on the fuel-specific emission factors. The emissions for 2005 are model levels calculated from the energy balance, and deviate slightly from the figures in the emission inventory. The model levels are shown here for consistency's sake. The summations for total greenhouse gases in Sec. 4.3.10 then use the levels from the emission inventory.

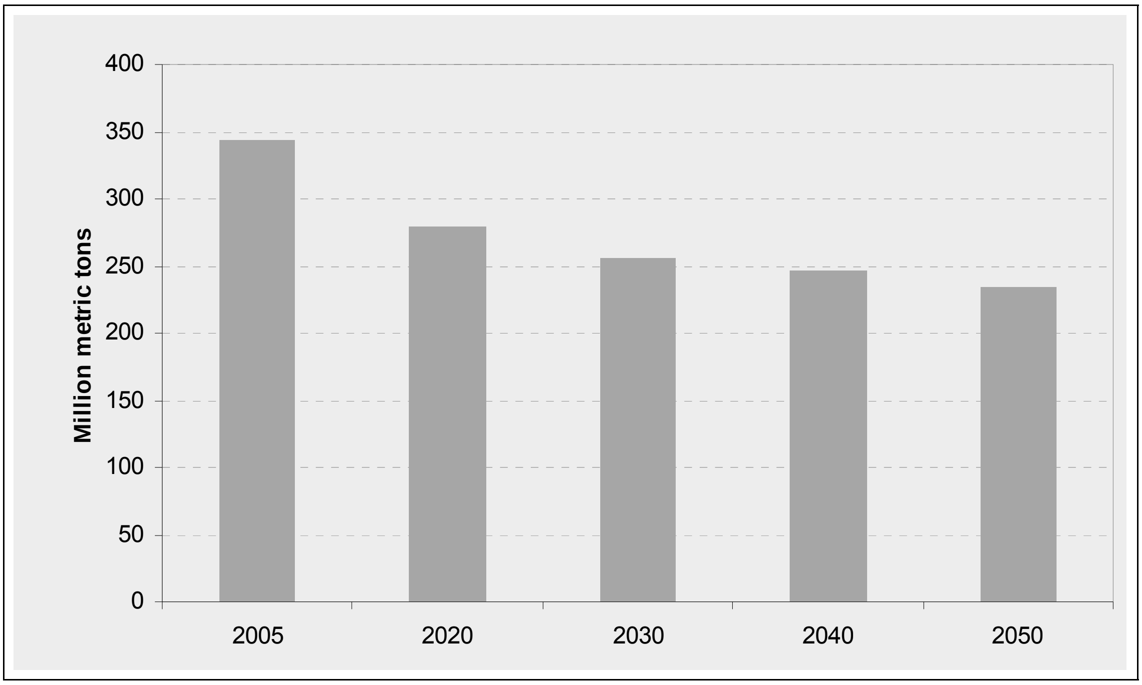
Table 4.3-47: Reference scenario without CCS: Fuel input in PJ and annual utilisation ratio in %, 2005 – 2050

		Reference w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input / Primary energy input					
Nuclear	1,658	332	0	0	0
Hard coal	1,182	1,461	971	1,004	840
Hard coal w/ CCS	0	0	0	0	0
Lignite	1,537	932	1,189	1,130	1,162
Lignite w/ CCS	0	0	0	0	0
Natural gas	571	473	371	271	281
Oil and others	314	0	0	0	0
Stored (pumped storage, other)	40	77	81	85	89
Hydroelectric	82	93	92	93	93
Wind power, total	98	314	342	351	359
Wind power, onshore	98	193	203	203	204
Wind power, offshore	0	121	139	148	155
Photovoltaics	4	56	60	62	63
Biomass	136	486	468	432	415
Geothermal	0	71	74	87	114
Total fuel input	5,622	4,294	3,649	3,514	3,416
Annual utilisation ratio in %					
Nuclear	33	33	-	-	-
Hard coal	39	42	45	49	47
Hard coal w/ CCS		-	-	-	-
Lignite	36	39	48	49	51
Lignite w/ CCS		-	-	-	-
Natural gas	42	47	48	48	47
Oil and others	21	22	22	-	-
Stored (pumped storage, other)	74	74	74	74	74
Hydroelectric	94	94	95	95	95
Wind power, total	100	100	100	100	100
Wind power, onshore	100	100	100	100	100
Wind power, offshore		100	100	100	100
Photovoltaics	100	100	100	100	100
Biomass	32	34	36	37	39
Geothermal	0	9	10	11	12
Average	37	46	52	54	55

Source: Prognos 2009

In the reference option without CCS, CO_2 emissions from power generation in Germany decrease by 32% between 2005 and 2050, from 344 million metric tons to 234 million metric tons.

Figure 4.3-38: Reference scenario without CCS: CO_2 emissions by the German power plant fleet, 2005 – 2050, in million metric tons



** Emissions excluding component from flue gas desulfurisation* *Source: Prognos 2009*

Table 4.3-48: Reference scenario without CCS: Fuel input in PJ and CO_2 emissions, 2005 - 2050

		Reference w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input in PJ					
Hard coal	1,182	1,461	971	1,004	840
Hard coal w/ CCS	0	0	0	0	0
Lignite	1,537	932	1,189	1,130	1,162
Lignite w/ CCS	0	0	0	0	0
Natural gas	571	473	371	271	281
Oil and others	314	0	0	0	0
Biomass / Waste	136	486	468	432	415
CO_2 emission factors in kg/GJ					
Hard coal	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9
Lignite	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11
Natural gas	56	56	56	56	56
Oil and others	80	80	80	80	80
Biomass / Waste	23	23	23	23	23
CO_2 emissions in million metric tons					
Hard coal	111	137	91	94	79
Hard coal w/ CCS	0	0	0	0	0
Lignite	172	104	133	127	130
Lignite w/ CCS	0	0	0	0	0
Natural gas	32	27	21	15	16
Oil and others	25	0	0	0	0
Biomass / Waste	3	11	11	10	9
Total CO_2 emissions	344	279	256	246	234

Source: Prognos 2009

4.3.6.2.4 Costs

The comparison of the costs of the scenarios is based on the full costs of power generation in Germany.

The full costs of domestic power generation include all costs incurred to build and operate power plants. These include investment costs, fuel costs (including CO_2 costs), and all costs for supplies, repair and maintenance, personnel, financing, and plant insurance.

Costs of conventional power generation are based on the calculations from the Prognos AG power plant model. For renewable energy sources and power imports, own production costs are used, based on the guideline study [DLR/Nitsch 2008] (Table 4.3-50).

Primarily because of the construction of new gas power plants needed for peak loads and balancing, specific power production costs will increase by 80% between 2005 and 2050, from EUR 0.052 to EUR 0.094 per kWh. Annual full costs for all power generation will increase 63%.

Table 4.3-49: *Reference scenario without CCS: Specific production cost and full cost of power generation, 2005 – 2050*

		Reference w/o CCS			
	2005	2020	2030	2040	2050
Specific production cost of net power generation in euro cents/kWh (real, 2007)					
Average – Conventional generation	4.3	7.8	8.2	8.8	10.0
Nuclear	4.0	4.1	-	-	-
Hard coal	4.6	7.4	8.1	8.8	11.3
Hard coal w/ CCS					
Lignite	3.3	6.6	6.1	6.5	6.4
Lignite w/ CCS					
Natural gas	8.0	12.6	14.9	18.4	22.1
Oil and others					
Stored (pumped storage, other)	10.3	11.3	11.0	11.2	11.8
Power imports	0.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	9.0	8.5	8.4
Hydroelectric	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	7.1	6.9
Onshore	11.1	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1
Average – Total	5.2	8.7	8.6	8.8	9.4
Full cost of power generation in EUR bn (real, 2007)					
Conventional generation – Total	22.3	28.2	26.8	28.5	31.0
Nuclear	6.0	1.2	0.0	0.0	0.0
Hard coal	5.9	12.6	9.9	12.0	12.3
Hard coal w/ CCS	-	-	-	-	-
Lignite	5.0	6.7	9.6	9.9	10.7
Lignite w/ CCS	-	-	-	-	-
Natural gas	5.3	7.7	7.3	6.6	8.0
Oil and others	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.8	1.8	2.0	2.2
Power imports	-	0.0	0.5	0.6	0.7
Average – Renewable generation	7.5	18.0	16.7	15.9	16.0
Hydroelectric	2.2	2.4	2.4	2.4	2.4
Wind power, total	3.0	7.5	7.0	6.9	6.9
Onshore	3.0	4.3	4.2	4.1	4.1
Offshore	-	3.2	2.8	2.8	2.8
Photovoltaics	0.7	2.3	1.8	1.7	1.7
Biomass	1.6	5.6	5.3	4.7	4.7
Geothermal	0.0	0.2	0.2	0.2	0.3
Total full cost of power generation	30.5	48.0	45.8	47.0	49.8

Source: Prognos 2009

4.3.6.3 Results for reference scenario with CCS

4.3.6.3.1 Energy

In terms of net power consumption, net imports, and the resulting net power generation in Germany, the reference scenario option with CCS does not differ from the reference option without CCS (see Section 4.3.6.2.1).

Table 4.3-50: Reference scenario with CCS: Net power consumption and generation, 2005 – 2050, in TWh

		Reference w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Final energy consumption – Electricity	517	492	474	478	472
Consumption for conversion	16	14	13	10	8
Line losses	29	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	22	24	25
Net power consumption	573	554	534	536	530
Net imports*	-9	0	6	8	10
Net power generation	583	554	528	528	520

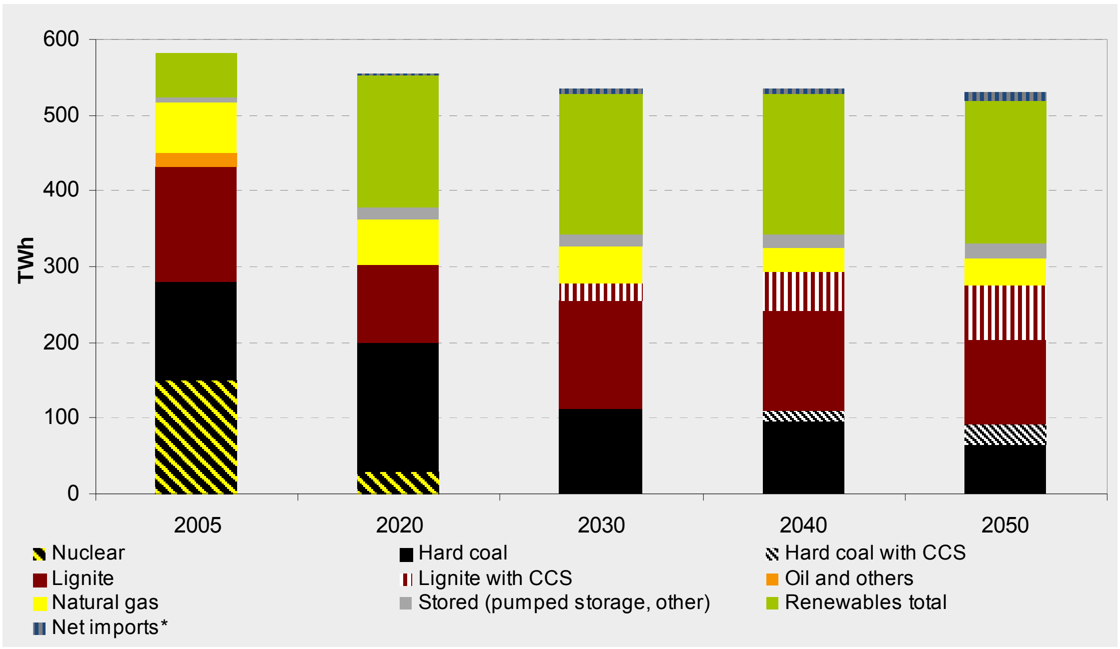
** Imported electricity is from renewable sources from 2021 onwards* *Source: Prognos 2009*

The net power generated by the power plant fleet, including storage units, will decrease by a total of 9.4% by 2050, to 520 TWh. Renewables will be able to more than double their share of net power generation, just as in the reference scenario option without CCS (for details of results, see Table 4.3-52).

- Power generated from hard coal without the use of CCS technology will decrease 50%, from a 21.9% to a 12.4% share by 2050.
- CCS technology will be used in 5.4% of power generation from hard coal by 2050.
- Power generation from lignite will increase substantially on the whole. Although power generated without CCS will decrease from 27% to 21.3% by 2050, lignite-fired CCS power plants will then already be contributing a substantial 13.9% of power generation.
- Power generated from natural gas will decrease, from 11.5% in 2005 to 7.0% in 2050.
- As in the reference scenario option without CCS, storage units will increasingly be used to balance out fluctuating feed-ins from renewable sources.
- Renewable sources will expand their share of net power generation by a factor of 3.6, from 10% to 36.5%.

In the net power generation discussed above, if we consider only primary power generation and set aside interim storage units as secondary generation plants, the share of renewable sources increases further. A total of 37.9% of total primary power generation in Germany will be based on renewable energy sources in 2050.

Figure 4.3-39: *Reference scenario with CCS: Net power generated by German power plant fleet, 2005 – 2050, in TWh*



** Imported electricity is renewably generated from 2021 onwards* *Source: Prognos 2009*

4.3.6.3.2 Capacity

The reference scenario options with and without CCS are based on the same assumptions about the development of combined heat and power and renewable energy sources and long-term energy imports in Germany. Differences between the options arise because in the option with CCS, CCS technology is available for lignite and hard coal, and gradually becomes established throughout the German power plant fleet from 2025 onwards. The difference in the addition of new conventional power plant capacity yields slight differences in secured capacity.

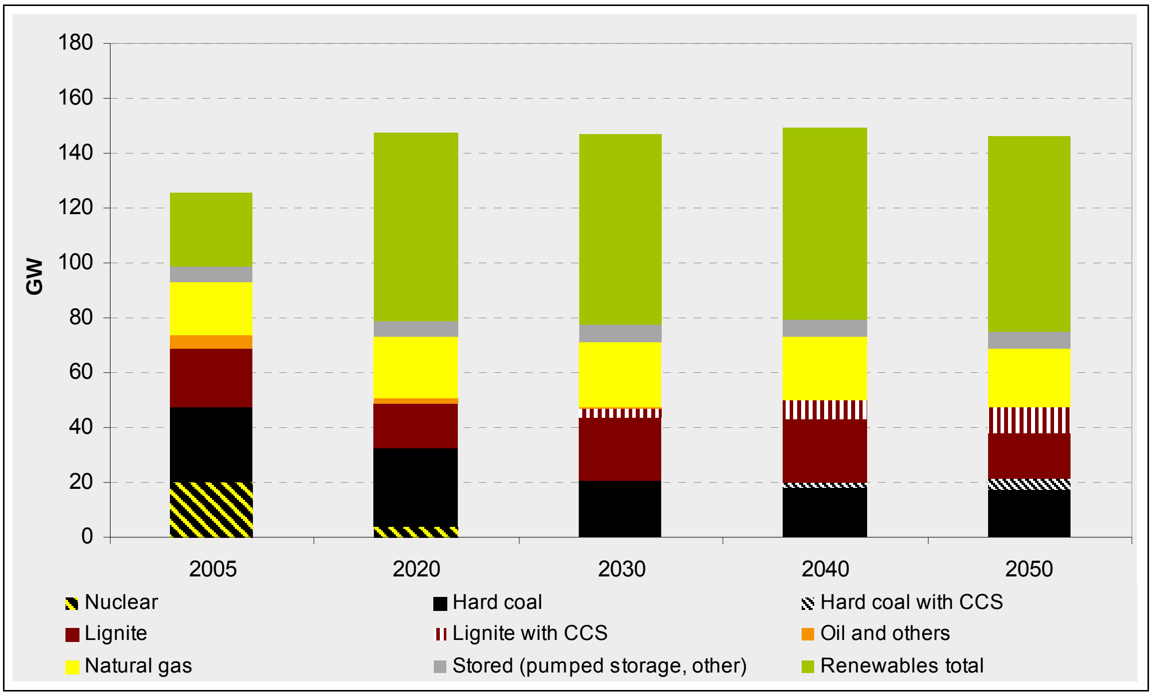
Table 4.3-51: *Reference scenario option with CCS: Peak load and secured capacity, 2005 – 2050, in GW*

		Reference w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Peak load	84	76	74	75	74
Secured capacity	96	81	80	82	79
Renewables (incl. imports)	6	13	14	14	15
Conventional and stored	89	67	66	67	64

Source: Prognos 2009

In the reference scenario option with CCS, the installed net capacity of the German power plant fleet grows by 16% between 2005 and 2050, from a total of 125.9 GW to 146.2 GW. In the long term, the power plant fleet will include conventional power plants fired with hard coal (with and without CCS), lignite (with and without CCS) and natural gas, plus systems for generating electricity from renewable sources.

Figure 4.3-40: Reference scenario with CCS: Installed capacity of the German power plant fleet, 2005 – 2050, in GW



Source: Prognos 2009

All nuclear power plants will leave the fleet after generating their respective remaining power outputs. For cost reasons, no new oil-fired power plants will be built (for details of results see Table 4.3-52). Details of developments from 2005 to 2050:

- The installed capacity of hard coal power plants without CCS will decrease drastically, from 22.2% to 11.9% by 2050.
- Installed capacity of lignite-fired power plants without CCS will also decrease as CCS technology is introduced. Over the long term, its share will decline from 16.5% to 11.3%.
- CCS power plants for lignite will be built after 2025, and for hard coal as well after 2030. The installed capacity of these plants will represent 2.9% for hard coal in 2050, and 6.5% for lignite.
- The installed capacity of natural gas power plants will decrease from 15.6% to 14.6%.
- As in the reference option without CCS, pumped-storage capacity will remain nearly constant. Here too, peak loads will be covered primarily by natural gas power plants.
- Renewables will not be affected by CCS technology, and their share of total capacity will expand steadily from 21.5% to 48.9%.

Just as in the reference scenario option without CCS, the mean utilisation of capacity in the power plant fleet (annual capacity factors) will decline overall between 2005 and

2050. The reason is the greater share of renewables in the mix, the phase-out of the use of nuclear energy, and the substantial decline in the capacity factors of hard coal-fired power plants. All other energy sources, and especially pumped storage power plants, will see an increase in their mean annual utilisation.

Table 4.3-52: *Reference scenario with CCS: Net capacity, net power generated and annual capacity factors by input energy sources, 2005 – 2050*

		Reference w/ CCS			
	2005	2020	2030	2040	2050
Net capacity in GW					
Nuclear	19.9	4.1	0.0	0.0	0.0
Hard coal	27.9	28.1	20.3	18.1	17.3
Hard coal w/ CCS		0.0	0.0	2.2	4.2
Lignite	20.8	16.8	23.4	22.7	16.5
Lignite w/ CCS		0.0	3.0	7.0	9.5
Natural gas	19.6	22.6	23.9	23.0	21.3
Oil and others	5.2	1.7	0.7	0.0	0.0
Stored (pumped storage, other)	5.4	5.7	5.9	6.2	6.4
Hydroelectric	4.6	5.1	5.1	5.1	5.1
Wind power, total	18.4	38.1	38.8	39.4	39.7
Wind power, onshore	18.4	28.1	28.1	28.2	28.3
Wind power, offshore		10.0	10.7	11.2	11.4
Photovoltaics	1.9	17.9	18.2	18.4	18.5
Biomass	2.2	7.1	7.2	7.2	7.2
Geothermal		0.3	0.3	0.4	0.5
Total net capacity	125.9	147.5	146.8	149.6	146.2
Net power generation in TWh					
Nuclear	151.0	30.2	0.0	0.0	0.0
Hard coal	128.0	169.6	112.3	95.2	64.5
Hard coal w/ CCS		0.0	0.0	15.3	28.2
Lignite	152.0	101.8	144.0	131.8	110.7
Lignite w/ CCS		0.0	22.3	51.9	72.1
Natural gas	67.0	61.5	48.4	29.8	36.5
Oil and others	18.1	0.0	0.0	0.0	0.0
Stored (pumped storage, other)	7.1	15.8	16.6	17.4	18.3
Hydroelectric	19.6	24.3	24.3	24.4	24.4
Wind power, total	27.2	87.2	95.0	97.6	99.8
Wind power, onshore	27.2	53.5	56.4	56.5	56.6
Wind power, offshore		33.7	38.6	41.1	43.1
Photovoltaics	1.2	15.5	16.6	17.1	17.6
Biomass	12.0	46.2	46.5	44.7	44.7
Geothermal		1.8	2.1	2.6	3.6
Total net power generation	583.2	554.0	528.0	527.9	520.4
Annual capacity factors in hrs/yr					
Nuclear	7,588	7,435	-	-	-
Hard coal	4,588	6,024	5,522	5,261	3,725
Hard coal w/ CCS	-	-	-	7,020	6,762
Lignite	7,308	6,067	6,156	5,810	6,712
Lignite w/ CCS	-	-	7,431	7,415	7,631
Natural gas	3,418	2,722	2,025	1,294	1,708
Oil and others	3,481	8	3	-	-
Stored (pumped storage, other)	1,315	2,786	2,808	2,834	2,866
Hydroelectric	4,261	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,452	2,475	2,514
Wind power, onshore	1,478	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000
Average	4,632	3,757	3,597	3,527	3,560

Source: Prognos 2009

4.3.6.3.3 Fuel input and CO_2 emissions

CO_2 emissions are calculated on the basis of fuel input broken down by energy source. Fuel input is derived from net power generation and the associated mean annual fuel utilisation ratios of the generating plants (annual utilisation ratios). Technical progress will raise the fuel utilisation ratios for all conventional power plants, and those ratios will gradually become established throughout the fleet.

The results for the Reference option with CCS do not differ from the option without CCS until CCS technology is introduced. The triggering factors here are the lower fuel utilisation ratios of CCS plants compared to conventional plants, and the lower annual utilisation hours for conventional lignite and hard coal-fired power plants.

Table 4.3-53: Reference scenario with CCS: Fuel input in PJ and annual utilisation ratio in %, 2005 – 2050

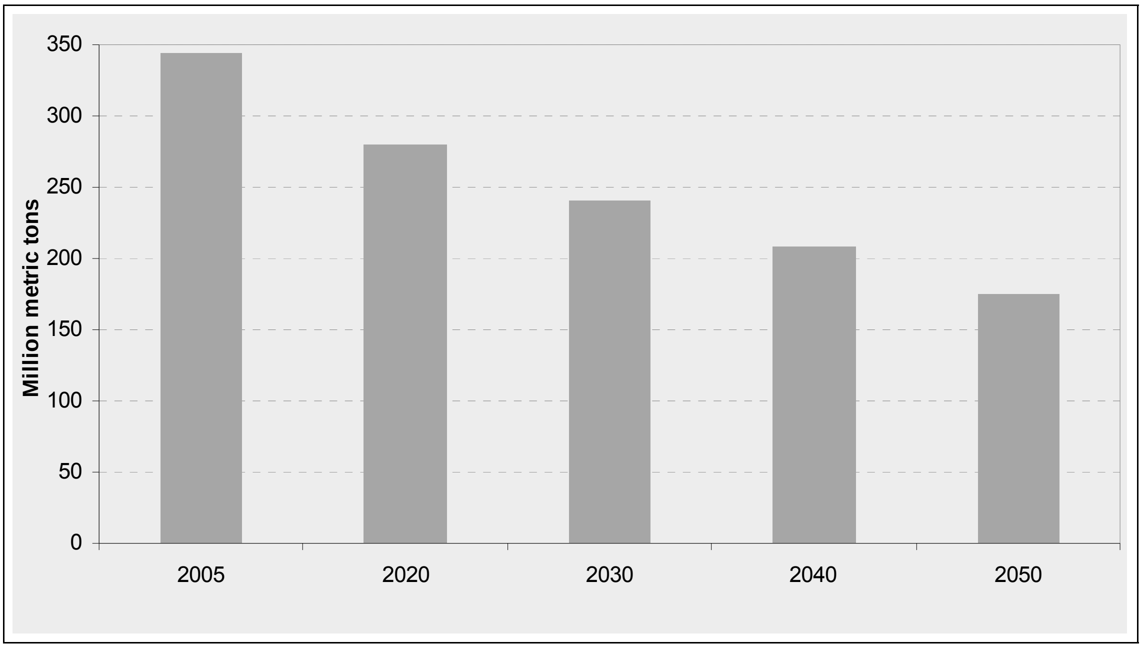
		Reference w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input / Primary energy input					
Nuclear	1,658	332	0	0	0
Hard coal	1,182	1,461	909	738	537
Hard coal w/ CCS	0	0	0	121	220
Lignite	1,537	932	1,086	983	812
Lignite w/ CCS	0	0	193	426	562
Natural gas	571	473	366	228	282
Oil and others	314	0	0	0	0
Stored (pumped storage, other)	40	77	81	85	89
Hydroelectric	82	93	92	93	93
Wind power, total	98	314	342	351	359
Wind power, onshore	98	193	203	203	204
Wind power, offshore	0	121	139	148	155
Photovoltaics	4	56	60	62	63
Biomass	136	486	468	432	415
Geothermal	0	71	74	87	114
Total fuel input	5,622	4,294	3,672	3,605	3,546
Annual utilisation ratio in %					
Nuclear	32.8	32.8	-	-	-
Hard coal	39.0	41.8	44.5	46.5	43.3
Hard coal w/ CCS	-	-	-	45.4	46.1
Lignite	35.6	39.3	47.7	48.3	49.1
Lignite w/ CCS	-	-	41.7	43.9	46.2
Natural gas	42.2	46.8	47.5	47.0	46.5
Oil and others	20.8	22.4	22.2	-	-
Stored (pumped storage, other)	74.0	74.0	74.0	74.0	74.0
Hydroelectric	94.0	94.3	94.5	94.8	95.0
Wind power, total	100.0	100.0	100.0	100.0	100.0
Onshore	100.0	100 .0	100.0	100.0	100.0
Offshore	-	100.0	100.0	100.0	100.0
Photovoltaics	100.0	100.0	100.0	100.0	100.0
Biomass	31.8	34.2	35.8	37.3	38.8
Geothermal	-	9.4	10.1	10.8	11.5
Average	36.9	46.4	51.8	52.7	52.8

Source: Prognos 2009

All in all, fuel input in the reference scenario with CCS decreases 36.9% between 2005 and 2050. This decrease is somewhat less than in the reference scenario option without CCS.

CO_2 emissions from power generation in Germany decrease by nearly half from 2005 to 2050 in this option.

Figure 4.3-41: Reference scenario with CCS: CO_2 emissions by the German power plant fleet, 2005 – 2050, in million metric tons



** Emissions excluding component from flue gas desulfurisation* *Source: Prognos 2009*

The use of renewable energy sources for power generation is treated as CO_2-emission neutral, in accordance with the generally applicable definition. For that reason, only fossil fuels – hard coal, lignite, natural gas, oil, and other combustibles (biomass including waste with small amounts of non-renewable fuels) – were used in calculating carbon emissions from power generation. The calculation is based on fuel input broken down by energy source, and on the fuel-specific energy factors. A 90% sequestration rate was assumed for CCS technology. The specific emission factors for fuel input in these plants were accordingly estimated at one-tenth of their levels for conventional power plants using the same fuel.

Table 4.3-54: Reference scenario with CCS: Fossil fuel input, CO_2 emission factors and CO_2 emissions, 2005 – 2050

		Reference w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input in PJ					
Hard coal	1,182	1,461	909	738	537
Hard coal w/ CCS	0	0	0	121	220
Lignite	1,537	932	1,086	983	812
Lignite w/ CCS	0	0	193	426	562
Natural gas	571	473	366	228	282
Oil and others	314	0	0	0	0
Biomass / Waste	136	486	468	432	415
CO_2 emission factors in kg/GJ					
Hard coal	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9
Lignite	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11
Natural gas	56	56	56	56	56
Oil and others	80	80	80	80	80
Biomass / Waste	23	23	23	23	23
CO_2 emissions in million metric tons					
Hard coal	111	137	85	69	50
Hard coal w/ CCS	0	0	0	1	2
Lignite	172	104	122	110	91
Lignite w/ CCS	0	0	2	5	6
Natural gas	32	27	21	13	16
Oil and others	25	0	0	0	0
Biomass / Waste	3	11	11	10	9
Total CO_2 emissions	344	279	241	208	175

** Emissions excluding component from flue gas desulfurisation* *Source: Prognos 2009*

4.3.6.3.4 Costs

The production costs and full costs of power generation are briefly presented here, analogously to Sec. 4.3.6.2.4 (Table 4.3-55).

The specific production costs behave similarly to the case in the reference scenario option without CCS, rising to EUR 0.091 per kWh by 2050. Because of the cost difference in dealing with CO_2 (CCS is specifically less expensive than the CO_2 certificate price, otherwise it would not be installed), full costs in 2050 are slightly lower (by just under 3%) than in the option without CCS.

Table 4.3-55: Reference scenario with CCS: Specific production cost and full cost of power generation, 2005 – 2050

		Reference w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Specific production cost of net power generation in euro cents/kWh (real, 2007)					
Average – Conventional generation	4.3	7.8	8.1	8.4	9.5
Nuclear	4.0	4.1	-	-	-
Hard coal	4.6	7.4	8.2	9.4	12.4
Hard coal w/ CCS				8.1	9.4
Lignite	3.3	6.6	6.1	6.7	6.8
Lignite w/ CCS			5.1	5.0	4.9
Natural gas	8.0	12.6	15.0	19.3	22.1
Oil and others					
Stored (pumped storage, other)	10.3	11.3	11.0	11.0	11.5
Power imports	0.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	9.0	8.5	8.4
Hydroelectric	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	7.1	6.9
Onshore	11.1	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1
Average – Total	5.2	8.7	8.5	8.5	9.1
Full cost of power generation in EUR bn (real, 2007)					
Conventional generation – Total	22.3	28.2	26.5	27.3	29.7
Nuclear	6.0	1.2	0.0	0.0	0.0
Hard coal	5.9	12.6	9.3	8.9	8.0
Hard coal w/ CCS	-	-	-	1.2	2.7
Lignite	5.0	6.7	8.9	8.8	7.52
Lignite w/ CCS	-	-	1.1	2.6	3.5
Natural gas	5.3	7.7	7.3	5.8	8.1
Oil and others	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.8	1.8	1.9	2.1
Power imports	-	0.0	0.5	0.6	0.7
Average – Renewable generation	7.5	18.0	16.7	15.9	16.0
Hydroelectric	2.2	2.4	2.4	2.4	2.4
Wind power, total	3.0	7.5	7.0	6.9	6.9
Onshore	3.0	4.3	4.2	4.1	4.1
Offshore	-	3.2	2.8	2.8	2.8
Photovoltaics	0.7	2.3	1.8	1.7	1.7
Biomass	1.6	5.6	5.3	4.7	4.7
Geothermal	0.0	0.2	0.2	0.2	0.3
Total full cost of power generation	30.5	48.0	45.5	45.8	48.5

Source: Prognos 2009

4.3.7 District heat generation

Demand for district heating decreases in the reference scenario from 300 PJ to 167 PJ. In 2005, almost half of district heating was supplied with natural gas (combined heat and power plants and heating plants), followed by heat drawn from hard coal and lignite-fired power plants, with fuel input totalling 306 PJ. With fewer conventional power plants constructed, and declining heat density, the reference scenario assumes that in the future district heating will be generated with growing shares of waste heat, biomass and thermal solar energy. Gas input will rise another 16% by 2030; by 2050 it will be 8% below the 2005 level. All in all, by 2050 about 211 PJ of primary energy will be used for district heat generation.

4.3.8 Other energy conversion

In the remaining conversion sectors, in parallel with the receding consumption of energy sources, energy input for production will decrease from 556 PJ to 540 PJ (without CCS) or 538 PJ (with CCS). The use of biomass to produce biogas and biofuels will rise from 72 PJ to 274 PJ.

4.3.9 Primary energy

4.3.9.1 Option without CCS

As explained in Sec. 2.1, primary energy consumption (deviating from the convention in the energy balance sheet) is shown here without consumption for non-energy purposes.

Primary energy input is reduced by 38% from 2005 to 2050 in the reference scenario. The biggest contributor here will be efficiency measures in the end consumer sectors, but gradual structural changes in power generation will also play a role. The use of renewable energy sources – solar thermal energy, photovoltaics, geothermal energy, wind – will reduce primary energy consumption by virtue of their efficiencies, which are high by definition.

Biomass fuels and biogas require the input of biomass in order to generate power, and this input counts towards the primary energy balance. Here, as opposed to the usual convention, a representation of biomass products was chosen in which the final energy sources biofuel and biogas are recorded separately, and the additional conversion input needed for their generation is recorded under the “biomass” item. This makes it easier to see biofuels’ gradual replacement of fossil fuels in particular (Table 4.3-56, Figure 4.3-42).

The use of coal will decrease by 33% between 2005 and 2050: hard coal by 39% and lignite by 27%. The principal reasons here are declining power generation at coal-fired power plants, and higher efficiencies at new plants.

Table 4.3-56: Reference scenario without CCS: Primary energy consumption (excluding non-energy consumption) by energy source and sector, 2005 – 2050, in PJ

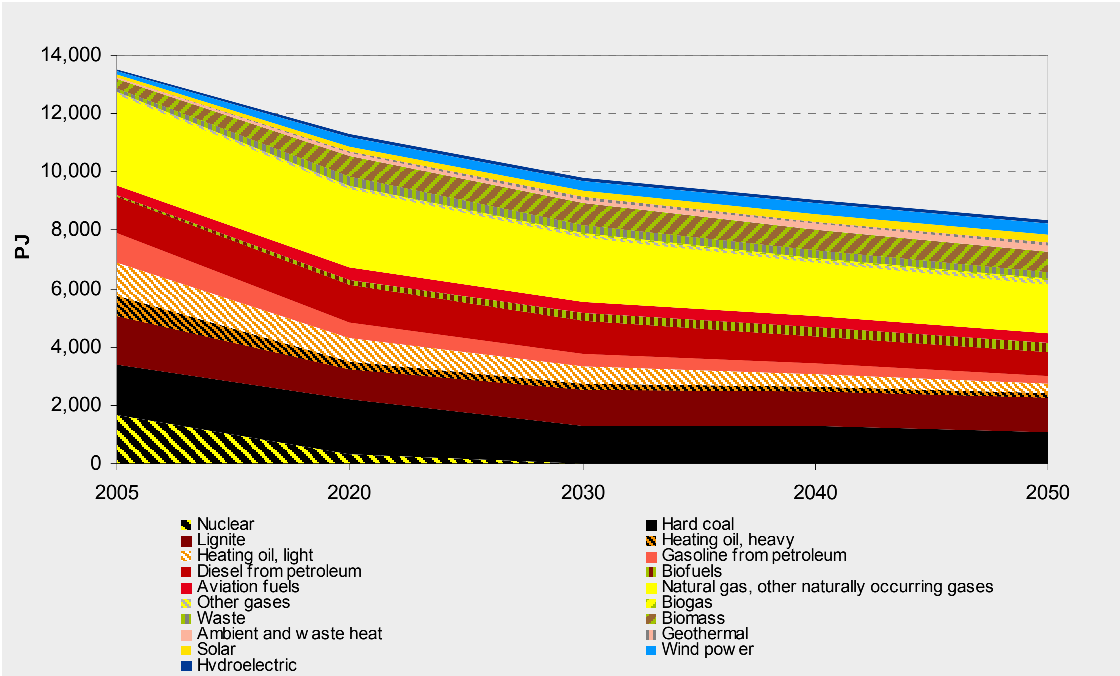
		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
By energy source, without CCS					
Nuclear	**1,658**	**332**	**0**	**0**	**0**
Coal	**3,412**	**2,888**	**2,529**	**2,458**	**2,284**
Hard coal	1,749	1,888	1,274	1,268	1,066
Lignite	1,662	1,000	1,255	1,190	1,218
Petroleum products	**4,407**	**3,299**	**2,753**	**2,293**	**1,865**
Heating oil, light	1,151	787	576	423	325
Heating oil, heavy	675	275	227	183	149
Gasoline from petroleum	1,033	583	461	369	254
Diesel from petroleum	1,202	1,260	1,114	952	787
Aviation fuels	345	394	374	365	350
Other petroleum products	1	0	0	0	0
Gases	**3,228**	**2,818**	**2,318**	**1,933**	**1,792**
Natural gas, other naturally occurring gases	3,105	2,697	2,210	1,827	1,673
Other gases	123	121	108	106	119
Waste	**87**	**283**	**272**	**251**	**241**
Renewable energy sources	**741**	**1,678**	**1,937**	**2,090**	**2,148**
Biomass	337	698	724	711	689
Ambient and waste heat	69	112	150	187	200
Solar	77	180	237	280	292
Hydroelectric	82	93	92	93	93
Wind power	98	314	342	351	359
Biofuels	77	193	268	321	340
Biogas	0	17	50	60	60
Geothermal	0	71	74	87	114
Total primary energy consumption	13,532	11,298	9,808	9,024	8,330
By sector, without CCS					
Residential	2,069	1,660	1,445	1,255	1,096
Services	923	685	464	322	270
Industry	1,556	1,444	1,281	1,176	1,127
Transport	2,529	2,361	2,180	1,996	1,760
District heat generation	306	271	255	248	211
Power generation	5,583	4,217	3,568	3,429	3,327
Other energy conversion	567	661	616	598	540
Total primary energy consumption	13,532	11,298	9,808	9,024	8,330

Source: Prognos 2009

Petroleum products will decline by 58%. This is primarily due to higher energy efficiency (and the use of renewable energy sources) in the production of space heating, and to a lesser extent in the provision of process heat. Efficiency and substitution effects from vehicles are a further factor.

Gas consumption decreases by 44%. Contributing factors here are a nearly 50% reduction in the use of natural gas for electricity (used primarily for peak and balancing energy), and also a lower use in the case of space heating, as well as the partial replacement of gas with renewable energy sources (ambient heat, solar thermal energy) for space heating.

Figure 4.3-42: Reference scenario without CCS: Primary energy consumption (excluding non-energy consumption) by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

In industry, gas consumption decreases by only a little less than 20%; in transport, it rises by a factor of nearly 30, starting from a low level.

The contribution of renewable energy sources (including the use of waste for energy) towards covering primary energy consumption will grow by a factor of almost 3. Here biofuels and biomass (in some cases in the energy conversion segment) will see the strongest growth (factor of 4.3), closely followed by wind energy, with a factor of 4, and solar energy, with a factor of 3. Renewable energy sources' share of primary energy consumption will quintuple, from 5% to nearly 26%.

4.3.9.2 Option with CCS

In the option with CCS, primary energy input changes little compared to the option without CCS; it decreases by 37% from 2005 to 2050 (Table 4.3-57, Figure 4.3-43).

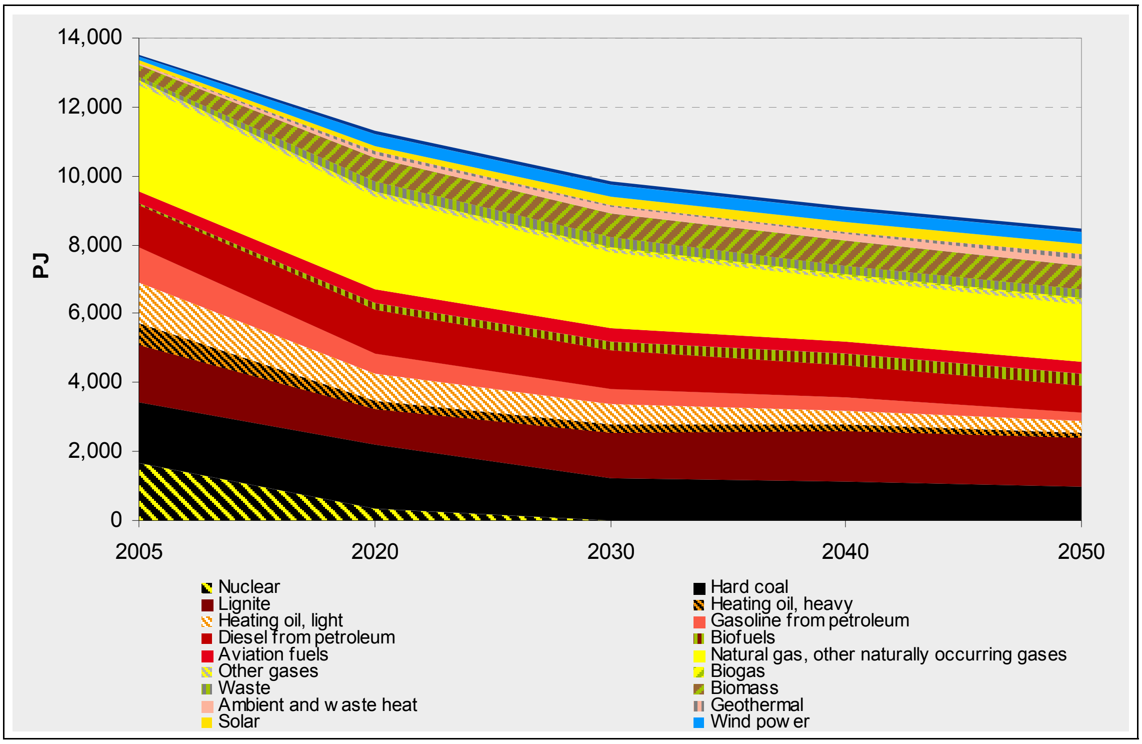
The reason for this is the more extensive use of coal in power generation with CCS technology. This additional consumption will represent about 6% of total primary energy consumption of coal by 2050. Referred to power generation, the additional consumption will be 11% for hard coal, and 15% for lignite. All other figures remain unchanged (see Sec. 4.3.9.1).

Table 4.3-57: Reference scenario with CCS: Primary energy consumption (excluding non-energy consumption) by energy source and sector, 2005 – 2050, in PJ

		Reference scenario			
	2005	**2020**	**2030**	**2040**	**2050**
By energy source, with CCS					
Nuclear	**1,658**	**332**	**0**	**0**	**0**
Coal	**3,412**	**2,888**	**2,554**	**2,585**	**2,409**
Hard coal	1,749	1,888	1,207	1,112	975
Lignite	1,662	1,000	1,347	1,474	1,434
Petroleum products	**4,407**	**3,299**	**2,753**	**2,293**	**1,865**
Heating oil, light	1,151	787	576	423	325
Heating oil, heavy	675	275	227	183	149
Gasoline from petroleum	1,033	583	461	369	254
Diesel from petroleum	1,202	1,260	1,114	952	787
Aviation fuels	345	394	374	365	350
Other petroleum products	1	0	0	0	0
Gases	**3,228**	**2,818**	**2,313**	**1,890**	**1,794**
Natural gas, other naturally occurring gases	3,105	2,697	2,205	1,784	1,675
Other gases	123	121	108	106	119
Waste	**87**	**283**	**272**	**251**	**241**
Renewable energy sources	**741**	**1,678**	**1,937**	**2,090**	**2,148**
Biomass	337	698	724	711	689
Ambient and waste heat	69	112	150	187	200
Solar	77	180	237	280	292
Hydroelectric	82	93	92	93	93
Wind power	98	314	342	351	359
Biofuels	77	193	268	321	340
Biogas	0	17	50	60	60
Geothermal	0	71	74	87	114
Total primary energy consumption	13,532	11,298	9,828	9,109	8,457
By sector, with CCS					
Residential	2,069	1,660	1,445	1,255	1,096
Services	923	685	464	322	270
Industry	1,556	1,444	1,281	1,176	1,127
Transport	2,529	2,361	2,180	1,996	1,760
District heat generation	306	271	255	248	211
Power generation	5,583	4,217	3,591	3,520	3,457
Other energy conversion	567	661	613	591	538
Total primary energy consumption	13,532	11,298	9,828	9,109	8,457

Source: Prognos 2009

Figure 4.3-43: Reference scenario with CCS: Primary energy consumption (excluding non-energy consumption) by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

4.3.10 Energy-related greenhouse gas emissions

Energy-related emissions of greenhouse gases (GHGs) include direct CO_2 emissions from the combustion process, and the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) produced during (incomplete) combustion (UBA 2009). Emissions that result, for example, from leakage, conversion losses and transport losses are counted among the fugitive emissions from the energy sector (see Sec. 4.3.11.1).

Since the differences in greenhouse gas emissions between the options with and without CCS appear only in the conversion sector (power generation and other conversion), both options are addressed in a single section here (Table 4.3-58).

By convention, the reference year for greenhouse gas reduction targets is 1990, so that emission data (inventory data) for 1990 are also shown. The definition of sectors in the model used for this study differs significantly, for methodological reasons, from the categorisation of German greenhouse gases, and therefore only the summary data for energy-related greenhouse gases are considered for 1990. Moreover, the calibrated model data, adjusted for weather, is shown for the actual data from 2005 in the demand sectors, since standardised conditions for weather conditions, etc. were used for the projection period. CO_2 emissions from the electric power sector are used in accordance with the emission inventory, and are supplemented with emissions from flue gas cleaning. All the same, the rates of change for all energy-related greenhouse gas emissions are shown referred to the indicated actual emission figure from the German greenhouse gas inventories.

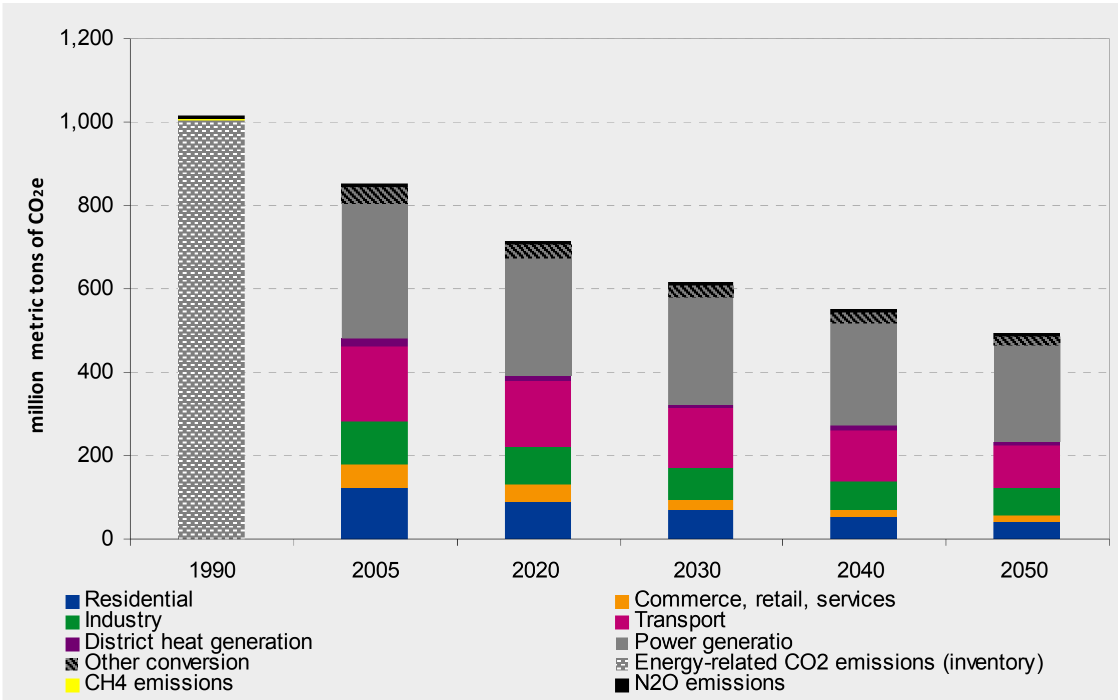
Table 4.3-58: Reference scenario: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent

			Reference scenario			
Million metric tons of CO_2 equivalent	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Residential		121.1	89.6	69.9	54.4	42.5
Commercial		58.0	40.3	25.6	16.3	13.4
Industry		100.7	90.5	77.7	69.3	64.8
Transport		179.5	159.1	140.4	123.0	103.5
Energy transformation sectors						
Public district heating		22.3	12.0	9.6	8.5	7.3
Power generation without CCS		323.4	280.5	257.1	247.0	235.4
Power generation with CCS		323.4	280.5	241.7	209.0	176.0
Other energy sectors without CCS		40.0	34.5	27.3	24.7	20.0
Other energy sectors with CCS		40.0	34.5	27.3	24.7	20.0
Total CO2 without CCS	1,005.4	845.0	706.5	607.7	543.2	486.9
Total CO2 with CCS	1,005.4	845.0	706.5	592.2	505.2	427.6
CH4 without CCS	4.5	1.3	1.0	0.9	0.9	0.8
CH4 with CCS	4.5	1.3	1.0	0.9	0.9	0.8
N2O without CCS	7.7	7.9	7.3	6.1	5.6	5.0
N2O with CCS	7.7	7.9	7.3	6.0	5.2	4.4
Total GHG without CCS	1,017.6	854.2	714.8	614.7	549.7	492.7
Total GHG with CCS	1,017.6	854.2	714.8	599.1	511.3	432.8
Total without CCS						
Change from 1990	-	-16.1%	-29.8%	-39.6%	-46.0%	-51.6%
Change from 2005	20.7%	1.3%	-15.2%	-27.1%	-34.8%	-41.5%
Total with CCS						
Change from 1990	-	-16.1%	-29.8%	-41.1%	-49.8%	-57.5%
Change from 2005	20.7%	1.3%	-15.2%	-28.9%	-39.3%	-48.7%
Notes: Emission data for 2005 have been adjusted; the change compared to 2005 refers to the emission level of the German GHG inventories (842.9 m tons of CO_2e); emissions of power production including CO_2 from flue gas desulfurization plants						

Source: Prognos 2009

In the option without CCS, the energy-related GHG emissions in 2050 are nearly 52% lower than the 1990 value; in the option with CCS, they are 57.5% lower. Referred to 2005, the reduction is 41.5% in the option without CCS, and about 49% in the option with CCS.

Figure 4.3-44: Reference scenario without CCS: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent

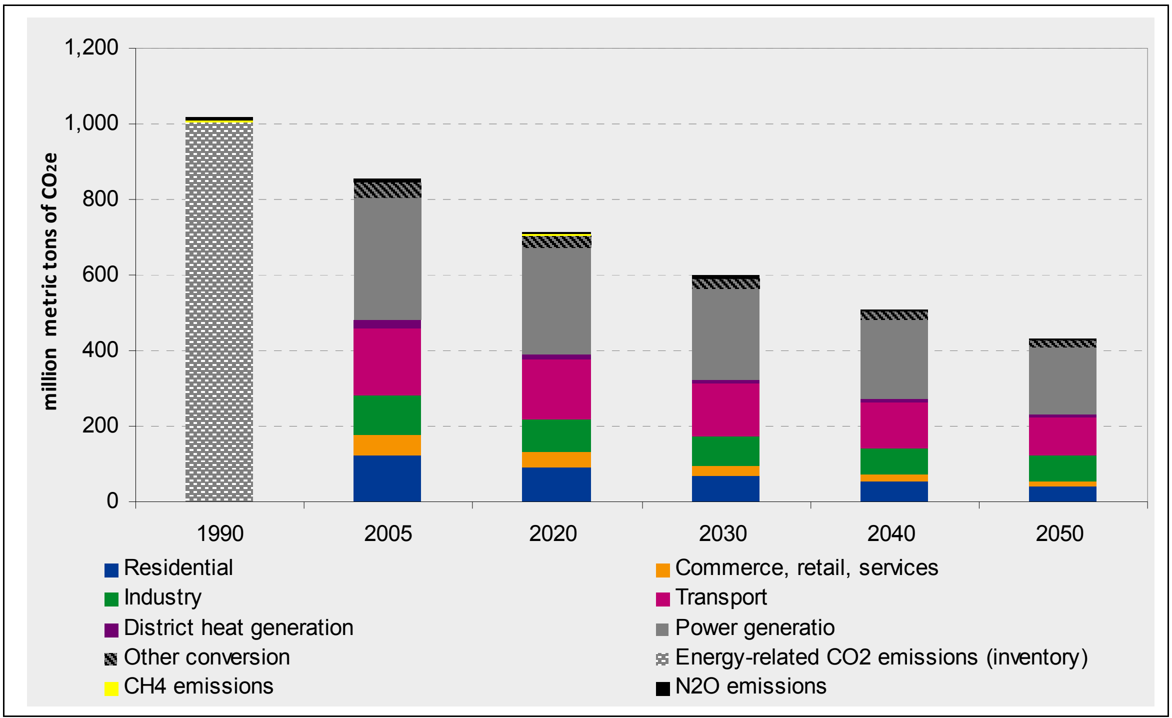


Source: Prognos 2009

Since CO_2 emissions represent the largest share of energy-related GHG emissions, they are broken down by sector. The demand sectors here do not take account of emissions for power generation or district heating; these are included in the total for the conversion sector.

CO_2 emissions decrease by 65% between 2005 and 2050 for the residential sector, by 77% in the service sector, by 36% in the industry sector, and by 42% in the transport sector. For the conversion sector, the reduction from 2005 to 2050 is about 32% in the option without CCS, and about 47% in the option with CCS. A more detailed consideration of the conversion sector shows a reduction of 67% in district heating from 2005 to 2050. The reduction in power generation is 27% without CCS and 46% with CCS; for the rest of the conversion sector it is 50%.

Figure 4.3-45: *Reference scenario with CCS: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent*



Source: Prognos 2009

Methane emissions were already reduced substantially from 1990 to 2005, by significant improvements in combustion processes. The savings from 1990 to 2050 will be 82%; for 2005 to 2050 the savings will be 36%. N_2O emissions differ in the options with and without CCS, because they depend on coal combustion, and can be reduced along with CO_2 in the carbon separation process, depending on the technology. Here the reductions from 1990 to 2050 represent 35% in the option without CCS (2005-2050: 38%), and 42% in the option with CCS (44%).

4.3.11 Fugitive emissions from the energy sector and non-energy-related emissions from the industry sector

4.3.11.1 Fugitive emissions from the energy sector

Fugitive emissions from the energy sector represented 2.3% of total greenhouse gas emissions in 1990. By 2005, the emissions from this source sector had been reduced by about 54%, primarily as a consequence of the massive reduction in hard coal mining in Germany, but also because of improvements in technical infrastructure and, for example, the reduction of leakage losses in the natural gas industry. Thus in 2005 only 1.2% of total greenhouse gas emissions were attributable to fugitive emissions from the energy sector.

Fugitive emissions from the energy sector – in Germany this pertains only to CH_4 emissions – result predominantly from the quantity structures for energy industry activities in various segments:

- Emissions from active coal mining result from the volumes of hard coal and lignite mined, and from the use of mine gas.

- Emissions from oil production parallel the associated volumes produced. Emissions from the storage of petroleum products result from the input volumes of petroleum products.

- Emissions from natural gas production and distribution are coupled to domestic production and to input volumes in the various sectors.

Apart from demand-driven emissions from various energy sources, the following aspects were also taken into account:

- For the contribution to emissions from active hard coal mining, the development of the volume produced is crucial. Here both scenarios assumed that hard coal production would decrease to 12 million metric tons per year by 2012, and be completely halted in German mines by 2018.

- The CH_4 emissions from shut hard coal mines were extrapolated from the current (low) levels.

- For the production of petroleum and natural gas in Germany, the quantity structures taken as a basis for EWI/Prognos (2006) were used, with the implicit assumption that changes in consumption levels would result solely in changes in petroleum and natural gas imports.

- Moreover, the quantity structures for oil and gas demand in particular are the central determining levels for fugitive CH_4 emissions by the energy sector.

Table 4.3-59: Reference scenario: Development of fugitive CH_4 emissions from the energy sector, 2000 – 2050, in kt

		Reference scenario			
kt CH_4	**2005**	**2020**	**2030**	**2040**	**2050**
CH_4 emissions					
Mining activities					
Underground mining activities	254.5	0.0	0.0	0.0	0.0
Handling of hard coal	14.3	0.0	0.0	0.0	0.0
Surface mining activities	2.0	1.1	1.4	1.4	1.4
Solid fuels transformation	0.4	0.2	0.1	0.1	0.1
Post-mining activities	2.9	2.9	2.9	2.9	2.9
Oil production and processing					
Production	3.9	1.9	0.6	0.0	0.0
Storage	2.3	1.7	1.4	1.2	1.0
Natural gas					
Production	53.1	50.6	41.8	34.1	25.9
Transport	40.1	35.3	29.5	24.8	23.1
Distribution	165.9	131.8	97.0	71.7	58.3
Other leakages	67.0	53.2	39.2	28.9	23.5
Total CH_4	606.3	278.8	214.0	165.1	136.1
Change from 1990	-54.1%	-78.9%	-83.8%	-87.5%	-89.7%
Change from 2005		-54.0%	-64.7%	-72.8%	-77.6%

Source: Öko-Institut 2009

Table 4.3-59 shows the development of fugitive CH_4 emissions from the energy sectors for the reference scenario. More than half of the total emission reduction of some 470 kt CH4 between 2005 and 2050 comes from the reduction of German hard coal mining, which has the net effect of reducing emissions by about 252 kt CH_4 (due to lower emissions in active mining and constant emissions from shut mines). Another reduction results from lower CH_4 emissions from natural gas distribution, due to less use of natural gas in residential and the service sector.

All in all, fugitive CH_4 emissions from the energy sector decrease about 78% during the period from 2005 to 2050.

4.3.11.2 Process-related CO_2 emissions

Process-related CO_2 emissions – within the boundaries defined for this project – contributed 3% of total greenhouse gas emissions in 2005. From 1990 to 2005, these emissions already decreased, but at 1.8% the reduction was considerably less than the reduction in total greenhouse gas emissions. Accordingly, there was a slightly rising trend in the share of total emissions (from 3.2% in 1990 to 3.6% in 2005).

The largest contributions to process-related CO_2 emissions come from chemical production processes (e.g., ammonia or methanol production), from metal production (e.g., production of primary aluminium), from the stone and soil segment (cement and lime production), and from glass and ceramic production and petroleum processing.

A first unusual feature to be noted here is that CO_2 emissions from iron ore reduction in this analysis are not categorised as process-related emissions, but rather as energy-related emissions from the use of coke in the steel industry, and therefore they are shown here only for information. Thus the iron and steel industry's remaining share of process-related CO_2 emissions is limited only to emissions from the use of limestone. A second unusual factor relates to CO_2 emissions from flue gas cleaning systems at power plants. These are derived below, but are included with the energy-related emissions in the summation, and thus are likewise only included for information here.

A three-step approach was used in preparing the projections for process-related CO_2 emissions:

1. Certain (highly relevant) sources can be projected in the reference scenario by way of assumptions about the development of production levels for clearly identifiable products.

2. The determinants of emissions from some (less relevant) sources were not analysed further, and emissions were kept constant at 2005 levels in the scenarios.

3. For some other sources (some of them likewise relevant), the CO_2 emission trends can be derived from developments in the energy industry (e.g., with regard to petroleum demand).

Table 4.3-60: Reference scenario: Development of process-related CO_2 emissions for selected industrial processes, 2005 – 2050, in kt

		Reference scenario			
kt CO_2	**2005**	**2020**	**2030**	**2040**	**2050**
Process emissions					
Cement production	12,921	12,595	12,345	12,094	11,844
Limestone production	5,415	5,279	5,174	5,069	4,964
Glass production	894	865	842	819	797
Ceramics production	359	359	359	359	359
Ammonia production	5,253	5,253	5,253	5,253	5,253
Karbide production	16	16	16	16	16
Catalytic burning	2,883	2,077	2,005	1,933	1,864
Conversion loss	3,776	2,720	2,625	2,532	2,441
Methanol production	2,351	2,351	2,351	2,351	2,351
Carbon black production	589	589	589	589	589
Iron and steel production (limestone use only)	2,225	1,828	1,523	1,217	912
Ferroalloys production	3	3	3	3	3
(Primary) aluminium production	883	871	862	853	844
Total CO_2	37,569	34,807	33,946	33,089	32,237
Change from 1990	-1.8%	-9.0%	-11.3%	-13.5%	-15.7%
Change from 2005		-7.4%	-9.6%	-11.9%	-14.2%
Memo items:					
Iron and steel production (iron ore reduction)	40,330	33,132	27,594	22,057	16,520
Flue gas desulfurization	1,382	1,003	1,069	1,029	1,012

Source: Öko-Institut 2009

Process-related CO_2 emissions for cement production were calculated by directly linking the projected development of production in this sector to the specific CO_2 emission factor on the basis of cement as the end product. As a result, future emissions of process-related CO_2 from cement production are shown as decreasing slightly by 2050, because demand for cement will decrease due to less new buildings.

Consequently CO_2 emissions decrease only slightly, from about 13 million metric tons in 2005 to just under 12 million metric tons in 2050.

In process-related CO_2 emissions from lime production, a distinction must be made between emissions from burning limestone and from burning dolomite. The specific emissions for quicklime production are about 16% higher than those for burnt dolomite. However, the proportion of quicklime to burnt dolomite is very stable in the long-term trend, and is dominated by the large share of quicklime (more than 90%), so that no differentiation was necessary for the projection. Here too, the combination of the projection for future lime production with the slight decline in production and a specific emission value yields only a slightly reduced level of process-related CO_2 emissions. These decrease only about 0.5 million metric tons from 2005 to 2050.

The situation with process-related CO_2 emissions from glass production is somewhat more complicated, because these emissions depend to a large degree on the various glass products and other factors (e.g., the proportion of recycled glass). All the same, the historical trend – especially in the past few years – shows a relatively stable ratio of emissions and aggregate production. Given this, a fixed factor for specific CO_2 emissions per metric ton of glass produced is also applied for future process-related CO_2 emissions from glass production. This results in 0.8 million metric tons of CO_2 emissions for the period of 2005 to 2050.

Steel production is the largest single item in process-related CO_2 emissions. Here the following source groups must be distinguished:

1. CO_2 emissions from the use of reducing agents in pig iron production and from the subsequent burning off of carbon in oxygen steelmaking that are defined as process-related;

2. CO_2 emissions from the use of limestone in smelting;

3. CO_2 emissions from electric furnace steel production (electrode burnoff, use of foamed coal, etc.).

The largest source group here is pig iron production and oxygen-furnace steelmaking, and in this process, the reduction of iron ore. The quantities of carbon needed for this purpose, and the resulting CO_2 emissions, parallel the production volumes relatively strictly. In the present project, however, by convention these emissions are categorised as energy-related CO_2 emissions. For process-related CO_2 emissions from the use of limestone in smelting, as a good approximation a firm coupling to the amount of steel produced can likewise be assumed. The same applies to process-related CO_2 emissions from electric-furnace steel plants.

The assumption here is that oxygen-furnace steelmaking will decrease, and electric-furnace steel production will increase. Electric-furnace steel is produced from scrap steel. Steel can remain in the loop for a very long time if products are recycled at the end of their service life. The assumption is that the volume of steel recycling will continue to increase. It is assumed that steel demand will decline, and that oxygen-furnace steelmaking will be the first to decrease. Accordingly, process-related CO_2 emissions from oxygen steelmaking (including the use of limestone) will decrease to approx. 17 million metric tons from 2005 to 2050. By contrast, there will be a slight increase in CO_2 emission levels for electric furnace steel products, but at roughly 0.08 million metric tons in 2050 these will be of an entirely different order of magnitude.

The remaining process-related CO_2 emissions from the production of primary aluminium, carbide, ferro alloys, ceramics, carbon black, ammonia and methanol are kept constant in the reference scenario. Total CO_2 emissions from these sources will remain at a level of 10 million metric tons.

Process-related CO_2 emissions from catalyst burnoff and conversion losses were projected using the same dynamics as for the primary energy consumption of petroleum. This yields decreasing emission levels for both areas even in the reference scenario, so that in 2050, process-related CO_2 emissions from catalyst burnoff will be about 1.9 million metric tons, and those from conversion losses at refineries will be about 2.4 million metric tons.

The CO_2 emissions from flue gas cleaning systems – provided merely for information here – result predominantly from sulfur deposition by way of the use of coal at power plants. As a gross approximation, the projection assumes that process-related CO_2 emissions will change proportionately with the use of coal at power plants (broken down as hard coal and lignite, and weighted for mean sulfur content). This methodological approach yields the changes shown in Table 4.3-60. CO_2 emissions amount to 1 million metric tons in the reference scenario for 2050, and thus about 27% below 2005 levels.

4.3.11.3 Process-related CH_4 and N_2O emissions

Process-related emissions of CH_4 represent less than 0.1% of all greenhouse gases. Process-related N_2O emissions represented about 1.4% in 2005.

Since CH_4's contribution to total process-related emissions is very small, the reference scenario keeps emission levels constant for the projection period to 2050.

Projections for adipic acid and nitric acid production were based on the following assumptions:

- Future production levels were based on the dynamics that were also applied for the GAINS model calculations for the EU climate and energy package. Accordingly, by 2030 production levels for adipic acid will expand by a factor of about 2.7 against 2000, and the corresponding production of nitric acid by 2030 will be about 3.1 times the 2000 value. Production will remain constant at this level until 2050.

- The reference scenario assumes reductions of 95% for N_2O emissions from the production of nitric and adipic acids.

Since the overall level of process-related CH_4 and N_2O emissions from industrial processes is determined primarily by N_2O emissions from adipic and nitric acid production, the measures taken in this area have a substantial impact (Table 4.3-61).

Table 4.3-61: Reference scenario: Development of CH_4 and N_2O emissions from industrial processes and product use, 2005 – 2050, in kt of CO_2 equivalent

		Reference scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
CH_4 emissions					
Industrial proceesses	2	2	2	2	2
Chemical industry	0.2	0.2	0.2	0.2	0.2
Metal production	2.0	2.0	2.0	2.0	2.0
N_2O emissions					
Chemical industry	14,194	1,751	1,764	1,764	1,764
Total CO_2 equivalents	14,197	1,753	1,766	1,766	1,766
Change from 1990	-40.3%	-92.6%	-92.6%	-92.6%	-92.6%
Change from 2005		-87.7%	-87.6%	-87.6%	-87.6%

Source: Öko-Institut 2009

4.3.11.4 Emissions of HFCs, PFCs and SF_6

Although emissions of HFCs, PFCs and SF_6 represented only 1.5% of total greenhouse gas emissions in 2005, this area of emissions is characterised by massive rates of increase. Emissions here increased more than 30% from 1990 to 2005.

The reference scenario takes account of a number of measures to reduce or slow emission trends for the time period to 2030.

- Obligatory maintenance / seal testing for stationary refrigeration systems.
- Definition of maximum leakage rates for stationary refrigeration systems (Meseberg Resolution No. 23).
- Reduction of emissions of fluorinated greenhouse gases in semiconductor production.
- Voluntary commitment by the German primary aluminium industry.
- Bans on the use of synthetic greenhouse gases (new kinds of aerosols, disposable containers, car tires, shoes).

The following measures are taken into account for HFCs:

- Support for replacement of HFCs in commercial refrigeration systems (about 30% per year of new refrigeration systems in food retail; about 540 systems per year).
- Replacement of HFCs by refrigerants with a GWP of less than 150, and improvement of seals on mobile air conditioning systems for selected classes of vehicles.
- Replacement of HFCs by refrigerants with a GWP well below 150 for mobile refrigeration systems.

- Extensive replacement of HFCs as the propellant for polyurethane foams.

The following measures were taken into account for SF_6:

- Replacement of SF_6 as the inert gas in large magnesium production facilities.
- Replacement of SF_6 technology with modified glazing structures in noise-proofed window panes for residential buildings.
- Voluntary commitment by German makers and users of switching systems and SF_6 producers to limit SF_6 emissions from electrical supplies.

All in all, this will result in a stabilisation of emissions by 2020. Emission levels will be kept constant after that.

Table 4.3-62: Reference scenario: Development of emissions of fluorinated greenhouse gases, 2005 – 2050, in kt of CO_2 equivalent

		Reference scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Fluorinated GHG					
HFC emissions					
Refrigeration and air conditioning	7,491	8,399	8,399	8,399	8,399
Foam production	1,250	471	471	471	471
Other sources	1,155	1,210	1,210	1,210	1,210
Subtotal HFC	9,896	10,080	10,080	10,080	10,080
PFC emissions					
Aluminium production	338	167	167	167	167
Refrigeration and air conditioning	132	78	78	78	78
Semiconductor manufacture	249	125	125	125	125
Other sources	0	13	13	13	13
Zwischensumme FKW	718	383	383	383	383
SF_6 emissions					
Magnesium foundries	668	524	524	524	524
Electrical equipment	762	595	595	595	595
Car tyres	65	0	0	0	0
Double glas windows	1,348	1,904	1,904	1,904	1,904
Other sources	537	442	442	442	442
Subtotal SF_6	3,380	3,464	3,464	3,464	3,464
Total fluorinated GHG	13,994	13,927	13,927	13,927	13,927
Change from 1990	18.0%	17.4%	17.4%	17.4%	17.4%
Change from 2005		-0.5%	-0.5%	-0.5%	-0.5%

Source: Öko-Institut 2009

4.3.11.5 Summary

From 2005 to 2050, the reference scenario postulates a decrease of about 36% in the fugitive emissions from the energy sector, emissions from industrial processes, and emissions from fluorine gases considered here. This less-than-proportionate reduction is attributable to the limited potential for emission reduction that is available without substantial technological innovations. At the same time, current and planned measures will have only limited effects in these areas.

Table 4.3-63: Reference scenario: Development of emissions of fluorinated greenhouse gases from industrial processes and fugitive emissions from the energy sector, 2005 – 2050, in kt of CO_2 equivalent

		Reference scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Process emissions CO_2	37,569	34,807	33,946	33,089	32,237
Fluorinated GHG	13,994	13,927	13,927	13,927	13,927
Fugitive CH_4 emissionen from energy sectors	12,732	5,855	4,494	3,467	2,857
CH_4 and N_2O from industrial processes	15,371	1,753	1,766	1,766	1,766
Total CO_2 equivalents	79,665	56,341	54,134	52,250	50,788
Change from 1990	-21.6%	-44.6%	-46.7%	-48.6%	-50.0%
Change from 2005		-29.3%	-32.0%	-34.4%	-36.2%
Memo items:					
Iron and steel production (iron ore reduction)	40,330	33,132	27,594	22,057	16,520
Flue gas desulfurization	1,382	1,003	1,069	1,029	1,012

Source: Öko-Institut 2009

4.3.12 Emissions from waste management

Waste management in Germany gives rise to a comparatively small, but not negligible, share of greenhouse gas emissions. Its CH_4 and N_2O emissions in 2005 represented 1.3% of total greenhouse gas emissions. The share was still 3.4% as recently as 1990. Allowing for the overall higher level of emissions in 1990, this is equivalent to a reduction of about 68% in the period from 1990 to 2005. The waste industry has thus made a more-than-proportional contribution towards the current level of greenhouse gas mitigation.

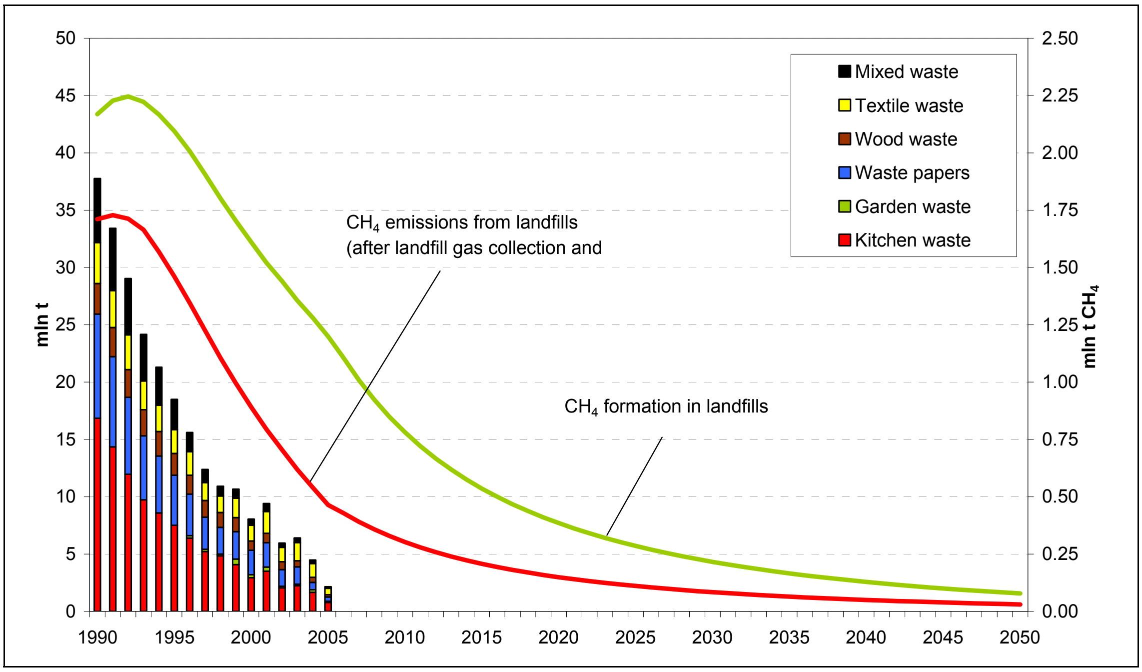
The largest share of CH_4 emissions come from the release of landfill gas (due to the organic waste deposited there). N_2O emissions in waste management arise primarily in municipal sewage treatment.

The substantial greenhouse gas reductions of the past few years are the result of extensive regulation in the waste sector. Germany's key regulatory provisions for the waste sector are the Technical Guideline for Municipal Waste (TASi) and the associated regulations under the Closed Substance Cycle and Waste Management Act (KrW-/AbfG); the Waste Storage Regulation (AbfAblV); the Regulation on Biological Treatment of Waste (30th BImSchV), and the amended version of the Regulation on Burning Waste (17th BImSchV). As of June 2005, these largely prohibited the dumping of untreated waste (and thus also the organic substances which release gas), and permitted other forms of disposal by burning or biological-mechanical waste treatment.

As a consequence of these regulations, dumping of waste that can form CH_4 has been forbidden since 2005, and the remaining CH_4 emissions result from organic waste deposited in the past. Methane emissions from landfills will decrease about three-quarters from 2005 levels over the next two decades, and to nearly zero by the end of the scenario period (Figure 4.3-46). This means that the quantities of landfill gas available for energy use will likewise decrease very substantially, and will no longer be available as an energy source.

Between 2005 and 2050, CH_4 emissions will decrease from 464 kt CH_4 (just under 10 million metric tons of CO_2 equivalent) to about 30 kt CH_4 (0.6 million metric tons of CO_2 equivalent). This is a reduction of more than 90%. Most of the decrease in emissions will occur during the period before 2030.

Figure 4.3-46: *Development of deposition of organic waste, methane formation in landfills and methane emissions from landfills, 1990 – 2050, in million metric tons of CH_4*



Source: Öko-Institut 2009

Lagging far behind, the second most important source of greenhouse gas emissions in the waste management industry is N_2O emissions from sewage treatment (Table 4.3-64). Here little change can be expected in the next few years or decades, and what change there is will result primarily from the declining population. The decrease between 2005 and 2050 is about 6%; the emission level will remain at roughly 2 million metric tons of CO_2 equivalent.

The CH_4 and N_2O emissions from composting, fermentation and mechanical-biological waste treatment plants will parallel the input quantities, which will likewise roughly parallel population change. Another relevant factor for CH_4 developments is the share of waste brought to anaerobic digestion plants. The reference scenario assumes that the ratio of organic waste used in anaerobic digestion or composting plants will be equivalent to the 2005 figure until 2050. All in all, these systems' contribution to emissions will decrease only slightly during the scenario period from 2005 to 2050, to just under 1 million metric tons of CO_2 equivalent.

Table 4.3-64: Reference scenario: CH_4 and N_2O emissions from waste management, 2005 – 2050, in kt

		Reference scenario			
kt	**2005**	**2020**	**2030**	**2040**	**2050**
Input quantities					
Solid waste disposal (biogenic material)	2,154	0	0	0	0
Composting installations	9,658	8,814	8,748	8,606	8,400
Waste fermentation installations	2,842	2,593	2,574	2,532	2,471
Mechanical-biological waste treatment	2,520	3,652	3,625	3,566	3,480
CH_4 emissions					
Waste disposal	464	149	84	50	30
Domestic & commercial waste water	6	5	5	5	5
Composting and waste fermantation	28	25	25	25	24
Mechanical-biological waste treatment	0.38	0.20	0.20	0.20	0.19
Subtotal CH_4	498	179	114	79	59
N_2O emissions					
Domestic & commercial waste water	7.57	7.43	7.38	7.26	7.08
Composting and waste fermentation	0.71	0.65	0.64	0.63	0.62
Mechanical-biological waste treatment	0.35	0.37	0.36	0.36	0.35
Subtotal N_2O	8.63	8.45	8.38	8.25	8.05
Total CH_4 + N_2O (kt CO_2 equivalents)	13,129	6,386	4,989	4,223	3,742
Change from 1990	-67.5%	-84.2%	-87.7%	-89.6%	-90.7%
Change from 2005	-	-51.4%	-62.0%	-67.8%	-71.5%

Source: Öko-Institut 2009

Greenhouse gas emissions in the waste management industry from 2005 to 2050 will change substantially in terms of both the level of total greenhouse gas emissions and the structure by source sectors or by type of gas.

Total emissions are projected to decrease more than 71% between 2005 and 2050. This is equivalent to more than a 90% reduction from the original 1990 level.

Where nearly three-quarters of emissions derived from waste landfills in 2005, this share will shrink to about 18% by 2050. Municipal sewage treatment will become the most significant source of emissions in waste management by 2050; at that point it will represent about 59% of total emissions. The equivalent value for 2005 was about 18%. Finally, a substantial dynamism, as well as substantial absolute emission levels, ultimately derives from CH_4 emissions from composting and anaerobic digestion plants, which by 2050 will represent about 0.5 million metric tons of CO_2 equivalent, or 13% of total greenhouse gas emissions from the waste management industry.

CH_4 emissions represented about four-fifths of total waste industry emissions in 2005. By 2050 this contribution will decrease to about one-third. Accordingly, the contribution of N_2O emissions will increase from 20% to about two-thirds.

4.3.13 Emissions from agriculture

Greenhouse gas emissions from agriculture are composed of CH_4 emissions from the animals' digestive processes (enteric fermentation; 32.5% of total agricultural GHG emissions in 2005), CH_4 and N_2O emissions from commercial manure management (15%), and the release of N_2O from soils used for agriculture (52.5%). In accordance with the guidelines of the IPCC (Intergovernmental Panel on Climate Change), energy-related GHG emissions are attributed to the commerce, retail and services sector.

CH_4 emissions from agriculture derive from animal husbandry, and are primarily caused by enteric fermentation in ruminants, especially dairy and beef cattle. The second source of CH_4 is commercial manure management, and again cattle are the most important emitter group. N_2O emissions from animal husbandry likewise arise in commercial manure management, and derive primarily from cattle, poultry and pig farming. Because of the significant decrease in cattle herds, especially due to the transformation process in the eastern German states, methane emissions from agriculture decreased 19% between 1990 and 2005, and nitrous oxide emissions from animal farming decreased 16%.

Greenhouse gas emissions from agriculture in 2005 came to about 53 million metric tons, equivalent to 5.1% of total greenhouse gas emissions in Germany. The distribution of agricultural greenhouse gases is shown in Table 4.3-65.

Table 4.3-65: Methane and nitrous oxide emissions from German agriculture in 2005

GHG and sources	1,000 t	GWP	mln t CO_2e	Share
CH_4 from enteric fermentation	872.5	21	17.2	76%
CH_4 from manure management	266.5	21	5.5	24%
Subtotal CH_4	1,139.0		22.7	100%
N_2O from manure management	7.8	310	2.4	8%
N_2O from agriculrural soils	91.5	310	28.4	92%
Subtotal N_2O	99.3		30.8	100%
Total			**53.4**	

Source: Öko-Institut 2009

Of the total greenhouse gas emissions from agriculture, about 47% comes from animal farms. Table 4.3-66 shows the distribution of these gases among the IPCC's principal categories for animals.

Table 4.3-66: Shares of CH_4 and N_2O from animal husbandry

Category	Methane		Nitrous Oxide
	Enteric fermentation	Manure management	Manure management
Cattle	92.6%	65.2%	55.4%
Swine	3.4%	29.6%	14.1%
Sheep	2.5%	0.2%	1.1%
Poultry	-	3.9%	20.7%
Others	1.5%	1.2%	8.7%
Total	**100.0%**	**100.0%**	**100.0%**

Source: Öko-Institut 2009

CH_4 emissions from fermentation are caused primarily by cattle. During the fermentation processes in ruminants' stomachs, methane is generated as a metabolic product in the conversion of nutrients under the anaerobic conditions prevailing there, and is released by the animals into the environment. Influence over these methane emissions is very limited.

CH_4 emissions from commercial manure management derive primarily from cattle and pig farming. Cattle, poultry and pig farming are especially responsible for the N_2O emissions from commercial manure management. Sheep and other animals (goats, horses, buffalo) play a minor role for the two gases and also as sources. CH_4 and N_2O emissions are released from animal waste (liquid, solid and mixed manure/urine combinations) in the barn or in storage containers during storage. For all species, the GHG emissions from commercial manure management can normally be influenced by changing methods of farming the animals and storing manure.

N_2O emissions from agricultural soils in 2005 came to about 53% of total emissions from agriculture; 31% came from the application of synthetic fertilizers, and 15% from the use of mineral fertilizers. Marshland management contributed 18% of N_2O emissions, and working plant residues into the soil accounted for 10%. Indirect contributions of nitrogen species that are coupled to the amount of nitrogen applied in fertilizers accounted for 21%, while animal excrement in pasturage contributed 5% of N_2O emissions.

By reducing nitrogen usage in the 1990s, N_2O emissions from agricultural land were reduced nearly 10% between 1990 and 2005 (use of fertilizers after reunification).

Because of the above emission profile, the input rate for nitrogen is the manipulated variable for reducing N_2O emissions from agricultural soils. Since policy regulations about agriculture are usually made at the EU level as part of common agricultural policy, the reference scenario does not assume specific measures and instruments for reducing greenhouse gas emissions in the agricultural sector. A reduction of nitrogen fertilizer use, however, will be supported by the reform of common agricultural policy and the promotion of organic agriculture. As a function of the development of the price of mineral fertilizers, the decrease in agricultural fertilizers (reduction of cattle herds) and better fertilizer management, the reference scenario includes projections for 2010, 2015 and 2020. For lack of the ability to make projections of sufficient quality, the scenario retains the 2020 value for the entire remainder of the time to 2050.

Accordingly, N_2O emissions from agricultural soils will be reduced 7% from 2005 to 2050. Compared to the 1990 emission level this is equivalent to a 16% decrease by 2050.

Greenhouse gas emissions from agricultural soils also include methane consumption. This involves methanotrophic bacteria that bind methane in well-ventilated soils, in the amount of 0.6 million metric tons of CO_2 equivalent in 2005. Since this process depends on many factors (oxygen content after heavy rains, moisture conditions in the soil), and there are no reliable data for estimating future binding rates, no further consideration is given to this point.

In the reference scenario, total emissions of CH_4 decrease by 13% between 2005 and 2050, and N_2O emissions decrease by a total of 6% (animal farming and agricultural soils). This change is based on the following assumptions, among others:[4]

- An expectation of a further decrease in animal herds, especially by increasing the milk quota in two steps (2008 and 2014/2015), and enhancements of productivity in milk production;
- Reductions of herds by uncoupling animal-based direct payments for mother cows, fattening bulls and sheep;
- Reduction of the use of nitrogen fertilizers.

The effects of these assumptions were analysed to 2020. Since further changes cannot be foreseen either in agricultural soils or in animal farming, and since no measures have been taken politically to mitigate GHG emissions in agriculture, the total emission levels from 2020 are projected to 2050, as shown in Table 4.3-67.

Table 4.3-67: Reference scenario: CH_4 and N_2O emissions from agriculture, 2005 – 2050, in million metric tons of CO_2 equivalent

		Reference scenario			
mln t CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Source category					
CH_4 emissions					
Enteric fermentation	17.2	14.5	14.5	14.5	14.5
Manure management	5.5	5.1	5.1	5.1	5.1
Agricultural soils	-0.6	-0.6	-0.6	-0.6	-0.6
Summe CH_4	22.0	19.0	19.0	19.0	19.0
N_2O emissions					
Manure management	2.4	2.3	2.3	2.3	2.3
Agricultural soils	28.4	26.3	26.3	26.3	26.3
Summe N_2O	30.8	28.6	28.6	28.6	28.6
Total CH_4 + N_2O	52.8	47.6	47.6	47.6	47.6
Change from 1990	-14.3%	-22.7%	-22.7%	-22.7%	-22.7%
Change from 2005		-9.8%	-9.8%	-9.8%	-9.8%

Source: Öko-Institut 2009

Agricultural greenhouse gas emissions will decrease about 10% between 2005 and 2020 (2050). Compared to 1990 emission levels this is equivalent to a decrease of approx. 23%.

4 Dämmgen/Osterburg, 2008

4.3.14 Emissions from land use, land use change and forestry

Greenhouse gas binding and emissions from land use, land use change and forestry (LULUCF) comprise binding CO_2 to forest biomass, and CO_2 emissions from various sources (combustion, decomposition and harvesting of forest biomass, use of marshland for cultivation, drainage of pastureland, deforestation of areas for development, etc.).

As plants grow – especially forest trees – they absorb carbon dioxide from the atmosphere through photosynthesis, store carbon in biomass, and release oxygen back into the atmosphere. Thus forests function as a CO_2 sink until the trees die, are cut down and used, or the carbon bound in them as CO_2 is released by forest fires. The size and development of the sink depends on a number of factors: climate conditions, extreme weather events, tree species composition and age class structure in the forest, natural disruptions (forest fires, insect infestations), silviculture methods, and harvesting practices.

About one-third of Germany is covered with forests. The results of the two federal forest inventories conducted to date in the country show that the existing forest has represented a net sink in the past, by **binding CO_2.** However, this sink has already become less, and will continue to decline in coming years, especially from the mid-2020s onwards. The reasons are increasing wood use due to market conditions (rising prices of energy and raw materials) and the development of age class structures. In the coming decades a large share of the areas planted to trees after the Second World War will have a large overhang of high-storage older age classes that have reached harvesting age. In addition to higher pressure from use, the increase in such disruptions as storms like Lothar (1999) and Kyrill (2007) may reduce sink capacity.

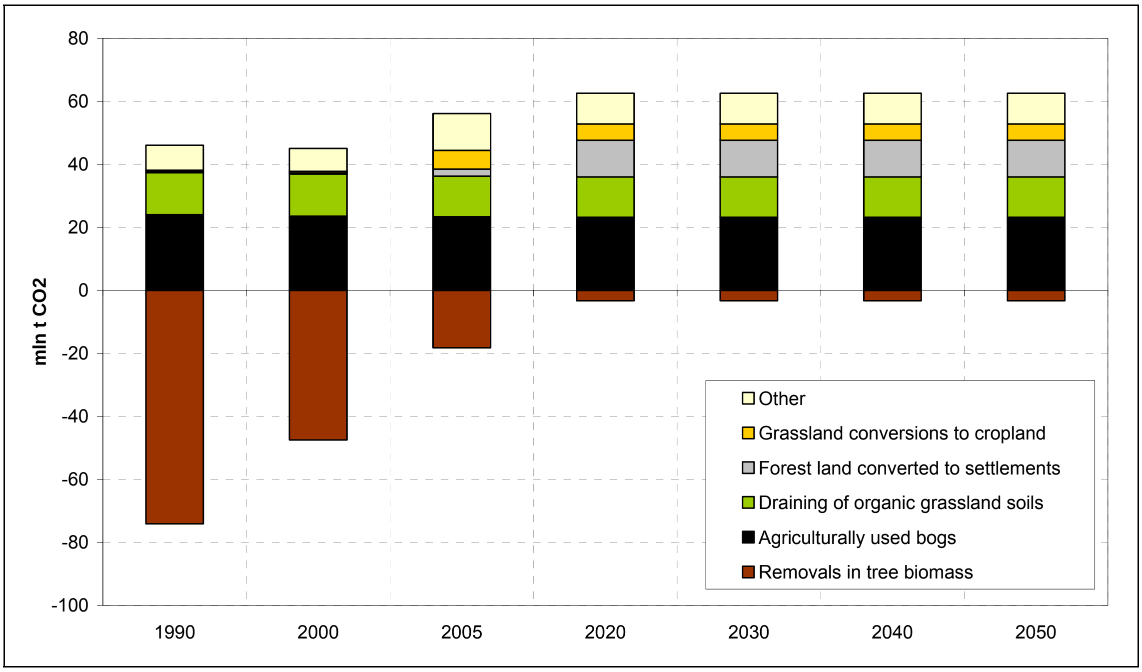
CO_2 emissions from the land use sector result from changes in carbon storage as space is used (e.g. liming of forest soils) and from the changes in those spaces. Various sources thus cause CO_2 emissions, but in the past they have been compensated by the sink characteristics of the existing forest.

The largest sources in the land use sector in 2005 were cultivation of marshland (42% of CO_2 emissions from the land use sector, not including sinks, in 2005), drainage of organic grasslands (23%), deforestation for development (20%), breakup of grassland for cultivation (11%), and other land use changes. The latter comprise 31 subcategories (from conversion of forest into cultivated land to liming of forests).

No measures to influence the individual subcategories can be derived in this project. Their CO_2 emissions are summarised for the scenarios in the “other” group.

CO_2 emissions from land use represented 5.8% of total greenhouse gas emissions in 2005; after allowances for CO_2 retained in forest biomass, the figure decreases to 4%. In 1990, the share of CO_2 emissions was still 3.8% of total greenhouse gases.

Figure 4.3-47: Reference scenario: Carbon dioxide emissions and retention from land use, land use change and forestry, 1990 – 2050, in million metric tons of CO_2



Source: Öko-Institut 2009

The change in emissions between 1990 and 2005 is dominated primarily by the decrease in CO_2 retention in forest biomass because of greater biomass losses due to storms and heavier logging. Since 2003 it has no longer been possible to compensate for the emissions from the other land use categories (Figure 4.3-47). At the same time, from 1990 to 2005 the emissions from the four primary sources in land use increased 21%, primarily due to increased cultivation of former grassland.

The manipulated variables for the reduction of CO_2 emissions in the land use sector are a change in uses of space that result in emissions, and the preservation or restoration of the sink. The reference scenario assumes that the use of space, and the changes in that use, will remain the same from 2007 onwards. Because of a lack of quantitative estimates about the development of emissions without specific measures, the levels for CO_2 emissions and CO_2 retention from the currently available greenhouse gas inventories are retained from 2007 onwards (Table 4.3-68).

Table 4.3-68: Reference scenario: CO_2 emissions and retention from land use, land use change and forestry, 1990 – 2050

			Reference scenario			
kha	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Land use change						
Area of agriculturally used bogs	596	579	575	575	575	575
Area subject to draining of organic grassland soils	726	704	698	698	698	698
Area of forest land converted to settlements	1	7	34	34	34	34
Area subject to grassland conversions to cropland	6	79	68	68	68	68
mln t CO_2						
CO_2 emissions and removals						
Removals in tree biomass	-74.1	-18.2	-3.3	-3.3	-3.3	-3.3
Agriculturally used bogs	24.0	23.4	23.2	23.2	23.2	23.2
Draining of organic grassland soils	13.3	12.9	12.8	12.8	12.8	12.8
Forest land converted to settlements	0.3	2.2	11.7	11.7	11.7	11.7
Grassland conversions to cropland	0.5	6.0	5.1	5.1	5.1	5.1
Other	7.9	11.7	9.8	9.8	9.8	9.8
Total CO_2 emissions (without removals)	46.1	56.1	62.6	62.6	62.6	62.6
Total CO_2 emissions and removals	-28.0	37.9	59.3	59.3	59.3	59.3
Change of CO_2 emissions from 1990		21.8%	35.9%	35.9%	35.9%	35.9%
Change of CO_2 emissions and removals from 1990		235.6%	312.0%	312.0%	312.0%	312.0%
Change of CO_2 emissions from 2005			11.6%	11.6%	11.6%	11.6%
Change of CO_2 emissions and removals from 2005			56.4%	56.4%	56.4%	56.4%

Source: Öko-Institut 2009

This yields a 12% increase in CO_2 emissions between 2005 and 2050 from the four primary sources mentioned above. Since the CO_2 retention rate in forest biomass decreased significantly, especially between 2020 and 2007, because of heavier demand for wood, and because of the age class structure, CO_2 emissions rose 56% over the same period when forestry is taken into account.

4.3.15 Total greenhouse gas emissions

Table 4.3-69 shows the change in total emissions of greenhouse gases for 1990 through 2050. Total greenhouse gas emissions decrease 45% between 1990 and 2050 for the option without CCS, and about 50% for the option with CCS.

Table 4.3-69: Reference scenario: Total greenhouse gas emissions, 1990 – 2050, in million metric tons of CO_2 equivalent

			Reference scenario			
Million metric tons of CO_2 equivalent	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Energy-related emissions (without CCS)						
CO_2	1,005	835	706	608	543	487
CH_4	5	1	1	1	1	1
N_2O	8	7	7	6	6	5
Energy-related emissions (with CCS)						
CO_2	1,005	835	706	592	505	428
CH_4	5	1	1	1	1	1
N_2O	8	7	7	6	5	4
Fugitive and process-related emissions						
CO_2	38	37	35	34	33	32
CH_4	28	13	6	4	3	3
N_2O	24	14	2	2	2	2
HFC	4	10	10	10	10	10
PFC	3	1	0	0	0	0
SF_6	5	5	3	3	3	3
Product use						
CO_2	3	2	2	2	2	2
CH_4	0	0	0	0	0	0
N_2O	2	1	1	1	1	1
Agriculture						
CH_4	27	22	19	19	19	19
N_2O	34	31	29	29	29	29
Land use, land use change and forestry						
CO_2	-28	38	59	59	59	59
N_2O	0	1	1	1	1	1
Waste sector						
CH_4	38	10	4	2	2	1
N_2O	2	3	3	3	3	2
Total withoutCCS	**1,199**	**1,031**	**888**	**785**	**717**	**658**
Total with CCS	**1,199**	**1,031**	**888**	**769**	**679**	**598**
Total without CCS						
Change from 1990	-	-14.0%	-25.9%	-34.5%	-40.2%	-45.1%
Change from 2005	16.3%	-	-13.8%	-23.9%	-30.5%	-36.2%
Total with CCS						
Change from 1990	-	-14.0%	-25.9%	-35.8%	-43.4%	-50.1%
Change from 2005	16.3%	-	-13.8%	-25.4%	-34.2%	-42.0%
Note: Emissions data for 2005 is inventory data; energy-related emissions include CO_2 from flue gas desulfurization						

Source: Prognos and Öko-Institut 2009

The changes in emissions – some of them highly variable – described in the preceding sections result in a serious change in the structure of total greenhouse gas emissions. While about 84% of total emissions in 1990 and about 82% in 2005 came from energy-related CO_2 emissions, this share decreases to 78% by 2030 and only 75% by 2050, in the option without CCS. In the option with CCS, the 2050 share of energy-related CO_2 emissions is even a bit lower, at 72%.

The share of process-related emissions remains roughly stable at 8%, but the (relative) contribution of process-related CO_2 emissions increases substantially, while process-related N_2O and CH_4 emissions decrease to well below 1%.

Increasing amounts of the total greenhouse gas emissions come from agriculture, land use and forests, because of their less than proportional contributions towards mitigation or because of the rising emission trend in agriculture.

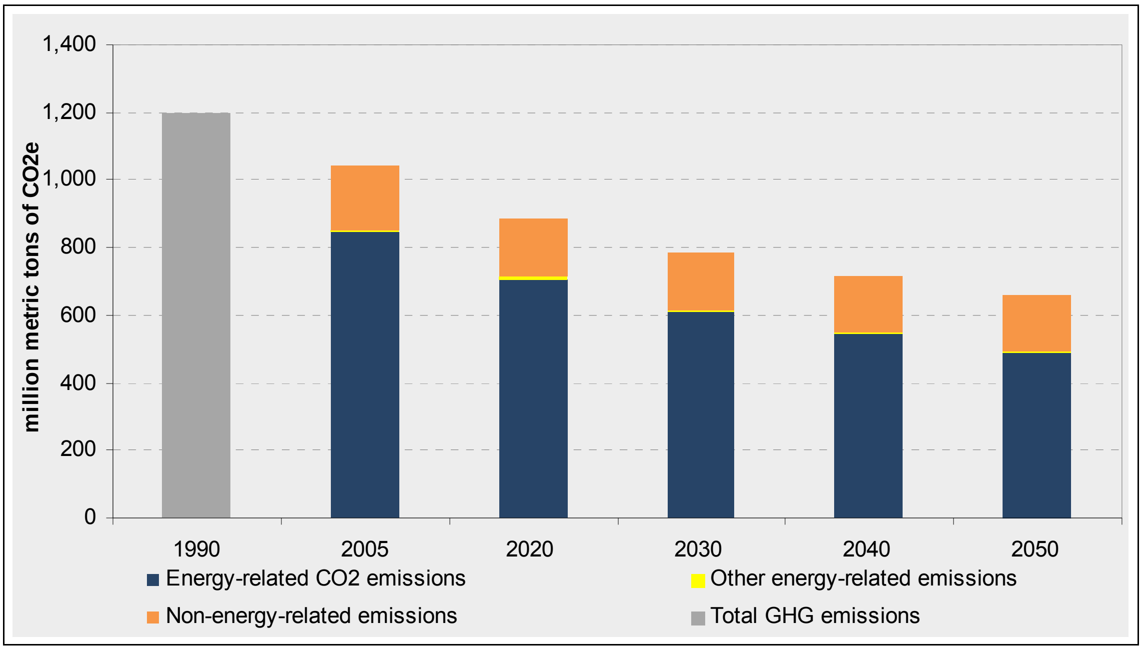
Although the reference scenario continues the general emission reduction trend of 1990 through 2005 – albeit somewhat less dynamically on the whole – the results fall far short of the aim of reducing emissions 95% from 1990 levels.

The structure of the various sectors' contributions to emissions, and a glance at the various greenhouse gases, shows that measures that go beyond the reference scenario are needed in every sector and for all greenhouse gases if the intended goal is to be achieved.

Per capita emissions in the reference scenario (in the option without CCS – the levels in the option with CCS differ only marginally) decrease from 12.5 metric tons of CO_2 equivalent or 11.1 metric tons of CO_2 in 2005 to 10.0 metric tons of CO_2 equivalent or 9.0 metric tons of CO_2 in 2030, and 9.1 metric tons of CO_2 equivalent (all greenhouse gases) or 8.0 metric tons of CO_2 in 2050. Thus allowing for developments between 1990 and 2005, a per capita reduction of 41% is achieved.

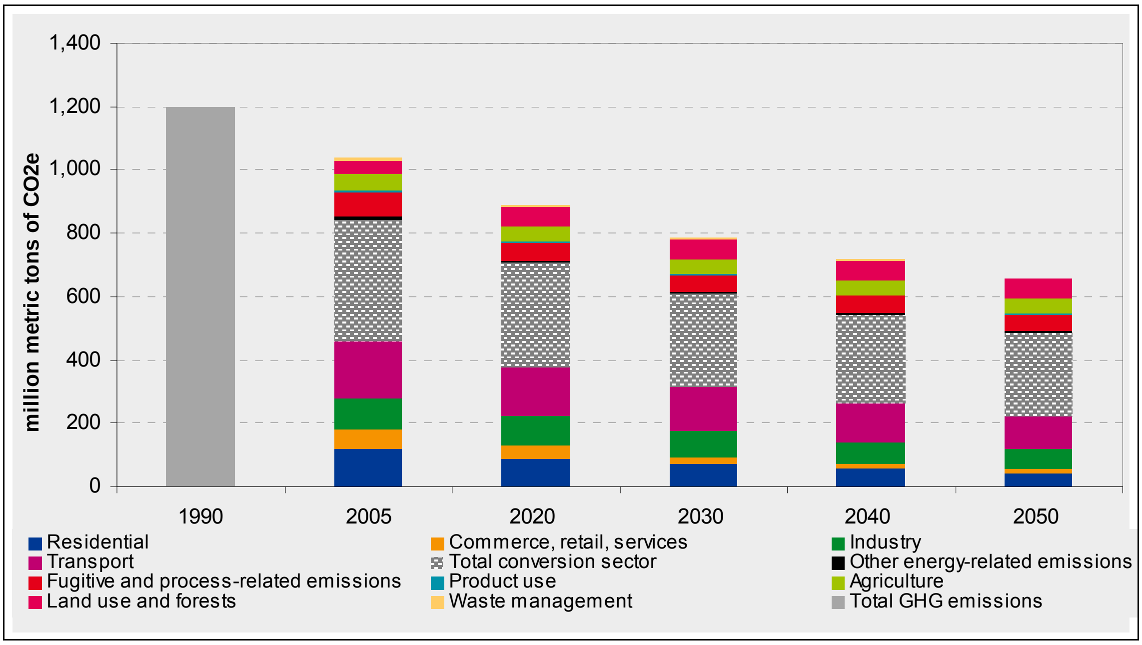
The calculation of cumulative emissions (from 2005 onwards) yields 24 billion metric tons of CO_2 equivalent (all greenhouse gases) in 2030, or 21.5 billion metric tons of CO_2. The merely slight decrease in emissions in subsequent years in the reference scenario still results in continuing growth of about 14 billion metric tons of CO_2 equivalent (all greenhouse gasses), or nearly 13 billion metric tons of CO_2, by 2050, so that cumulative emissions for the entire period from 2005 to 2050 are about 34 billion metric tons of CO_2 or 38 billion metric tons of CO_2 equivalent (all greenhouse gases). Thus the greenhouse gas emissions up to 2030 represent about 63% of the cumulative total emissions for 2005 to 2050. The equivalent share up to 2020 is 40%.

Figure 4.3-48: *Reference scenario without CCS: Total greenhouse gas emissions, 1990 – 2050, in million metric tons of CO_2 equivalent*



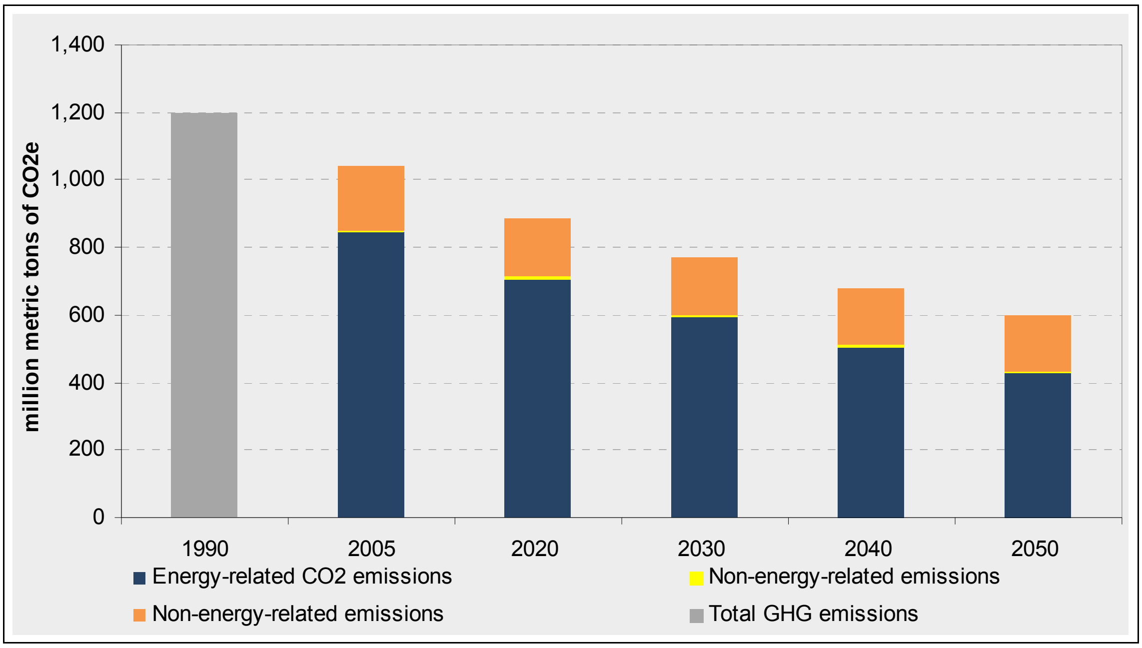
Source: Prognos and Öko-Institut 2009

Figure 4.3-49: *Reference scenario without CCS: Total greenhouse gas emissions, 1990 – 2050, in million metric tons of CO_2 equivalent*



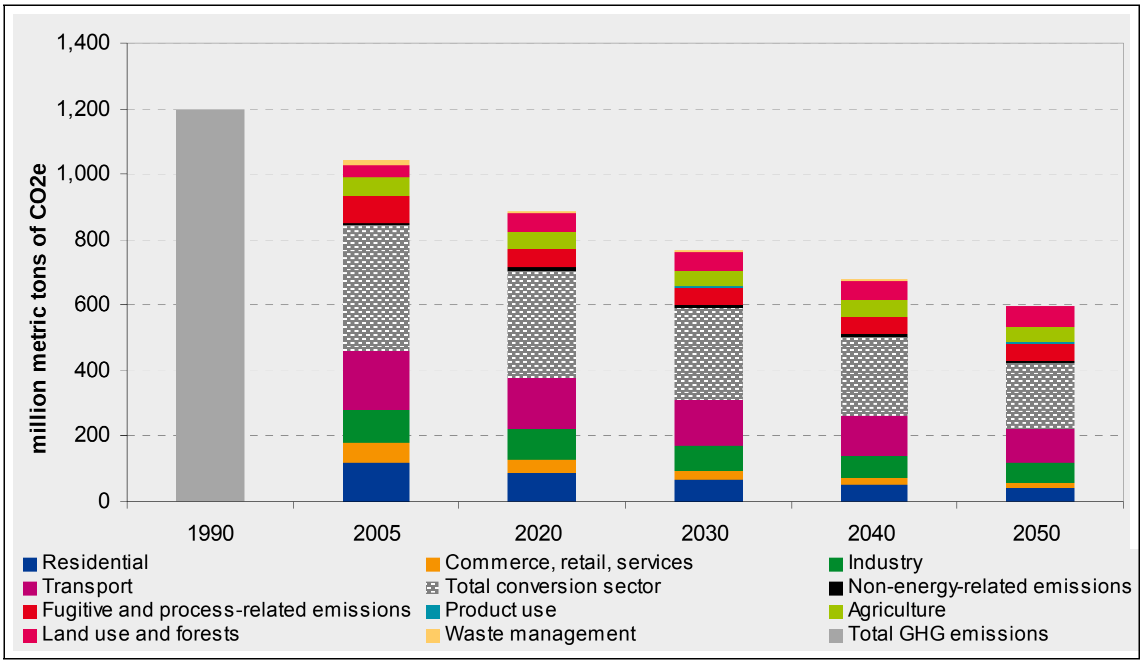
Source: Prognos and Öko-Institut 2009

Figure 4.3-50: Reference scenario with CCS: Total greenhouse gas emissions by gas, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

Figure 4.3-51: Reference scenario with CCS: Total greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

5 Innovation scenario

5.1 Overview of the scenario

Table 5.1-1: Numerical assumptions and results of innovation scenario without CCS

			Innovation scenario (w/o CCS)			
	Unit	2005	2020	2030	2040	2050
Price of oil (real) (2007 price base)	USD (2007) / bbl	54	100	125	160	210
Price of CO2 certificates (real) (2007 price base)	EUR (2007) / t	-	20	30	40	50
Socio-economic framework data / Germany						
Population	M	82.5	79.8	78.6	76.0	72.2
Residential	M	39.3	40.3	40.7	40.6	38.8
GDP (real) (2000 price base)	EUR bn (2000)	2,124	2,457	2,598	2,743	2,981
Industrial production (real) (2000 price base)	EUR bn (2000)	430	521	537	551	578
Passenger cars	M	45.5	48.5	48.7	47.8	45.8
Passenger transport volume	bn pkm	1,084	1,101	1,087	1,052	998
Freight transport volume	bn tkm	563	779	876	953	1,047
Household prices (incl. VAT), real (2005 price base)						
Heating oil, light	EUR cents(2005) / l	53.6	92.5	131.3	191.9	287.3
Natural gas	EUR cents(2005)/kWh	5.3	8.8	11.8	16.1	22.7
Electricity	EUR cents(2005)/kWh	18.2	28.9	34.3	41.8	50.3
Regular gasoline	EUR cents(2005) / l	120.0	186.9	244.2	327.9	450.9
Wholesale prices (not incl. VAT), real (2005 price base)						
Heating oil, light (industry)	EUR(2005) / t	499	884	1,244	1,802	2,694
Natural gas (industry)	EUR cents(2005)/kWh	2.5	5.1	7.0	10.0	14.6
Electricity (industry)	EUR cents(2005)/kWh	6.8	13.2	15.6	19.5	23.9
Primary energy consumption	**PJ**	**13,532**	**9,936**	**7,680**	**6,294**	**5,766**
Petroleum	%	32.6	28.3	21.0	13.8	6.7
Gases	%	23.9	22.8	21.0	18.3	15.2
Hard coal	%	12.9	14.9	10.6	5.2	1.0
Lignite	%	12.3	8.4	5.8	3.7	0.4
Nuclear energy	%	12.3	3.3	0.0	0.0	0.0
Biomass	%	3.1	11.0	20.9	26.6	29.8
Other renewable	%	3.1	11.3	20.7	32.4	46.8
Final energy consumption	**PJ**	**9,208**	**7,144**	**5,596**	**4,546**	**3,857**
Residential	%	29.7	28.0	26.2	22.4	17.2
Services	%	15.9	14.4	12.9	12.6	12.6
Industry	%	26.3	24.8	24.9	26.4	29.8
Transport	%	28.1	32.8	36.1	38.6	40.4
Petroleum products	%	41.2	36.8	26.9	17.8	9.4
Natural gases	%	27.0	23.9	20.4	19.4	19.9
Coal	%	4.3	3.7	3.0	2.4	2.0
Electricity	%	19.9	21.2	23.6	26.9	30.2
District heating	%	3.3	3.2	2.9	2.5	1.9
Renewables	%	4.3	11.3	23.2	31.0	36.6
Renewables incl. share for conversion	%	5.7	18.1	36.2	52.3	67.2
Net power generation	**TWh**	**583**	**485**	**428**	**403**	**405**
Nuclear	%	25.9	6.2	0.0	0.0	0.0
Hard coal	%	21.9	26.5	15.9	5.5	0.0
Lignite	%	26.1	17.7	11.6	5.7	0.0
Natural gas	%	11.5	10.2	10.9	7.0	2.8
Renewable energy sources	%	9.8	33.7	53.3	70.1	81.1
Other	%	4.8	5.6	8.3	11.7	16.1
Efficiency indicators						
PEC per capita	GJ per capita	164	125	98	83	80
GDP (real) 2000 / PEC	EUR / GJ	157	247	338	436	517
Industrial prod. / FEC ind.	EUR / GJ	177	295	386	460	503
Passenger-km / FEC passenger transp.	pkm / GJ	576	669	813	968	1,124
Metric ton-km / FEC freight transp.	tkm / GJ	800	1,121	1,282	1,424	1,557
GHG emissions						
Total GHG emissions	million t	1,031	709	447	276	157
Cumulative GHG emissions from 2005 on	million t	1,031	14,924	20,620	24,066	26,083
Total CO_2 emissions	million t	913	634	387	227	117
Cumulative CO_2 emissions from 2005 on	million t	913	12,796	17,828	20,737	22,318
Energy-related CO_2 emissions	million t	844	580	347	196	95
Energy-related GHG emissions	million t	852	588	352	199	97
Other GHG emissions	million t	180	121	95	77	60
GHG indicators						
GHG emissions / GDP (real)	g / EUR(2000)	485	289	172	101	53
CO2 emissions / GDP (real)	g / EUR(2000)	430	258	149	83	39
Energy-related GHG emissions / GDP (real)	g / EUR(2000)	401	239	136	73	32
GHG emissions per capita	t per capita	12.5	8.9	5.7	3.6	2.2
CO_2 emissions per capita	t per capita	11.1	7.9	4.9	3.0	1.6
Energy-related GHG emissions per capita	t per capita	10.3	7.4	4.5	2.6	1.3

Source: Prognos 2009

5.2 General assumptions

5.2.1 Description of scenario

The reference scenario showed how much ground will be gained with technological and policy developments that rely mainly on steady improvements in the efficiency of known processes and technologies. But that approach has physical limits, and the political base conditions are not sufficient to bring about a systematic development of new process technologies, the introduction of new transport solutions, or coverage of energy demand primarily from renewable sources.

These are tasks for the innovation scenario.

By definition, the innovation scenario aims to achieve an ambitious emissions goal, but without changing the system to the point of being utopian.

Similarities

We generally assume that the framework data for population change and economic development will remain similar, and that the world will not change unrecognizably from the “world as we know it.”

- People will still live in houses and use individual transport to meet their mobility needs.
- Business and value creation will continue to be organised in a variety of segments, in a worldwide exchange of goods and services. Germany will remain an industrialised country with a high-tech reputation.
- Information transfer will be carried out via computers and networks.

Trends towards globalisation, extensive international mobility, and the further development towards a service society will continue similarly to the reference scenario.

Differences

It is assumed that society will recognize that the ambitious goal for avoiding dangerous climate change is essential to survival, and will make that goal a high priority. Some areas will regard and utilise such a goal as an opportunity to develop new markets. Germany, as a high-tech country with a good infrastructure and its potential of well-trained skilled workers, can profit here.

It is assumed that there will be an international consensus on shared, intensified efforts to protect the climate, with each branch providing its own technological developments. It is assumed that there will be a worldwide agreement on climate protection obligations, binding under international law and accompanied by functional instruments. Here cross-border trading of emission rights plays a significant role. It is furthermore assumed that compensation systems will prevent putting too much of a burden on developing and emerging countries, or constricting their ability to develop. This can be accomplished, for example, through transfers of efficiency technologies and regenerative technologies, and/or with financial compensation payments. It is assumed that there will be very little or no leakage effects.

All consumption sectors must make major contributions towards achieving the goal, by applying efficiency measures and sometimes with extensive technical changes. Taking pressure off some sectors and segments at the expense of others is not efficient, either economically or ecologically.

The technical changes are considerable, in some cases, and may lead – for example in 2015 to 2043 – to additional costs to the economy that ultimately must be paid by the consumer or the taxpayer. The changes lead to a re-organisation of markets, a strengthening of the trend towards services and a slight shift in segment structures.

Strategic packages of measures are assumed in implementing the innovation scenario in the various sectors.

- Buildings: Energy performance standards will gradually be tightened so that new buildings and energy-saving refurbishments will meet the passive house standard as early as 2020, and demand for thermal energy will decrease to nearly zero by 2050 (average 5 $kWh/m^2/yr$). The overall stock of buildings must be upgraded to these standards by 2050. This means doubling the upgrade rate (at least). Only energy upgrades to high standards may be carried out, since otherwise the goal cannot be achieved. Fossil thermal energy sources will no longer be used for space heating. In exceptional cases, gas will be used in high-efficiency applications (fuel cells, combined heat and power, heat pumps with cooling functions) [Prognos 2009].

- Transport: A significant amount of freight transport will be shifted to rail (rail's share increases by nearly 10 percentage points). Here no new nationwide rail infrastructure is posited for the time being, but reactivation and a generally better condition of the rail infrastructure is assumed. Rail's larger share of freight transport will be achieved primarily with better utilisation of capacity and better control of the network.

- Individual mobility will systematically and strategically change over to electric mobility (partial, with the goal of complete electrification). This will be done by introducing technology with hybrids and plug-in hybrids as intermediate stages.

- In freight transport by road, only biofuels will be used in 2050, and no more fossil fuels. This is a strategic assumption that derives from the lack of alternatives and limitation of biomass potential discussed in Sec. 2.5.2. The requisite biomass will be produced primarily in Germany; limited imports will be permitted if domestic potential is insufficient. Here it will be ensured that imported biomass is produced sustainably. (This is a task of strategic policy.)

- Industry and services will produce, among other products, the necessary materials and technologies for the changes in building construction and transport. Upgrade activity will increase. All employed materials will be focused consistently on a low use of raw materials and energy throughout the process chain. For electric applications and in power generation, there will be a "second efficiency revolution." The substantial changes in building construction, automotive construction and material production will lead to associated changes in segment structure, which are discussed in more detail in Sec. 5.3.3.

- Renewable energy sources will be systematically, strategically expanded in power generation. Power generation based on renewable energy sources within the world's Sun Belt, with importation to Europe, will be seriously pursued. The innovation scenario does not set a priority on this option, but does not rule it out.

5.2.2 Energy policy and policies for climate protection

To transform to a society with sharply reduced emissions is a strategic policy goal. Even allowing for these assumptions, Germany and the EU Member States will in essence still remain high-tech, export-oriented industrialised countries, dependent on imported resources.

Policy measures will establish effective conditions for a reorganisation of markets in each sector. In some cases (for example in building construction), strict administrative law intervenes, with high standards for enforcement. This is paralleled with instruments that make the changes cost-effective for decision-makers.

Power generation from renewable energy sources will be encouraged, with the goal of deriving the entire supply from these sources. The mechanisms of the electricity market will be re-organised in such a way that renewables are regular participants in the market. Capacities for storage and balancing energy will be expanded accordingly.

Priority will be given to the use of domestic, renewable energy sources whose potential is limited (for the time being, the findings of [DLR/Nitsch 2008] are used as the quantitative limits).

It is assumed that biomass or biofuels can be imported only to a very limited degree until 2050, because all countries' own needs will rise, accompanied by the least possible competition with the food chain for space. A domestic primary energy potential for biomass from suitable land areas and residues is initially set at 1,200 PJ. Hence the use of biomass will be strategically steered towards the production of motor fuels.

CCS is a fallback option for power generation if the expansion of renewables or progress in efficiency is not advancing fast enough. For that reason the innovation scenario too includes options with and without CCS.

5.2.3 Technological developments

The new key technologies in particular will be developed systematically in the direction of energy efficiency and the efficient use of materials. Technological objectives along the same lines will be incorporated into plans for subsidising applied research. No forecasts about technology can or should be attempted here. Instead – indicatively in some cases – we mention what technologies might be necessary in an extreme climate protection scenario, on the basis of research results that are already evident. The exact configuration must be left to the innovative powers and creativity of research and industry. At most we can mention here some of the criteria that such technologies must meet.

Specifically, for example, the following is assumed:

Buildings

- High-performance insulation will be developed further: easy to handle, not too bulky, durable, and most importantly, retrofittable into existing buildings so as to make high energy performance upgrade rates possible;
- "Intelligent" window coatings, with switchable total energy permeabilities, adaptable to ambient conditions;
- New systems for wider use of daylight (e.g., sunlight diversion, light guides, concentrators, etc.);,
- Cooling technology based on high-efficiency absorption and adsorption processes, as well as electromagnetic cooling.

Equipment and appliances

- Replacement of cleaning processes that use solvents, water or steam with cleaning and disinfection processes using UV light or catalytic/enzymatic processes;
- Miniaturised and "decentralised" production (3D printing); process energy applications "within" the workpiece, not "outside" (e.g., concentrating infrared lasers);
- Series-produced magnetic refrigerators;
- Waterless washing machines that make dryers superfluous;
- Further miniaturisation (e.g., viewers instead of screens).

Materials

- New specific energy-efficient materials, provided especially through microtechnology 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;

- Medications applied in lower quantities and even lower orders of magnitude through the use of specific carriers.

Processes

- 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.

Energy

- Development of high and ultrahigh-efficiency batteries, covering the full range of sizes from portable applications to automotive batteries to capacities of several GW for balancing power;
- Development of third-generation photovoltaics (based on organochemical materials, such as dyes) to the point of readiness for the mass market;
- Development of electric cars over several phases, for launch on a broad market;
- Development and higher efficacy in production processes for future customised biofuels based on a broad range of original biogenic materials (e.g., biological pre-digestion of waste materials with high cellulose content).

The technologies mentioned here may sound speculative for now. But these are developments from academic and industrial research that have all gone through prototype phases and feasibility studies already, and whose development to maturity for application is considered possible [Prognos Technology Reports, MPI Publications, etc.]. Fundamentally, speculative aspects cannot be excluded from a long-term innovation scenario, on either the technological or the social level. This is particularly understandable because the reference scenario has demonstrated that the goal for climate protection does not appear achievable using only the instruments and technologies known to date.

On principle, these technological developments are not treated as cure-alls. Rather, it must be assumed that new technologies will also entail new risks. For biotechnologies and nanotechnologies, these include the consequences of uncontrolled release, unforeseeable health risks, and unforeseen effects on biological and ecological chains of effects. It is assumed that technologies will be developed further with a sense of proportion and responsibility, and that product development (from the laboratory to market launch) will apply benchmarks, assessments of technical implications, and ethical appraisals at strategic points. Every new technology must be carefully examined as to its risks and sustainability before it comes into large-scale use.

Given the challenges of climate protection, we must rely on the innovative powers and problem-solving skills of an industrial society. The ambitious goal cannot be achieved with technologies available to date.

5.3 Results

5.3.1 Energy consumption of the residential sector

5.3.1.1 Final energy consumption for space heating

5.3.1.1.1 Development of living space and heating systems

Generally the innovation scenario assumes that residential buildings and living space will develop identically with the reference scenario. The scenarios differ in the applied heating structure. The innovation scenario's development of heating structure in new residential buildings is shown in Table 5.3-1. From 2015 onwards, no oil, coal or direct electric heating will be installed in new residential structures.

The importance of gas will wane. In 2050, only about 30% of living space in new housing will be heated with gas. Mostly gas fuel-cell-based heating systems will be total used for this purpose (share about 75%). Conventional gas low-temperature or condensing-boiler heating systems will be used hardly at all any more. The shares of gas-fuelled heat pumps and mini and micro combined heat and power plants will be less than 5%. In some cases, natural gas will be replaced with biogas; biogas's share of gas consumption will be approx. 8%. These cases will occur, for example, in rural areas where biogas is being efficiently used for production purposes at the same time. Because of the limited potential of bioenergy sources, however, the use of biogas in the residential sector is not a strategy but an exception.

The use of wood in new residential construction will rise substantially until 2020, and then stagnate. This is in part due to the increasing competition for the use of wood as a resource. We assume that from around 2020 onwards, wood can be used efficiently in processes to generate second-generation biofuels.

Table 5.3-1: Innovation scenario: Heating structure of new residential construction 2005 – 2050, in % of new living space

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Single-family homes and duplexes					
District heating	3.9%	0.8%	0.9%	1.1%	1.1%
Oil	12.7%	0.0%	0.0%	0.0%	0.0%
Gas	74.2%	43.3%	31.0%	26.3%	25.0%
Coal	0.2%	0.0%	0.0%	0.0%	0.0%
Wood	2.9%	15.1%	16.1%	16.6%	16.6%
Electricity (n/incl. heat pumps)	1.5%	0.0%	0.0%	0.0%	0.0%
Electric heat pumps	4.3%	35.6%	38.9%	33.9%	33.6%
Solar	0.3%	5.2%	13.1%	22.1%	23.7%
Three-family and multi-unit buildings					
District heating	20.0%	20.0%	20.9%	22.0%	23.0%
Oil	0.0%	0.0%	0.0%	0.0%	0.0%
Gas	62.3%	62.3%	52.3%	43.8%	37.0%
Coal	0.0%	0.0%	0.0%	0.0%	0.0%
Wood	5.7%	5.7%	6.4%	6.4%	6.4%
Electricity (n/incl. heat pumps)	0.0%	0.0%	0.0%	0.0%	0.0%
Electric heat pumps	9.0%	9.0%	13.9%	18.8%	23.5%
Solar	3.0%	3.0%	6.5%	9.0%	10.0%
Non-residential buildings					
District heating	20.2%	20.2%	21.2%	22.4%	23.3%
Oil	0.0%	0.0%	0.0%	0.0%	0.0%
Gas	62.3%	62.3%	52.8%	44.4%	37.8%
Coal	0.0%	0.0%	0.0%	0.0%	0.0%
Wood	5.5%	5.5%	6.0%	6.0%	6.3%
Electricity (n/incl. heat pumps)	0.0%	0.0%	0.0%	0.0%	0.0%
Electric heat pumps	9.0%	9.0%	13.5%	18.2%	22.6%
Solar	2.9%	2.9%	6.4%	8.9%	10.1%
All buildings					
District heating	5.4%	5.4%	5.4%	5.7%	5.9%
Oil	0.0%	0.0%	0.0%	0.0%	0.0%
Gas	47.8%	47.8%	35.8%	30.2%	27.7%
Coal	0.0%	0.0%	0.0%	0.0%	0.0%
Wood	12.8%	12.8%	13.9%	14.3%	14.4%
Electricity (n/incl. heat pumps)	0.0%	0.0%	0.0%	0.0%	0.0%
Electric heat pumps	29.3%	29.3%	33.3%	30.6%	31.4%
Solar	4.7%	4.7%	11.7%	19.2%	20.6%

Source: Prognos 2009

Apart from new buildings, the replacement of old heating systems with new ones in the housing stock is a very important aspect of the change in heating structure. The replacement rate in the innovation scenario is higher than in the reference scenario. The winners in replacement are solar radiation and ambient heat, usually in combination with a long-term storage unit. Combined heat and power systems and district heating will lose their attractions over the longer term because demand for heating will decline significantly.

At the end of the period under consideration, oil, coal and electric resistance heating will be almost entirely eliminated; their share of heated living space will decrease to 0.5% (Table 5.3-2). Gas-heated living space will decrease from 2010 onwards, and will be only about half as great in 2050 as in 2005.

The greatest increase in terms of living space served will be in solar heating systems. Living space in which solar radiation is used for heat will increase from 2 million m^2 in 2005 to about 1.2 billion m^2 in 2050. About 80% of the growth will be in single-family homes and duplexes. With a share of more than 34% of heated living space, solar thermal installations will become the most important heating system (Table 5.3-2). It would not be realistic to assume a larger share, because solar use presupposes an appropriate orientation of roof area (southeast to southwest), which on average is available on only about 25% of buildings (assuming orientations are evenly distributed). Flat roofs have the option of inclined collector installation, increasing the opportunities for market penetration. Additionally, solar thermal can work well in single-family homes and duplexes because of the ratio of roof surface area to living space; for multi-story buildings, the roof surface area is generally not sufficient to supply several times as much living space with heat and hot water.

Wood-heated living space will expand by 450 m^2 during the period under consideration; space heated with electric heat pumps will expand 416 million m^2 and space served by district heating will increase 213 million m^2.

Table 5.3-2: Innovation scenario: Heating structure of existing living space 2005 – 2050, in million m^2 (occupied housing)

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
All homes					
District heating	307	381	441	486	524
Oil	1,082	833	569	288	13
Gas	1,537	1,500	1,309	1,078	842
Coal	60	36	25	12	1
Wood	41	160	279	391	494
Electricity (n/incl. heat pumps)	175	133	91	46	2
Heat pumps	18	142	248	348	440
Solar	2	300	621	926	1,207
All living space	3,223	3,484	3,582	3,574	3,524
Of which: single-family and duplex					
District heating	49	94	135	172	205
Oil	761	585	399	202	9
Gas	867	803	634	448	262
Coal	33	21	14	7	0
Wood	29	134	239	339	430
Electricity (n/incl. heat pumps)	100	76	52	26	1
Heat pumps	15	119	208	292	369
Solar	1	237	491	733	957
All single-family and duplex	1,856	2,069	2,171	2,220	2,235

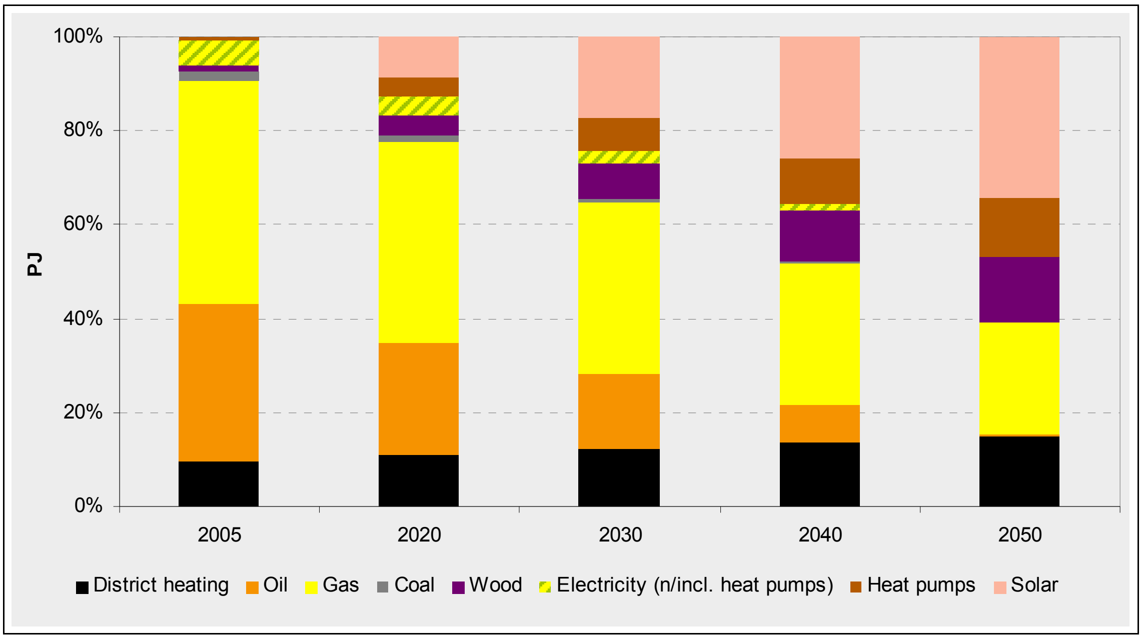
Source: Prognos 2009

Table 5.3-3: *Innovation scenario: Heating structure of existing living space 2005 – 2050, in % (occupied housing)*

		Innovation scenario			
	2005	2020	2030	2040	2050
District heating	9.5%	10.9%	12.3%	13.6%	14.9%
Oil	33.6%	23.9%	15.9%	8.0%	0.4%
Gas	47.7%	43.0%	36.6%	30.1%	23.9%
Coal	1.9%	1.0%	0.7%	0.3%	0.0%
Wood	1.3%	4.6%	7.8%	10.9%	14.0%
Electricity (n/incl. heat pumps)	5.4%	3.8%	2.5%	1.3%	0.1%
Heat pumps	0.5%	4.1%	6.9%	9.7%	12.5%
Solar	0.1%	8.6%	17.3%	25.9%	34.3%
All living space	100.0%	100.0%	100.0 %	100.0%	100.0%

Source: Prognos 2009

Figure 5.3-1: *Innovation scenario: Heating structure of existing living space 2005 – 2050, in % (occupied housing)*



Source: Prognos 2009

5.3.1.1.2 Energy performance standard performance standard of living space and heating systems

In new housing construction, the innovation scenario assumes a faster and sharper reduction in heat capacity than in the reference scenario. As early as 2020, new structures will begin achieving the "passive house" standard, with annual heating demand of 15 kWh/m^2 . After that, annual heating demand in new structures will continue to decrease in the direction of a zero-energy house. Here it must be borne in mind that even with a zero-energy house, there can be no guarantee that the need for space heating will vanish on average in all weather conditions. The concept of the zero-energy house represents a balance of different options for demand and generation. In the strict view adopted here, a remainder of demand for space heating must be retained for physical reasons. A specific demand averaging about 5 kWh/m^2 will be achieved by 2050.

To achieve the emission target, moreover, the upgrade rate and upgrade efficiency must be increased substantially in comparison to the Reference. The calculations increase the upgrade rate to more than 2% per year (Table 5.3-4). Consequently, during the period under study, every building built before 2005 will undergo at least one energy upgrade.

The upgrades are intended to achieve a thermal energy demand equivalent to that of new buildings (likewise 5 $kWh/m^2/yr$ in 2050). Since this cannot be assumed as entirely achievable, as a conservative assumption the average for the calculations is set slightly higher, especially for upgrades of older buildings (about 10 $kWh/m^2/yr$). The consequence is that upgrade efficiency – the improvement in thermal energy demand per upgrade – rises towards 90%. This can be accomplished only by regulating the upgrades of building components. If a component of a building is replaced, the part with the best energy performance standard is to be installed. Such regulatory requirements must also be strictly enforced. To enable nationwide implementation of such demanding upgrades, it will be necessary to develop extremely high-performance (and thus thin) insulators that are long-lived and easy to handle, and where applicable also suitable for interior insulation, offering solutions for complex architectures and technical requirements.

Table 5.3-4: Innovation scenario: Frequency of energy upgrades as a function of building age, in % per year

	Innovation scenario									
Building age	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
Single-family homes and duplexes										
till 1918	3.2%	2.7%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1919-1948	3.2%	2.7%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1949-1968	3.2%	2.7%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1969-1978	2.1%	1.8%	1.5%	2.0%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1979-1987	1.6%	1.3%	1.1%	1.5%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1987-1991	0.6%	1.1%	0.9%	1.2%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
1992-1995	0.0%	0.1%	0.2%	0.3%	0.5%	0.9%	2.3%	2.3%	2.3%	2.3%
1996-1997	0.0%	0.2%	0.2%	0.3%	0.5%	0.9%	2.3%	2.3%	2.3%	2.3%
1998-2000	0.0%	0.1%	0.1%	0.2%	0.4%	0.5%	0.9%	2.3%	2.3%	2.3%
2001-2005		0.0%	0.1%	0.2%	0.4%	0.5%	0.9%	2.3%	2.3%	2.3%
2006-2010			0.0%	0.2%	0.4%	0.4%	0.5%	0.9%	2.3%	2.3%
2011-2015				0.1%	0.3%	0.4%	0.4%	0.5%	0.9%	2.3%
2016-2020					0.1%	0.3%	0.4%	0.4%	0.5%	0.9%
2021-2025						0.1%	0.3%	0.4%	0.4%	0.5%
2026-2030							0.1%	0.3%	0.4%	0.4%
2031-2035								0.1%	0.3%	0.4%
2036-2040									0.1%	0.3%
2041-2046										0.1%
Multi-unit and non-residential buildings										
till 1918	3.2%	2.2%	2.6%	1.8%	1.3%	1.3%	0.9%	0.9%	0.9%	0.9%
1919-1948	3.2%	2.2%	2.6%	1.8%	1.3%	1.3%	0.9%	0.9%	0.9%	0.9%
1949-1968	3.2%	2.2%	2.6%	1.8%	1.3%	1.3%	0.9%	0.9%	0.9%	0.9%
1969-1978	2.5%	2.2%	2.7%	2.8%	2.3%	2.3%	1.8%	1.8%	0.9%	0.9%
1979-1987	2.1%	1.8%	2.3%	2.3%	2.3%	2.3%	1.8%	1.8%	1.8%	0.9%
1987-1991	1.9%	1.6%	2.3%	2.3%	2.3%	2.3%	1.8%	1.8%	1.8%	1.8%
1992-1995	0.1%	0.7%	2.0%	2.1%	2.2%	2.3%	2.2%	2.2%	1.8%	1.8%
1996-1997	0.1%	0.7%	2.0%	2.1%	2.2%	2.1%	2.2%	2.2%	2.2%	1.8%
1998-2000	0.0%	0.1%	1.1%	2.0%	2.1%	2.3%	2.2%	2.2%	2.2%	2.2%
2001-2005		0.1%	1.1%	2.0%	2.1%	2.2%	2.4%	2.2%	2.2%	2.2%
2006-2010			0.1%	1.2%	2.0%	2.1%	2.3%	2.4%	2.2%	2.2%
2011-2015				0.1%	1.2%	2.0%	2.1%	2.3%	2.4%	2.2%
2016-2020					0.1%	1.2%	2.1%	2.1%	2.3%	2.4%
2021-2025						0.1%	1.2%	2.1%	2.1%	2.3%
2026-2030							0.1%	1.2%	2.1%	2.1%
2031-2035								0.1%	1.2%	2.1%
2036-2040									0.1%	1.2%
2041-2046										0.1%

Source: Prognos 2009

As a consequence of the high efficiency of upgrades and upgrade rates, as well as strict requirements for new buildings, the specific thermal energy demand for the housing stock will decrease more than 85% during the period under study (Table 5.3-5). Intensified replacement in the direction of high-efficiency heating systems (heat pumps, solar installations) will increase the average utilisation ratio of systems to 111%. Specific final energy consumption will decrease by nearly 90% over the period.

Table 5.3-5: Innovation scenario: Mean specific space heating demand, utilisation ratio and final energy consumption by existing residential building stock, 2005 – 2050

		Innovation scenario			
	2005	2020	2030	2040	2050
Thermal energy demand (MJ/m2)	473	333	229	141	67
Utilisation ratio (%)	83	94	102	107	111
Final energy consumption (MJ/m2)	573	353	224	132	61

Source: Prognos 2009

All in all, final energy consumption for space heating decreases 86% between 2005 and 2050 in the Innovation scenario. The annual increase in energy productivity increases from an initial 1% to more than 6% towards the end of the period; the average annual efficiency increase is 4.3%. The final energy consumptions for space heating as shown in Table 5.3-6 are weather-neutral figures that take account of global warming of 1.75ºC by 2050.

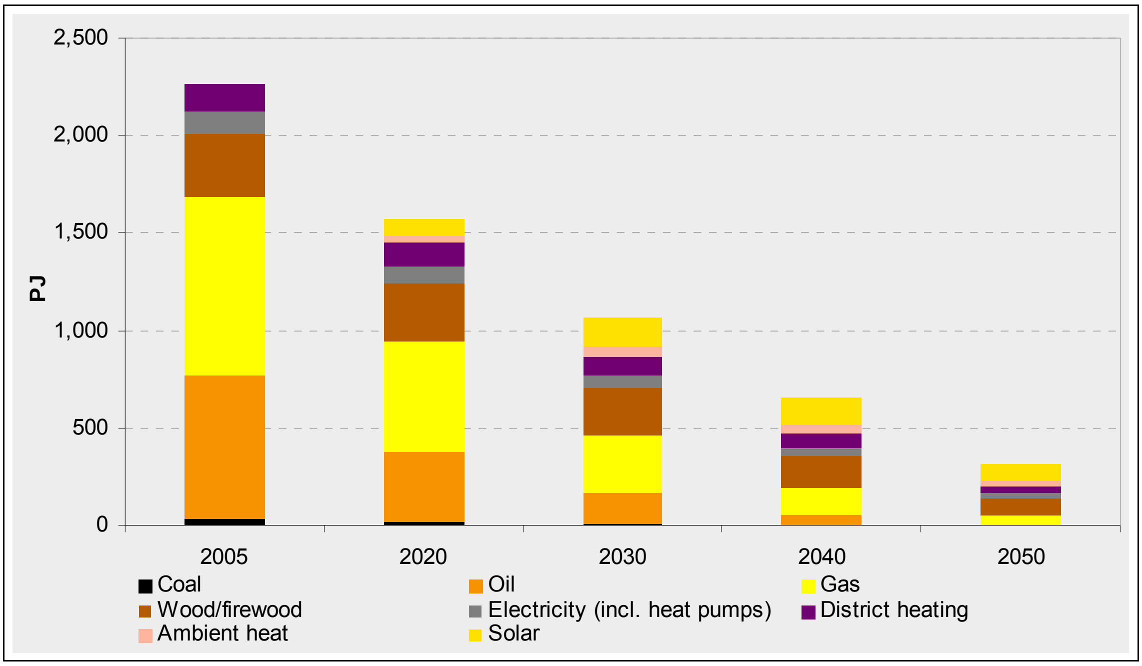
In 2050, solar radiation will the most important energy source for space heating, with a 26% share. Wood (including wood for stoves and fireplaces) will also be very significant, with a 21% share. Electricity will account for about 7%.

Table 5.3-6: Innovation scenario: Final energy consumption for space heating 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Weather-validated					
District heating	137	124	101	72	38
Oil	730	360	157	47	1
Gas	919	567	298	141	49
Coal	38	17	8	2	0
Wood	177	184	164	121	66
Electric heating (w/o heat pumps)	74	42	21	7	0
Electric heat pumps	3	11	12	10	6
Solar	1	87	149	135	83
Ambient heat	4	36	54	49	31
+ Firewood	149	115	81	50	23
+ Electricity direct heating	15	11	6	2	0
+ Electricity auxiliary energy	21	21	19	17	16
Total final energy consumption	2,268	1,573	1,070	653	315
Non-weather-validated					
Total final energy consumption	2,145	1,458	989	603	291

Source: Prognos 2009

Figure 5.3-2: Innovation scenario: Final energy consumption for space heating 2005 – 2050, in PJ



Source: Prognos 2009

5.3.1.2 Final energy consumption for water heating

The projection of the structure of water heating for the population is based on the following assumptions:

- Conventional central hot water systems based on district heating, oil, gas, coal and wood, and decentralised oil and gas systems, will disappear almost entirely.
- Solar installations will become the most important heating system. The market share of solar installations will rise from 3% in 2005 to 56% in 2050. On this the points already made in the preceding sections apply.
- Electric hot water systems, including heat pumps, will likewise gain slightly; their share will increase from 27% to 43% during the period.

Table 5.3-7: Innovation scenario: Structure of hot water supply for population 2005 – 2050, in million persons

		Innovation scenario			
	2005	2020	2030	2040	2050
Hot water from					
Central systems coupled to heating					
District heating	7.0	5.0	3.1	0.7	0.0
Oil	16.9	8.6	3.4	2.2	0.2
Gas	27.7	17.6	9.3	3.2	0.9
Coal	0.3	0.2	0.1	0.1	0.0
Wood	0.2	1.2	1.7	0.1	0.1
Central, non-coupled systems					
Solar*	2.6	10.5	21.6	31.8	40.2
Heat pumps	1.0	4.8	7.4	9.1	10.0
Decentralised systems					
Electricity	21.2	29.2	31.9	28.9	20.9
Gas	4.1	2.3	0.0	0.0	0.0
Total persons served	81.0	79.5	78.5	76.1	72.4
No own hot water heating	1.4	0.2	0.0	0.0	0.0

**Converted to full supply* *Source: Prognos 2009*

Table 5.3-8: Innovation scenario: Utilisation ratio of hot water supply 2005 – 2050, in %

		Innovation scenario			
	2005	2020	2030	2040	2050
Central systems coupled to heating					
District heating	78	81	83	84	86
Oil	63	72	77	81	84
Gas	69	81	90	98	103
Coal	52	56	58	61	64
Wood	57	63	64	66	67
Central, non-coupled systems					
Solar*	100	100	100	100	100
Heat pumps	206	221	231	241	251
Decentralised systems					
Electricity	92	92	92	92	92
Gas	73	77	79	79	79
Total hot water supply	74	89	97	103	106

** Converted to full supply* *Source: Prognos 2009*

Because of the larger share of electric heat pumps, the average overall efficiency of hot water systems in 2050 in the innovation scenario, at 106%, is greater than in the reference scenario (Table 5.3-8).

The two scenarios likewise differ in regard to the amount of demand for hot water. The innovation scenario assumes a reduction of per capita hot water consumption to barely 40 litres per day. This is accomplished with water-saving valves that reduce water flow-through.

In addition, the Innovation scenario includes greater shifts: the hot water needed for washing machines and dishwashers will largely be provided from a central hot water system, not by electric heaters within the appliances themselves. This will shift a portion of the energy consumed by electric appliances towards energy consumption for heating hot water (+7 PJ in 2050).

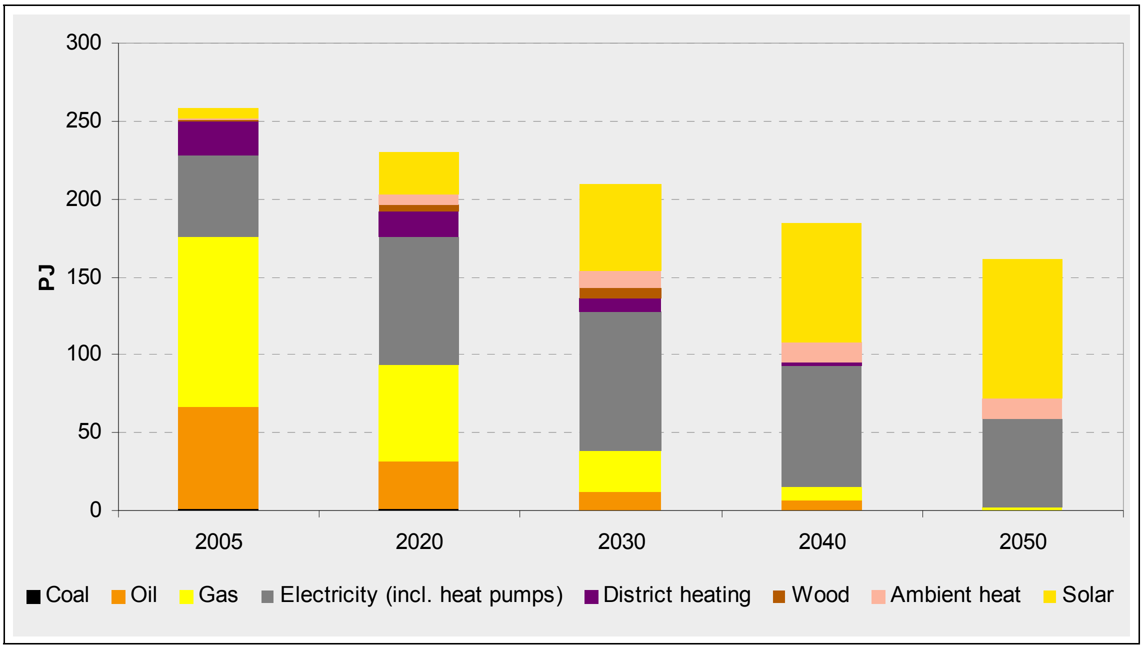
Because of the sharp increase in the efficiency of hot water systems and the decrease in demand for hot water, the energy consumption for heating hot water decreases more in the innovation scenario than in the reference scenario. Energy consumption for hot water heating is projected to decrease 37% in the period under study (Table 5.3-9).

Table 5.3-9: Innovation scenario: Final energy consumption for water heating 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
District heating	21.8	15.8	9.6	2.1	0.0
Oil	64.8	30.4	11.5	6.5	0.4
Gas	109.1	62.5	26.8	7.9	2.0
Coal	1.5	0.7	0.4	0.4	0.0
Wood	0.9	5.0	6.7	0.3	0.2
Electricity (incl. heat pumps)	53.0	82.1	88.5	78.3	56.4
Subtotal	251.0	196.5	143.4	95.4	59.1
Solar	6.3	26.6	55.7	76.1	89.4
Ambient heat	1.3	6.7	10.8	12.8	13.4
Total final energy consumption/ hot water	258.6	229.8	209.9	184.3	161.9

Source: Prognos 2009

Figure 5.3-3: Innovation scenario: Final energy consumption for water heating 2005 – 2050, in PJ



Source: Prognos 2009

5.3.1.3 Final energy consumption for cooking

The innovation scenario assumes that electric induction stoves will penetrate the market faster. This will reduce specific consumption somewhat faster than in the reference scenario. Since the two scenarios are based on identical assumptions about demographic changes, development of amounts of equipment, distribution among stove types, and user behaviour, they do not differ significantly as to energy consumption for cooking.

All in all, energy consumption for cooking in 2050, at 32 PJ, will be about 46% less than in 2005 (Table 5.3-10). Electric stoves will account for 85% of the energy consumption. The rest will be gas stoves.

Table 5.3-10: Innovation scenario: Final energy consumption for cooking, 2005 – 2050

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Percent of households with stoves	99.0%	98.0%	97.0%	96.0%	95.0%
Electric stove	79.4%	82.9%	83.9%	84.4%	84.2%
Gas stove	18.7%	14.9%	13.1%	11.6%	10.8%
Wood or coal stove	0.8%	0.1%	0.0%	0.0%	0.0%
Appliances used (million)					
Electric stove	31.2	33.5	34.1	34.4	32.8
Gas stove	7.4	6.0	5.3	4.7	4.2
Wood or coal stove	0.3	0.1	0.0	0.0	0.0
Specific consumption in kWh per appliance per year					
Electric stove	383.2	327.0	283.6	250.4	230.7
Gas stove	576.4	477.3	405.8	351.2	317.1
Wood or coal stove	622.8	617.0	591.1	548.7	531.4
Final energy consumption in PJ					
Electric stove	43.0	39.4	34.8	31.0	27.2
Gas stove	15.3	10.4	7.8	6.0	4.8
Wood or coal stove	0.7	0.1	0.0	0.0	0.0
Total final energy consumption	59.0	49.9	42.7	37.0	32.1

Source: Prognos 2009

5.3.1.4 Power consumption of electrical equipment

In the innovation scenario, the potential for increasing technical energy efficiency is utilised somewhat better than in the reference scenario, especially in refrigeration and freezing, and in washing and drying. The result will be a greater decrease in the associated mean specific appliance consumptions (Table 5.3-11).

The greater efficiency enhancement will be achieved in part by way of waterless washing machines that no longer need a dryer, and of magnetic refrigerators; these appliances will extensively penetrate the market. The miniaturisation of appliances – such as viewers being used in place of full-size screens – will also have a certain importance.

Table 5.3-11: Innovation scenario: Development of equipment component in specific consumption, 2005 – 2050, in kWh per appliance per year (= mean consumption per existing unit of equipment per year)

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Light	281	125	105	42	33
Refrigerator	256	191	126	92	70
Refrigerator-freezer	329	229	145	102	79
Freezer	299	218	152	114	89
Washing machine	223	163	113	76	42
Washer-dryer	613	480	340	232	147
Dryer	298	227	173	129	90
Dishwasher	243	200	176	153	133
Colour TV	162	207	148	94	79
Radio / sound system	51	48	46	44	42
Video / DVD player	40	8	8	8	8
Electric iron	25	24	23	22	20
Vacuum cleaner	24	23	22	21	20
Coffee maker	85	85	68	68	68
Toaster	25	24	23	22	20
Hair dryer	25	24	23	22	20
Extraction hood (cooker)	45	43	41	39	37
Microwave	35	33	32	30	29
PC (incl. peripherals)	196	84	62	62	62
Communal area lighting, etc.	28	21	20	17	17

Source: Prognos 2009

In regard to the number of electric appliances, the two scenarios do not differ. They assume an identical development of the population and residential sector, and identical numbers of appliances in use. One exception will be the change in air conditioners. In the innovation scenario, demand for air conditioning will be slowed by a greater use of construction features, such as better building insulation or water-cooled building cores. Additionally, more solar cooling systems and high-performance collectors will be used. This will mean that power consumption for air conditioning will rise less than in the reference scenario.

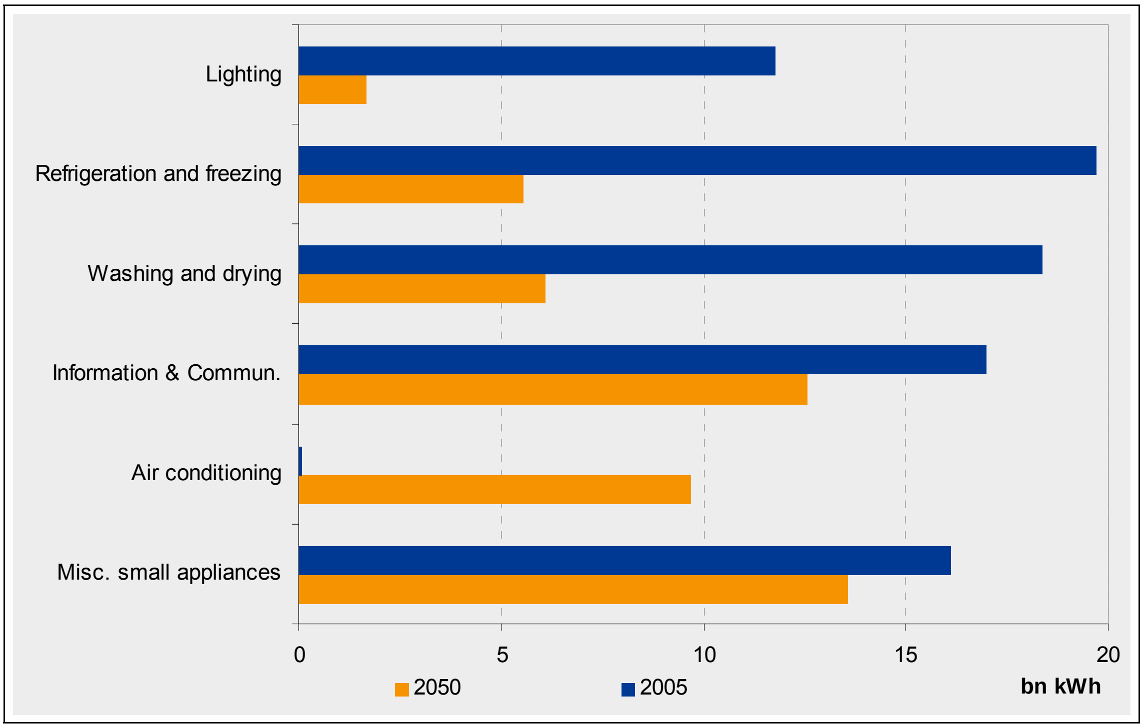
All told, power consumption for electric appliances and air conditioning is projected to decrease by 41% in the reference period, and will come to 49 TWh in 2050 (Table 5.3-12). The largest decrease will be in refrigeration and freezing, where consumption will decrease 14 TWh (–71%; Figure 5.3-4). Consumption for washing and drying will decrease 12 TWh during the period. Power consumption for air conditioning will increase to just under 10 TWh by 2050. Thus at the end of the period, about 20% of power consumption of the residential sector will be used for air conditioning.

Table 5.3-12: *Innovation scenario: Final energy consumption for electric appliances in the residential sector, 2005 – 2050, in billion kWh*

		Innovation scenario			
	2005	2020	2030	2040	2050
Light	11.2	5.2	4.4	1.8	1.3
Refrigerator	7.6	5.1	3.2	1.9	1.2
Refrigerator-freezer	4.2	3.6	2.4	2.0	1.6
Freezer	7.9	6.3	4.5	3.4	2.7
Washing machine	7.1	4.1	1.7	0.8	0.3
Washer-dryer	1.8	2.8	3.2	3.7	3.0
Dryer	4.1	3.3	2.4	1.4	0.7
Dishwasher	5.3	4.7	2.8	2.4	2.1
Colour TV	7.0	9.8	7.4	4.9	4.2
Radio / sound system	1.9	1.8	1.7	1.6	1.5
Video / DVD player	1.3	0.3	0.3	0.3	0.3
Electric iron	0.9	0.8	0.8	0.7	0.7
Vacuum cleaner	0.9	0.9	0.8	0.8	0.7
Coffee maker	3.1	3.2	2.6	2.6	2.4
Toaster	0.9	0.9	0.8	0.8	0.7
Hair dryer	0.8	0.8	0.7	0.7	0.7
Extraction hood (cooker)	1.0	1.1	1.1	1.0	1.0
Microwave	0.9	1.1	1.1	1.1	1.0
PC (incl. peripherals)	6.8	6.7	5.7	6.3	6.6
Communal area lighting, etc.	0.6	0.5	0.4	0.4	0.3
Air conditioning	0.0	1.9	4.5	6.9	9.7
Other consumption	7.7	8.9	9.4	7.9	6.4
Total final energy consumption	83.0	73.5	62.2	53.5	49.1

Source: Prognos 2009

Figure 5.3-4: *Innovation scenario: Final energy consumption for electric appliances in the residential sector by type of use, 2005 – 2050, in billion kWh*



Source: Prognos 2009

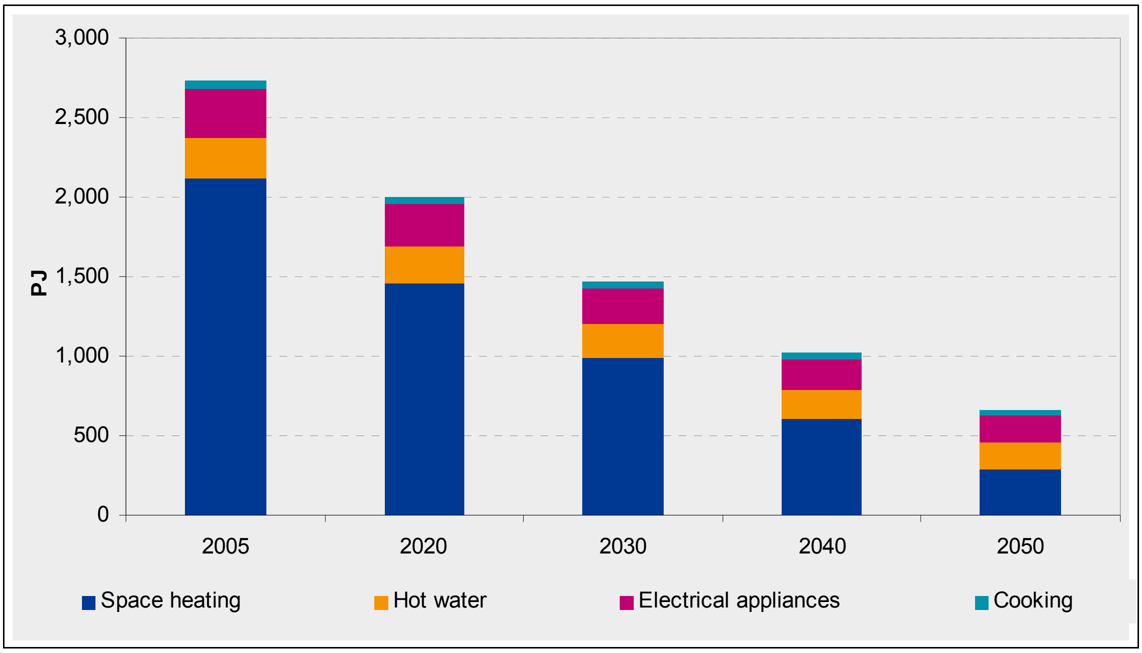
5.3.1.5 Final energy consumption

The framework data for population, areas and numbers of residential units will not change.

In the innovation scenario, the energy consumption of the residential sector decreases from 2,735 PJ in 2007 to 662 PJ in 2050 (–75%; Table 5.3-13).

Because of the substantial differences in the development of efficiency, there is a marked shift in the breakdown of total energy consumption by different types of use. Space heating will remain the dominant type of use, with a 44% share in 2050, but this represents a decrease of more than 31 percentage points against 2005 (Table 5.3-13). By contrast, hot water heating will rise by 14 percentage points and electric appliances (including air conditioning) will rise by nearly 16 percentage points. Energy consumption for cooking will still be of little significance, representing 5% of total energy consumption in 2050.

Figure 5.3-5: Innovation scenario: Final energy consumption in the residential sector by type of use (space heating, hot water, electric appliances, cooking), 2005 – 2050, in PJ



Source: Prognos 2009

The consumption of fossil fuels will decrease very sharply; consumption of both heating oil and coal will decrease more than 99%. Natural gas consumption will decrease 95%. Thus the share of fossil gas in the total energy consumption of the residential sector will decrease to 8% by 2050 (Table 5.3-14). Consumption of district heating (–76%), electricity (–44%) and wood (–62%) will also decrease significantly.

Table 5.3-13: Innovation scenario: Final energy consumption in the residential sector by type of use, 1990 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Type of use					
Space heating	2,118	1,458	989	603	291
Hot water	259	230	210	184	162
Cooking	59	50	43	37	32
Electrical appliances	299	265	224	193	177
Total final energy consumption	2,735	2,003	1,465	1,017	662
Share in %					
Space heating	77.5%	72.8%	67.5%	59.3%	44.0%
Hot water	9.5%	11.5%	14.3%	18.1%	24.5%
Cooking	2.2%	2.5%	2.9%	3.6%	4.8%
Electrical appliances	10.9%	13.2%	15.3%	18.9%	26.7%

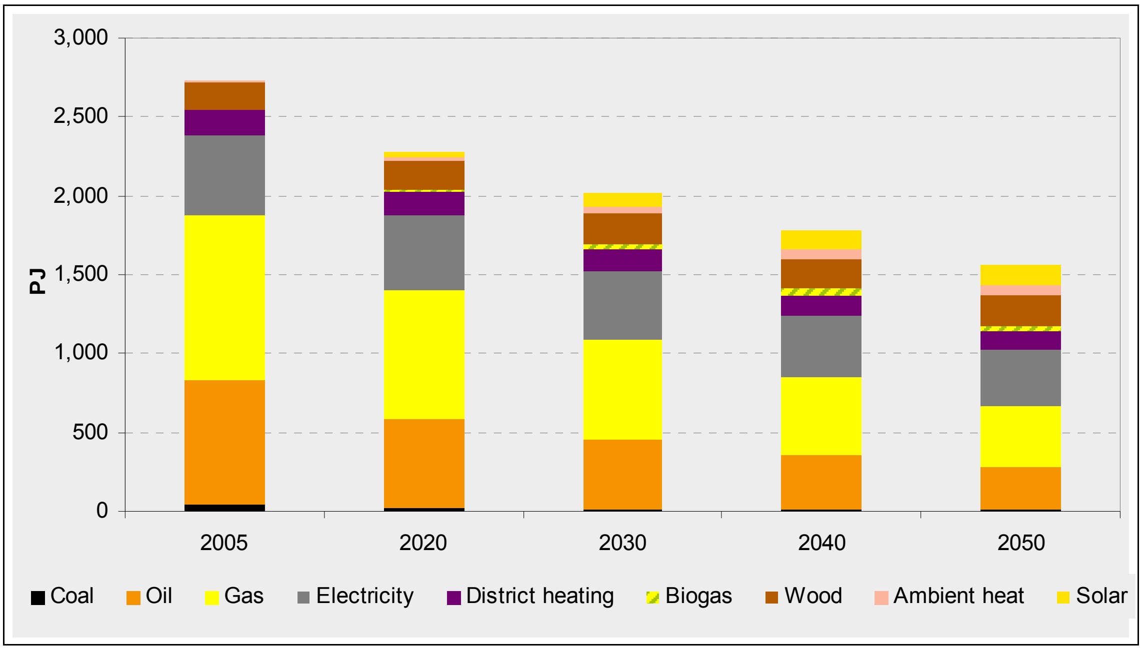
Source: Prognos 2009

Table 5.3-14: Innovation scenario: Final energy consumption in the residential sector by energy source, 2005 – 2050, in PJ and %

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Energy source in PJ					
District heating	158	140	111	74	38
Oil	795	390	168	54	1
Gas	1,043	633	316	144	51
Coal	40	18	8	3	0
Wood	178	189	171	122	66
Electricity	508	471	406	338	283
Ambient heat	6	42	65	62	44
Solar	7	113	205	211	173
Biogas	0	7	16	11	5
Total final energy consumption	2,735	2,003	1,465	1,017	662
Structure in %					
District heating	5.8%	7.0%	7.5%	7.2%	5.8%
Oil	29.1%	19.5%	11.5%	5.3%	0.2%
Gas	38.1%	31.6%	21.6%	14.1%	7.7%
Coal	1.5%	0.9%	0.6%	0.3%	0.0%
Wood	6.5%	9.4%	11.6%	11.9%	10.0%
Electricity	18.6%	23.5%	27.7%	33.2%	42.8%
Ambient heat	0.2%	2.1%	4.4%	6.1%	6.7%
Solar	0.3%	5.7%	14.0%	20.7%	26.1%
Biogas	0.0%	0.3%	1.1%	1.1%	0.8%

Source: Prognos 2009

Figure 5.3-6: Innovation scenario: Final energy consumption in the residential sector by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

Biogas will remain of little significance in the case of the residential sector; consumption will increase to 5 PJ during the period. Use of ambient heat will rise to more than 75 PJ by 2040; use of solar heat will rise to about 210 PJ. As a consequence of declining demand for heat, these forms of energy consumption will also begin declining slightly in 2040.

Electricity will become the most important energy source in 2050, with a share of about 40% of consumption. Just under 25% of consumption will be in solar heating; the share of renewable energy sources will rise to 45%.

5.3.2 Energy consumption by the service sector

5.3.2.1 Framework data

The innovation scenario assumes substantially higher-quality new buildings and more extensive, higher-quality upgrades, a change in the materials used, the development and production of new, less energy-intensive materials, and an overall greater effort to apply measurements and controls. Products will also change in the motor vehicle and transport sector (see Sec. 5.1.1, 5.2.4). These conditions correspond to a change in the sector structure. Various segments of the service sector (e.g., the construction industry, transport and data transmission) will grow faster than in the reference scenario. Knowledge-intensive preliminary services will likewise gain in importance. This will be evidenced, for example, in greater dynamism in other private services. All in all, gross value added by the service sector in 2050 is projected to be more than 4.6% greater than in the reference scenario.

Table 5.3-15: Innovation scenario: Framework data for service sector, 2005 – 2050

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Persons employed (in 1,000)					
Agriculture, gardening	853	728	649	580	516
Small industrial / crafts	1,673	1,347	1,210	1,087	980
Construction	2,185	2,115	2,063	1,979	1,940
Retail	5,903	5,646	5,373	5,116	4,852
Banking / insurance	1,239	1,181	1,164	1,141	1,120
Transport, telecommunications	2,118	2,187	2,179	2,175	2,132
Other private services	9,675	11,097	10,490	9,848	9,590
Healthcare	4,036	4,930	4,806	4,693	4,849
Education	2,281	2,522	2,404	2,300	2,284
Government, social insurance	2,298	2,060	1,858	1,677	1,535
Defence	373	350	351	351	351
All segments	32,634	34,163	32,546	30,947	30,150
Gross value added (EUR bn)					
Agriculture, gardening	23	25	25	26	27
Small industrial / crafts	68	79	82	85	89
Construction	76	82	89	94	102
Retail	215	236	254	271	297
Banking / insurance	69	91	101	111	128
Transport, telecommunications	114	145	159	173	196
Other private services	598	704	778	855	966
Healthcare	141	184	204	225	253
Education	84	91	92	93	97
Government, social insurance	99	111	108	107	108
Defence	16	19	20	22	25
All segments	1,503	1,766	1,912	2,062	2,288

Source: Prognos 2009

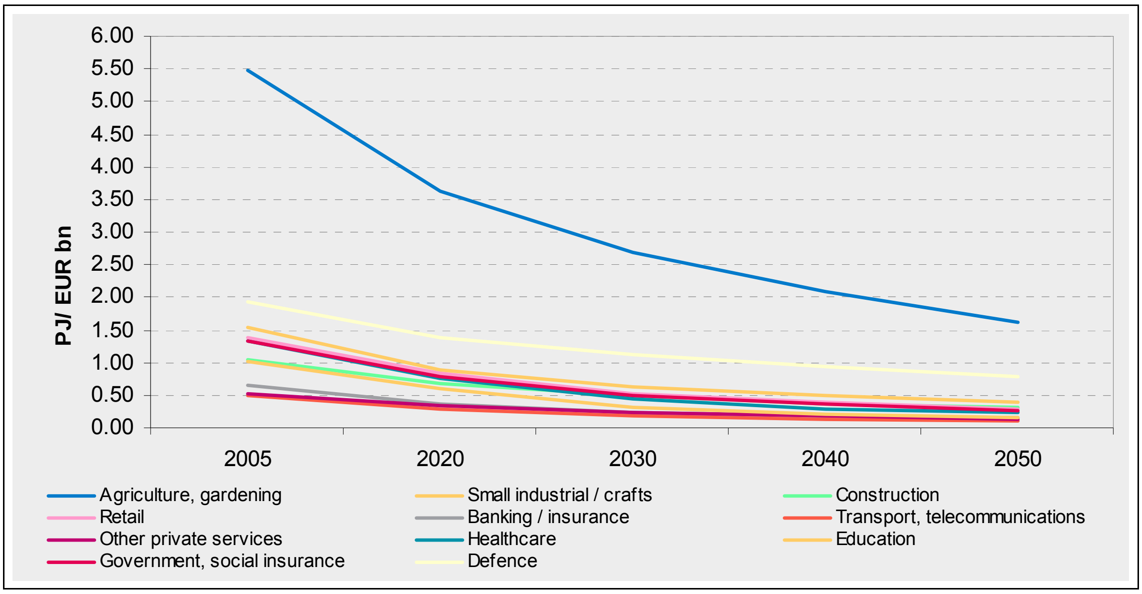
The measures that the reference scenario assumes will be taken to enhance energy efficiency also apply under the innovation scenario (Table 5.3-16, Figure 5.3-7, Figure 5.3-8). But here it is assumed that the potential for efficiency will be realised faster and utilised in full. Changes in specific consumption will tend to parallel the development in the reference scenario – in other words, specific consumption will decrease more in segments with large shares of space heating than in segments with large shares of process heat and mechanical energy. The various technological developments in materials and processes will have less impact in the service sector than in the industry sector. Here substantial savings are already realised in the reference scenario; any further increase in the innovation scenario is only gradual. Nevertheless, technological innovations are applied, for example for sterilisation in healthcare (UV light instead of steam, miniaturisation). Buildings' technical requirements and lower demand for space heating will, in their turn, parallel the residential sector.

Table 5.3-16: Innovation scenario: Specific consumption (energy consumption / gross value added) in service sector, absolute (in PJ/EUR bn) and indexed, 2005 – 2050, model results, temperature-adjusted

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Specific consumption					
Agriculture, gardening	5.48	3.62	2.69	2.10	1.63
Small industrial / crafts	1.54	0.88	0.62	0.49	0.38
Construction	1.04	0.68	0.49	0.38	0.30
Retail	1.39	0.82	0.51	0.38	0.28
Banking / insurance	0.65	0.36	0.24	0.19	0.15
Transport, telecommunications	0.49	0.28	0.17	0.12	0.09
Other private services	0.53	0.35	0.23	0.18	0.14
Healthcare	1.34	0.76	0.44	0.29	0.23
Education	1.02	0.60	0.31	0.20	0.15
Government, social insurance	1.34	0.78	0.50	0.35	0.27
Defence	1.93	1.38	1.13	0.94	0.78
Normalised specific consumption					
Agriculture, gardening	100	66	49	38	30
Small industrial / crafts	100	57	41	32	25
Construction	100	65	47	36	29
Retail	100	59	37	28	20
Banking / insurance	100	55	37	29	23
Transport, telecommunications	100	58	35	25	19
Other private services	100	66	44	34	27
Healthcare	100	57	33	22	17
Education	100	59	31	19	14
Government, social insurance	100	58	37	26	20
Defence	100	71	58	49	40

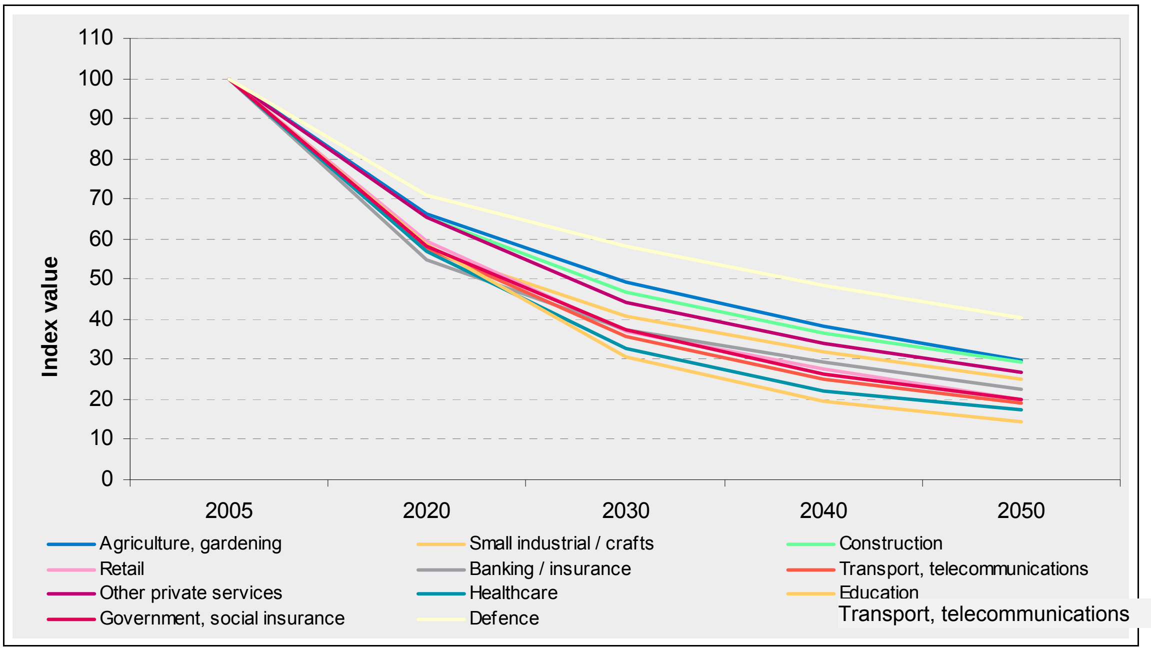
Source: Prognos 2009

Figure 5.3-7: Innovation scenario: Specific final energy consumption in service sector by segment, 2005 – 2050, in PJ/EUR bn



Source: Prognos 2009

Figure 5.3-8: Innovation scenario: Specific final energy consumption in service sector by segment, 2005 – 2050, indexed to 2005



Source: Prognos 2009

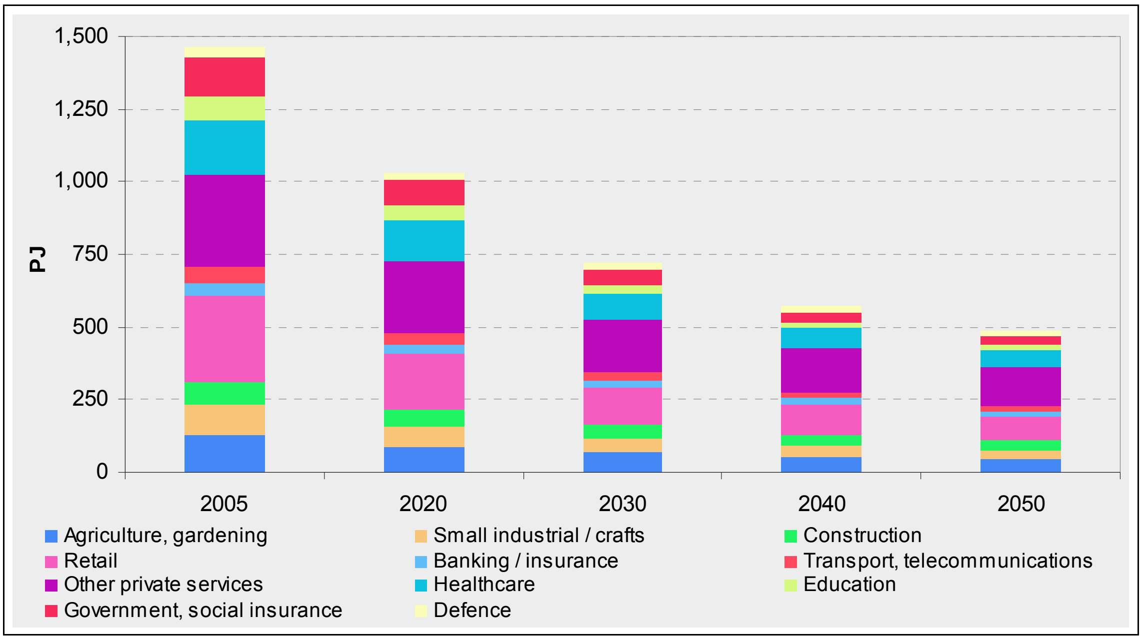
In the “energy-intensive” segments of agriculture and defence (because they involve high mobility), further efficiency improvements in engines and vehicles, as assumed in the transport sector, will be applied with a lesser scope to special vehicles.

In ICT-intensive branches, it is assumed that technology shifts (optoelectronics, further miniaturisation of high-performance technology for data storage and processing, new cooling technologies, etc.) will have an impact. Thus specific energy consumption in the innovation scenario is lowered between 60% and 86% in the period from 2005 to 2050.

5.3.2.2 Final energy consumption

The innovation scenario assumes that final energy consumption in the service sector will decrease by 67% to 486 PJ between 2005 and 2050, and will thus be more than 30% below the energy consumption in the reference scenario. In the breakdown by segment (Table 5.3-17, Figure 5.3-9), it is evident that the efficiency effects far outweigh the growth in value added in every segment. In particular, in the "other private services" segment, whose weight and value added grow by 61%, energy consumption decreases by 60%; in healthcare, which will grow 80%, energy consumption decreases by 69%.

Figure 5.3-9: Innovation scenario: Final energy consumption in service sector by segment, 2005 – 2050, in PJ



Source: Prognos 2009

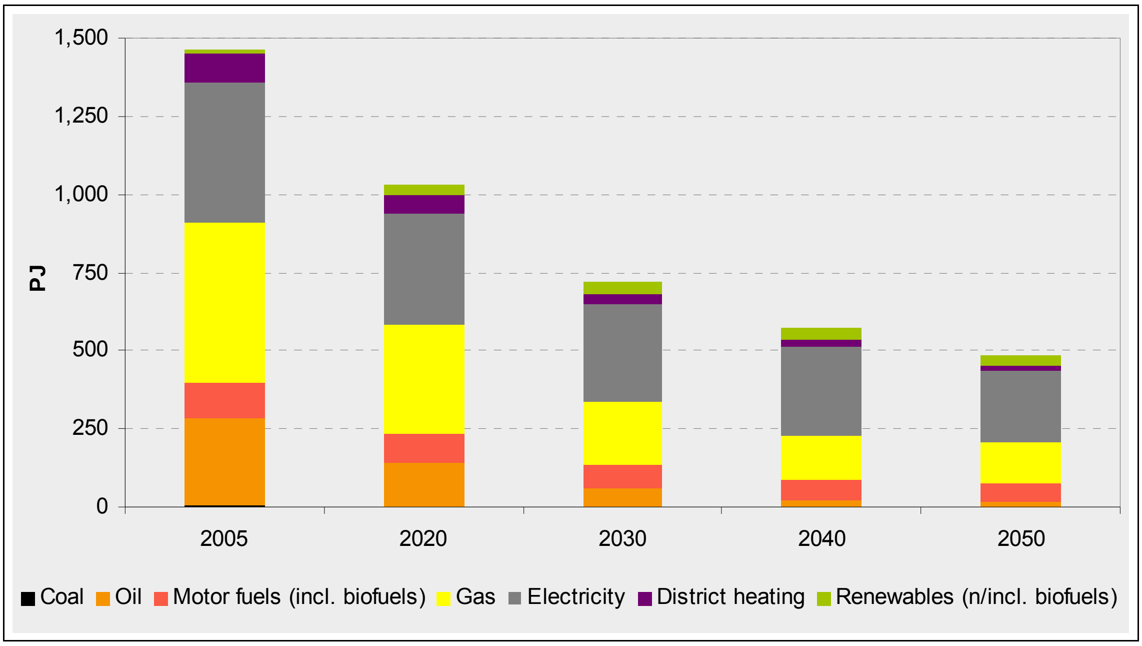
There are sometimes substantial structural shifts among individual energy sources. Electricity's share is projected to increase, representing about 50% of energy consumption in 2050, 17 percentage points more than in 2005. Gas will cover 27% of the demand in 2050, compared to 30% in 2005. The shares provided by district heating and petroleum (heating oil and motor fuels) will decrease by more than half. Coal will vanish almost completely.

Table 5.3-17: Innovation scenario: Final energy consumption in service sector, 1990 – 2050, by segment, type of use and energy source, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Segment					
Agriculture, gardening	127	89	68	55	45
Small industrial / crafts	104	69	51	41	34
Construction	79	56	43	35	31
Retail	298	194	130	104	82
Banking / insurance	45	32	25	21	19
Transport, telecommunications	55	41	27	21	18
Other private services	315	243	181	153	136
Healthcare	189	141	89	66	59
Education	85	54	29	18	14
Government, social insurance	133	86	54	38	29
Defence	32	26	23	21	19
All segments	1,462	1,031	720	574	486
Type of use					
Space heating	664	347	108	18	2
Process heat	310	300	283	265	256
Cooling and ventilation	65	63	79	96	75
Lighting	148	95	64	43	30
Office equipment	56	46	36	26	18
Mechanical force	220	180	151	126	106
All types of use	1,462	1,031	720	574	486
Energy sources					
Coal	5	0	0	0	0
Oil	279	140	57	19	15
Gas	515	350	201	141	130
Electricity	443	354	310	282	229
District heating	96	61	34	22	19
Renewables (without biofuels)	10	32	37	39	32
Fuels (including biofuels)	114	94	82	70	60
Total energy sources	1,462	1,031	720	574	486

Source: Prognos 2009

Figure 5.3-10: *Innovation scenario: Final energy consumption in service sector by energy source, 2005 – 2050, in PJ*



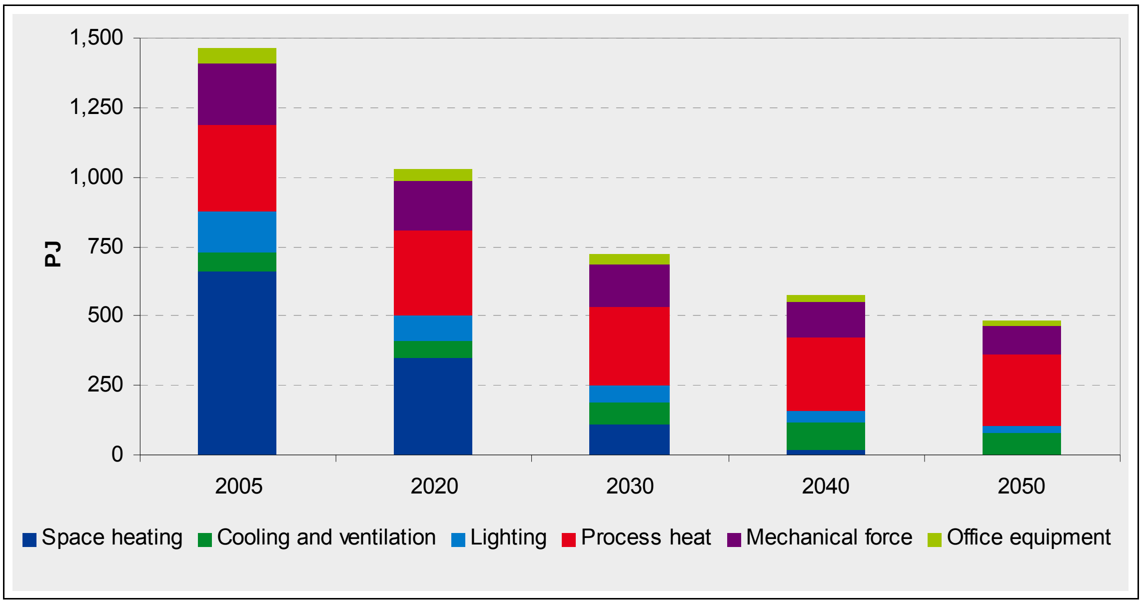
Source: Prognos 2009

5.3.2.3 Final energy consumption by type of use

By 2050, energy consumption for space heating will decrease gradually further against the Reference, to almost zero (Figure 5.3-11).

The specific energy demand of the installations used to generate process heat will decrease an average of between 40% (electricity) and 45% (combustibles) during the period under consideration. The assumed measures taken to enhance energy efficiency are the same as in the reference scenario. But faster implementation and a full utilisation of potential are assumed. Additionally, there are slight process shifts, such as sterilization with ultraviolet light instead of steam in the healthcare sector, analogous processes for laundries (waterless washing, thus eliminating drying processes), different processes in surface treatment, such as drying with solvents in a closed-loop process instead of air drying, and hardening and tempering processes that apply infrared lasers to the material rather than a hot bath, etc.

Figure 5.3-11: Innovation scenario: Final energy consumption in service sector by type of use, 2005 – 2050, in PJ



Source: Prognos 2009

The energy consumption for cooling and ventilation uses will rise more than 16% between 2005 and 2050. In contrast to the reference scenario, a greater use of energy-efficient air conditioning and ventilation systems is assumed, with a replacement of existing systems or their adaptation to new needs and standards. The decreased need for cooling in new IT technology will also contribute to the savings. Rising amounts of equipment and heavier utilisation ratios will result in higher energy demand, which will be partially offset by the efficiency measures mentioned above. This will limit the increase to about 75 PJ.

In the innovation scenario, energy consumption for lighting decreases 80% between 2005 and 2050, and in 2050 represents only 6% of total final energy consumption. This represents half the demand in the reference scenario.

There are also significant opportunities to reduce specific consumption by office equipment. Even in the reference scenario, specific consumption was reduced by as much as 60%. In the innovation scenario, consumption is reduced 77%, through full market penetration and especially through alternatives to video screens. By 2050, final energy consumption for this type of use will be reduced to one-third of its earlier value.

Specific consumption for providing force will decrease, depending on the energy source, between 40% (combustibles) and 50% (electricity). By 2050, final energy demand for this use will decrease by half. This represents an additional decrease of 10% compared to the reference scenario.

5.3.3 Energy consumption by the industry sector

5.3.3.1 Framework data

In addition to the structural change assumed in the reference scenario, the innovation scenario includes further changes driven by innovations in efficiency. For example, changes in construction and in upgrade work, the production of new materials, and changes in processes all affect segment structure. The result is slight shifts compared to the structure in the reference scenario.

Production in the “other chemicals” industry and the glass and ceramic segments rises compared to the reference scenario because of higher demand for insulators, high-performance glasses, plastics and new materials, which are assigned here partly to the chemical industry and partly to the plastic and ceramic industry. Here it must be borne in mind, however, that these industry segments’ product ranges are generally very broad, so that changes there (for example, more production of insulation materials) will cause these segments to grow between 10% and 20% more than in the reference scenario (Table 5.3-18).

Contrarily, demand will decline for metals as a structural materials and raw production materials, as well as for infrastructure applications (partial replacement of copper by special materials in electric wiring, but especially, to begin with, in structural parts and in dispersion applications). This will reduce metal production in particular. Automotive and machine construction will use different raw materials, and in some cases will build different products (e.g., electric cars). The assumption is that production levels will remain similar to those in the reference scenario.

Consequently production in the energy-intensive segments will decline. All in all, production in stone quarrying, other mining, non-ferrous metals/foundries, basic chemicals, glass, ceramics, the paper industry, stone and soil processing, and metal production is projected to decrease by a total of 24% between 2005 and 2050 (Figure 5.3-12, Figure 5.3-13).

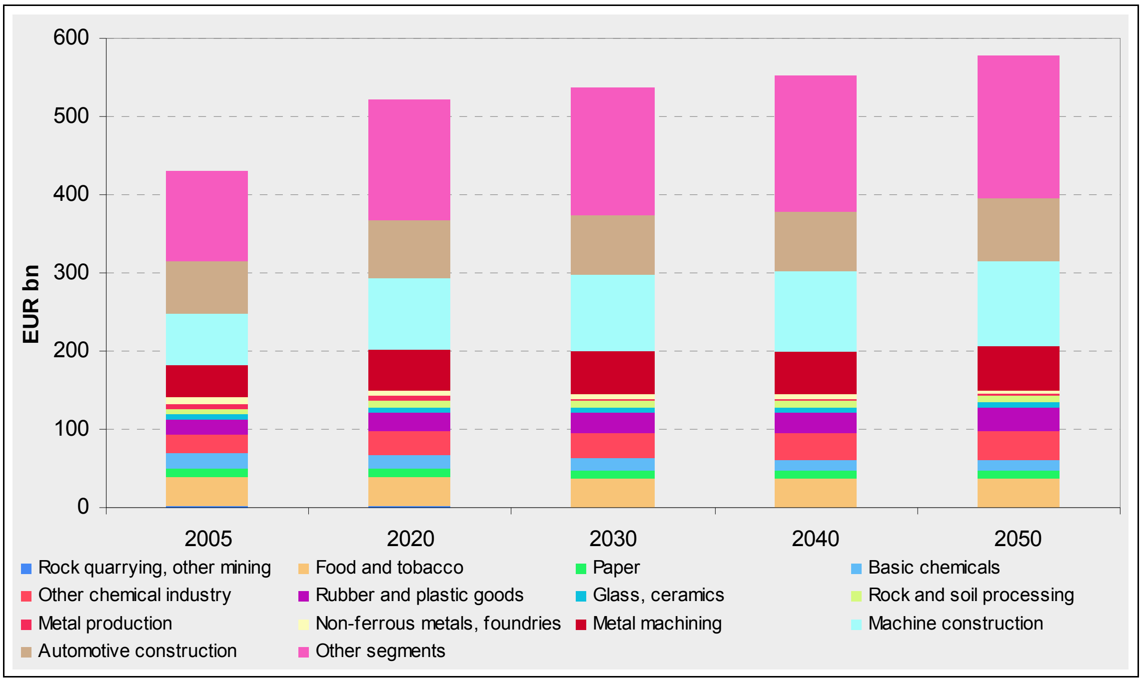
Non-energy-intensive segments, however, will grow significantly more – by 44% between 2005 and 2050. In total, industrial production will grow 34% by 2050. This is 0.7% less in 2050 than for the reference scenario.

Table 5.3-18: Innovation scenario: Industrial production 2005 – 2050 (categories from energy balance sheet), EUR bn, in 2000 prices

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	1.9	1.2	1.0	0.9	0.8
Food and tobacco	37.3	37.0	36.4	35.9	37.2
Paper	10.4	11.1	10.7	10.6	10.9
Basic chemicals	20.7	17.6	14.9	13.0	12.0
Other chemical industry	23.0	30.7	32.7	34.6	37.4
Rubber and plastic goods	20.6	25.0	26.0	27.1	28.9
Glass, ceramics	5.2	6.6	6.4	6.4	6.7
Rock and soil processing	8.0	8.2	8.2	8.4	8.9
Metal production	6.0	5.2	3.8	2.8	2.2
Non-ferrous metals, foundries	8.3	7.5	6.4	5.4	4.5
Metal machining	41.3	51.6	53.4	55.1	57.9
Machine construction	64.0	91.9	98.0	102.4	108.8
Automotive construction	68.0	74.4	75.0	76.3	78.8
Other segments	115.5	152.9	163.7	172.4	183.5
Total industrial production	430.3	521.1	536.6	551.2	578.4

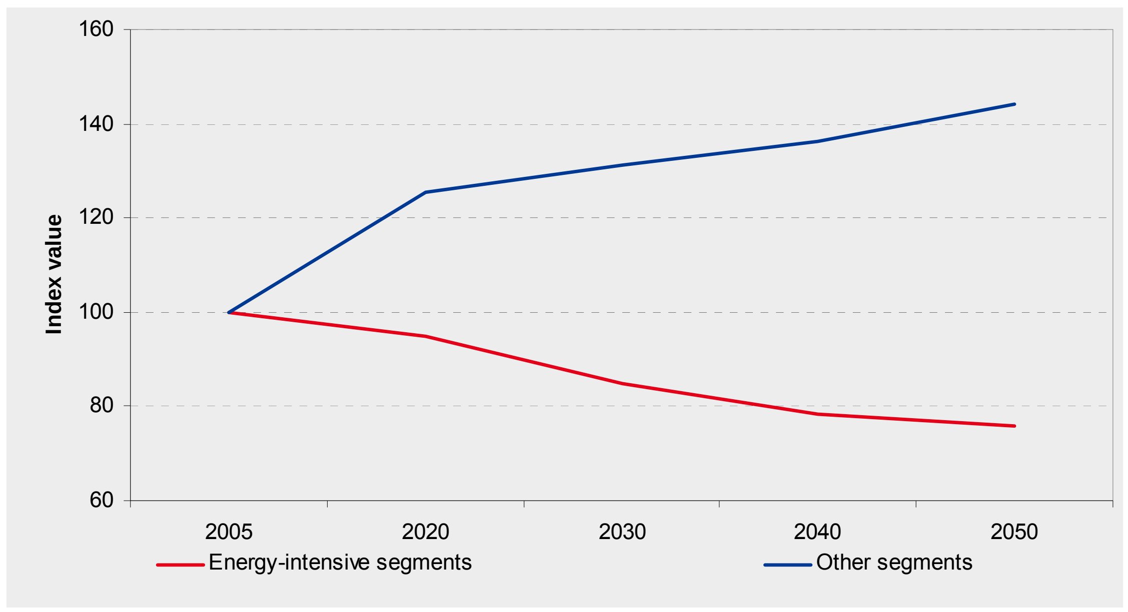
Source: Prognos 2009

Figure 5.3-12: Innovation scenario: Industrial production 2005 – 2050 (categories from energy balance sheet), EUR bn, in 2000 prices



Source: Prognos 2009

Figure 5.3-13: Innovation scenario: Development of industrial production, by energy-intensive and non-energy-intensive segments (categories from energy balance sheet), 2005 – 2050, indexed (EUR bn, in 2000 prices)



Source: Prognos 2009

The sector's fundamental structure, however, will change little because of its great diversity. As in the reference scenario, the greatest contributions in the innovation scenario will come from machine construction, automotive construction, metalworking, other chemicals, and the food and tobacco industry.

A further decrease in energy intensity in the various industry segments can be expected during the period under consideration. As in the service sector, this results in a greater reduction of specific energy consumption than in the reference scenario. Potential for efficiency is realised faster and fully. The assumed fundamental shifts, and in some cases substitutions, in processes and products will lead to a greater reduction of energy intensity in the innovation scenario than in the reference scenario. Examples here include catalytic and biological processes in chemistry that reduce the need for process heat; drying processes with closed solvent loops; hardening processes using infrared lasers; cleaning processes using ultraviolet light, etc.

The specific energy consumption decreases an additional 30 to 40%, depending on the segment, compared to the reference scenario. In metal production and in non-ferrous metals and foundries, the additional efficiency gains will remain limited. Specific consumption is between 10% (metal production) and 18% (non-ferrous metals, foundries) less than in the reference scenario. There are two reasons for this. First, the value of products and materials will increase because of their specific, customised characteristics. Second, process changes (especially miniaturisation, integration and intense spatial concentration of energy application to the workpiece) will enable further reductions in specific consumption that would not have been possible in conventional processes, for physical reasons.

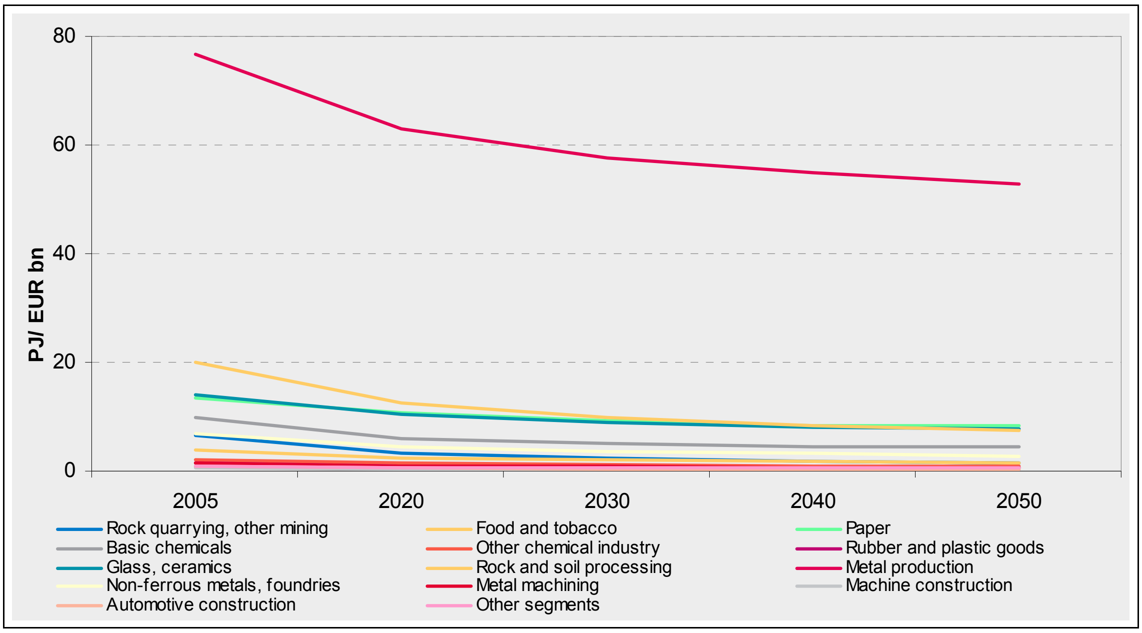
The specific fuel consumption levels in the innovation scenario are essentially similar to the reference scenario, but consistently decrease more with the above specifications (Table 5.3-19, Figure 5.3-14, Figure 5.3-15, Figure 5.3-16).

Table 5.3-19: Innovation scenario: Specific fuel consumption for industry by segment, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	6.6	3.2	2.3	1.7	1.4
Food and tobacco	3.8	2.5	2.0	1.7	1.6
Paper	13.6	10.6	9.2	8.5	8.3
Basic chemicals	9.7	6.0	5.0	4.5	4.4
Other chemical industry	2.2	1.5	1.2	1.0	1.0
Rubber and plastic goods	1.5	0.9	0.7	0.6	0.6
Glass, ceramics	14.1	10.4	8.8	8.0	7.7
Rock and soil processing	19.9	12.6	9.8	8.3	7.6
Metal production	76.7	63.1	57.7	55.0	52.9
Non-ferrous metals, foundries	7.0	4.6	3.7	3.2	2.8
Metal machining	1.4	1.0	0.8	0.7	0.7
Machine construction	0.7	0.4	0.3	0.3	0.3
Automotive construction	0.8	0.5	0.4	0.4	0.3
Other segments	1.0	0.6	0.5	0.5	0.5
Total fuel consumption	3.7	2.2	1.6	1.3	1.2

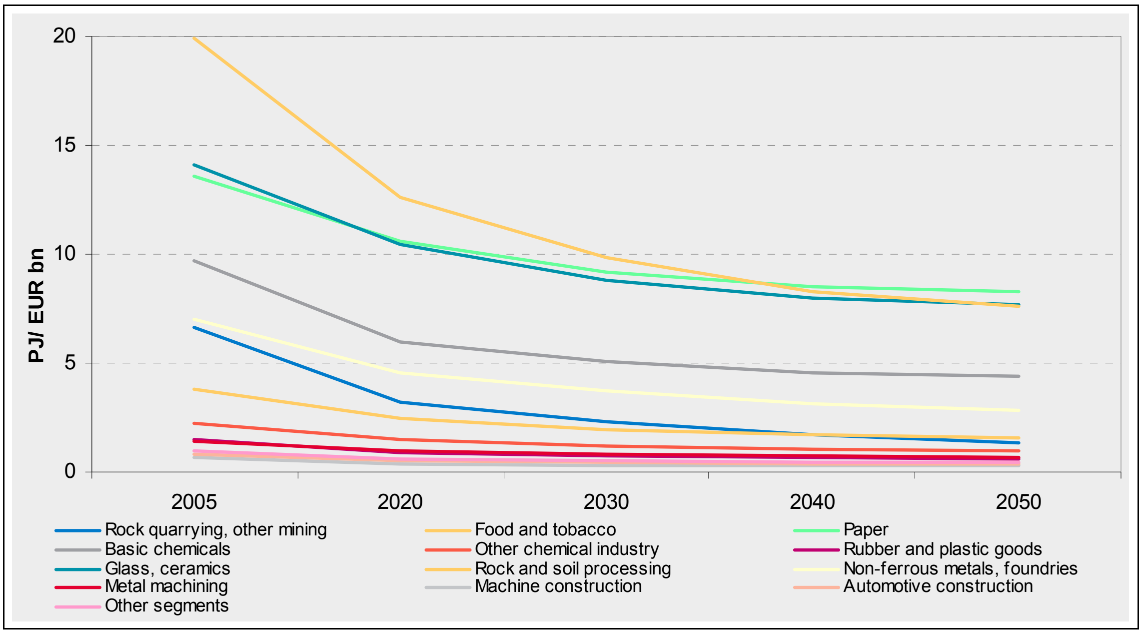
Source: Prognos 2009

Figure 5.3-14: Innovation scenario: Specific fuel consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn



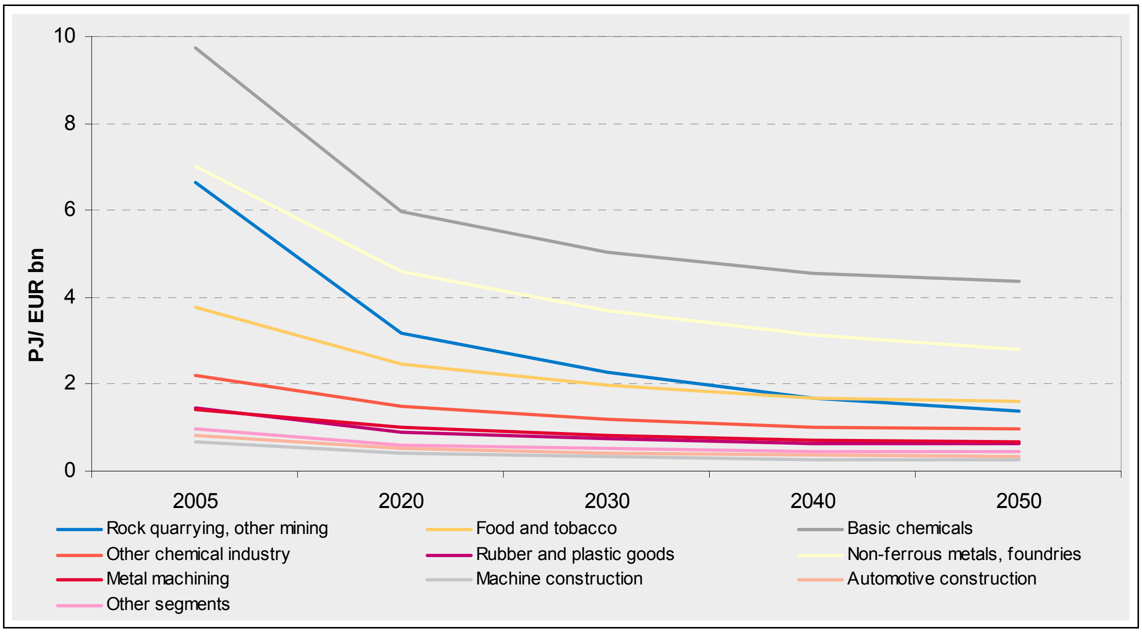
Source: Prognos 2009

Figure 5.3-15: Innovation scenario: Specific fuel consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn, excluding metal production



Source: Prognos 2009

Figure 5.3-16: Innovation scenario: Specific fuel consumption for industry (categories from energy balance sheet), 2005 – 2050, in PJ/EUR bn, non energy-intensive segments



Source: Prognos 2009

In specific power consumption, the additional potential for savings over the cross-application technologies already systematically applied in the reference scenario is limited. Contributions will come from miniaturisation and from the next and subsequent generation of light sources, IT technologies, refrigeration technologies, etc. Generally, process innovations will result in additional replacements of formerly fuel-fired processes with electricity-based technologies (e.g. hardening processes that use infrared lasers). In addition to the developments in the reference scenario, specific power consumption will decrease within a range from 24 to 33%, depending on the segment.

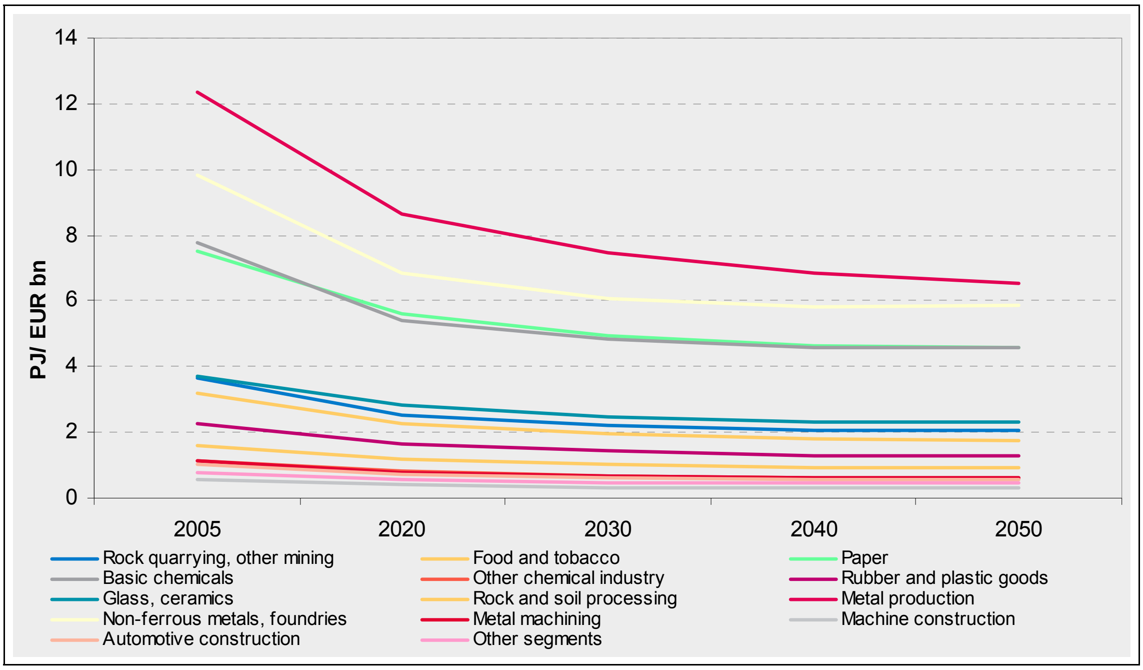
The segments with the highest specific power consumptions are metal production (electric furnace steel), non-ferrous metals/foundries, and the paper industry; stone and soil quarrying has a medium specific power consumption. All other segments (including metalworking, machine construction and automotive construction) are significantly lower by comparison (Table 5.3-20, Figure 4.3-16).

Table 5.3-20: Innovation scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	3.7	2.5	2.2	2.0	2.0
Food and tobacco	1.6	1.2	1.0	0.9	0.9
Paper	7.5	5.6	4.9	4.6	4.6
Basic chemicals	7.8	5.4	4.8	4.6	4.6
Other chemical industry	1.2	0.8	0.7	0.6	0.6
Rubber and plastic goods	2.2	1.7	1.4	1.3	1.3
Glass, ceramics	3.7	2.8	2.5	2.3	2.3
Rock and soil processing	3.2	2.3	1.9	1.8	1.8
Metal production	12.4	8.7	7.4	6.8	6.5
Non-ferrous metals, foundries	9.8	6.9	6.1	5.8	5.9
Metal machining	1.1	0.8	0.7	0.6	0.6
Machine construction	0.6	0.4	0.3	0.3	0.3
Automotive construction	1.0	0.7	0.6	0.6	0.5
Other segments	0.8	0.6	0.5	0.4	0.4
Total specific electricity consumption	1.9	1.2	1.0	0.8	0.8

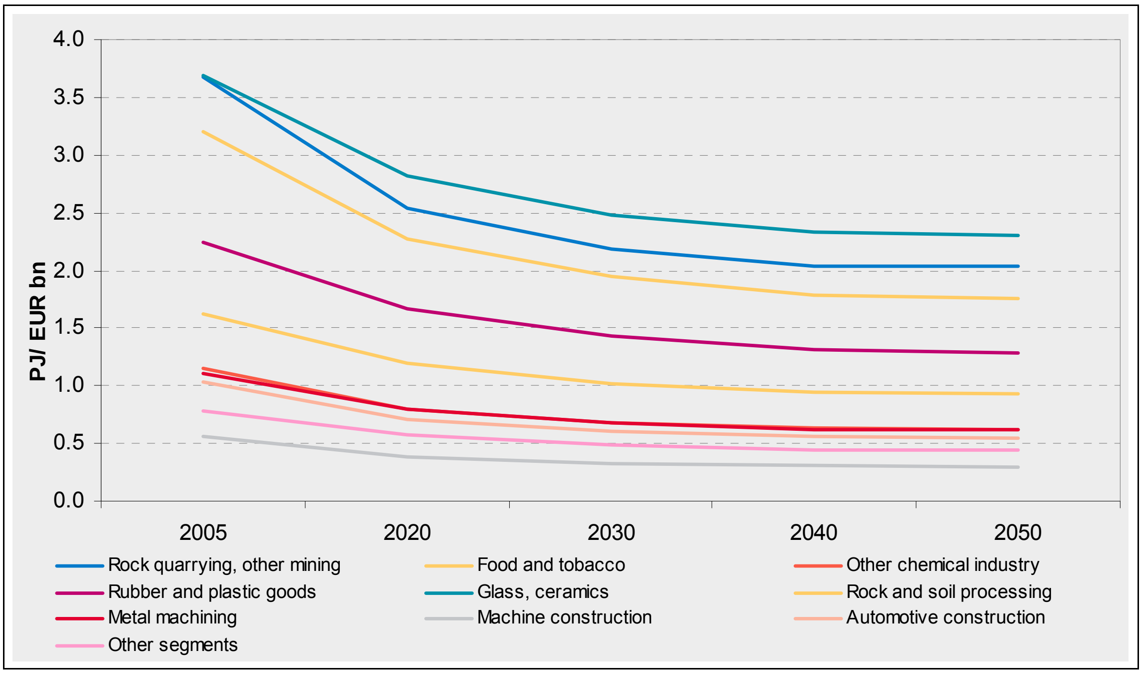
Source: Prognos 2009

Figure 5.3-17: Innovation scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn



Source: Prognos 2009

Figure 5.3-18: Innovation scenario: Specific power consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn, excluding electricity-intensive segments



Source: Prognos 2009

All in all, the specific energy consumption by industry in the innovation scenario will decline 65% by 2050 (Table 5.3-21).

Table 5.3-21: Innovation scenario: Specific energy consumption for industry, 2005 – 2050 (categories from energy balance sheet), in PJ/EUR bn

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	10.3	5.7	4.5	3.7	3.4
Food and tobacco	5.4	3.7	3.0	2.6	2.5
Paper	21.1	16.2	14.1	13.1	12.9
Basic chemicals	17.5	11.4	9.9	9.1	9.0
Other chemical industry	3.4	2.3	1.9	1.7	1.6
Rubber and plastic goods	3.7	2.6	2.2	2.0	1.9
Glass, ceramics	17.8	13.3	11.3	10.3	10.0
Rock and soil processing	23.1	14.9	11.8	10.0	9.4
Metal production	89.0	71.7	65.2	61.8	59.4
Non-ferrous metals, foundries	16.8	11.4	9.8	8.9	8.7
Metal machining	2.5	1.8	1.5	1.3	1.3
Machine construction	1.2	0.8	0.7	0.6	0.6
Automotive construction	1.9	1.2	1.0	0.9	0.9
Other segments	1.8	1.2	1.0	0.9	0.9
Total energy consumption	5.6	3.4	2.6	2.2	2.0

Source: Prognos 2009

5.3.3.2 Final energy consumption

In the innovation scenario, final energy consumption in the industry sector will decrease 53% between 2005 and 2050, to 1,149 PJ. This represents an additional decrease of 40% by the final year, compared to the reference scenario. In stone and soil quarrying, other mining, metal production and non-ferrous metals and foundries, the reduction in production significantly affects energy consumption. Consumption decreases by as much as 83% against 2005. The decrease came to as much as 74% under the reference scenario.

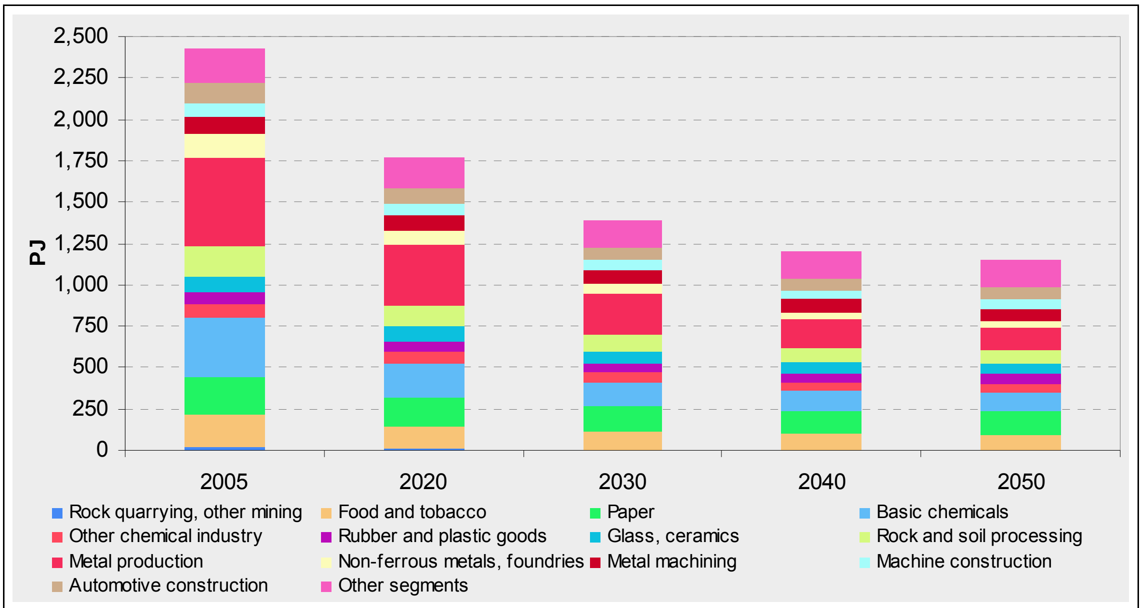
Unlike the reference scenario, energy consumption in most segments decreases because the reduction of specific consumption in each is greater than the expansion of production (Table 5.3-22, Figure 5.3-19).

Table 5.3-22: Innovation scenario: Energy consumption for industry, 2005 – 2050, by segment (categories from energy balance sheet), in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	19	7	4	3	3
Food and tobacco	201	136	109	95	94
Paper	220	181	151	140	141
Basic chemicals	362	201	147	119	108
Other chemical industry	77	71	61	57	59
Rubber and plastic goods	77	65	56	53	55
Glass, ceramics	92	87	73	66	67
Rock and soil processing	185	122	97	84	83
Metal production	537	373	245	173	130
Non-ferrous metals, foundries	140	86	63	48	39
Metal machining	104	93	79	73	75
Machine construction	79	74	64	59	61
Automotive construction	127	93	77	70	71
Other segments	203	182	164	158	165
Total energy consumption	2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

Figure 5.3-19: Innovation scenario: Final energy consumption for industry, by segment, 2005 – 2050, in PJ



Source: Prognos 2009

There are structural shifts between the individual energy sources (Table 5.3-23, Figure 5.3-20). The reduction in the use of coal and petroleum for process heat, thanks to efficiency measures and replacements in processes and energy sources, is assumed as a strategy and results in a substantial decrease in the use of these energy sources. Hard coal will decrease 84% between 2005 and 2050, lignite 61%, and petroleum products 79%.

Table 5.3-23: Innovation scenario: Final energy consumption for industry, by energy source, 2005 – 2050, in PJ

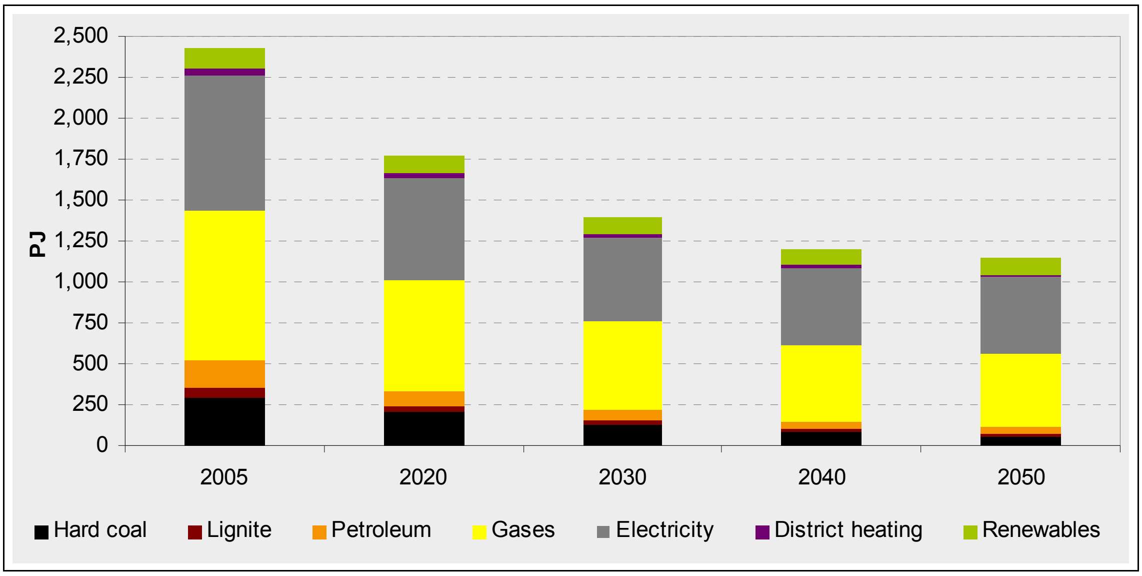
			Innovation scenario			
		2005	**2020**	**2030**	**2040**	**2050**
Hard coal		296	206	130	83	55
Lignite		59	38	29	24	22
Petroleum		162	93	61	43	35
of which:	Heating oil, light	77	44	31	23	20
	Heating oil, heavy	67	39	24	16	11
	Other petroleum products	19	10	7	5	4
Gases		921	677	536	467	451
of which:	Natural gases	800	597	484	429	422
	LPG, refinery gas	11	9	6	4	3
	Coke oven gas	33	21	14	10	8
	Furnace gas	77	49	33	24	18
Renewables		118	103	96	97	104
Electricity		823	623	517	467	466
District heating		45	28	21	17	16
Total final energy consumption		2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

The “replacement winners” are the gases, which lose “only” about 50%, but increase their share of the mix.

The share of electricity likewise increases; in 2050 it will cover more than 40% of energy demand, while absolute consumption decreases by 46%. Thus electricity and gases will become the most important energy sources for industry, together covering approx. 80% of energy demand. Renewable energy sources will continue to gain in importance. In 2050 they will cover 9% of energy demand. This will primarily be ambient and solar heat, used for preheating, hot water heating, air conditioning, and in cascade processes. Because demand for space heating will almost vanish, and because of the low energy density of renewable energy sources, these sources can offer only limited contributions to the industrial sector in our latitudes. Biomass will be used strategically in motor fuel production for freight transport, so that it will not be available to the industry sector (though otherwise this would be possible in principle, given different strategic base decisions).

Figure 5.3-20: Innovation scenario: Final energy consumption for industry, by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

5.3.3.3 Final energy consumption by type of use

During the period under study, the shares of total consumption attributed to different types of use hardly change (Table 5.3-24, Figure 5.3-21). Process heat continues to dominate; its share rises slightly, from 66% to 70% in 2050. Mechanical energy's share of total consumption likewise increases 4 percentage points, to 25%. Process heat and mechanical energy together account for about 95% of total consumption in 2050.

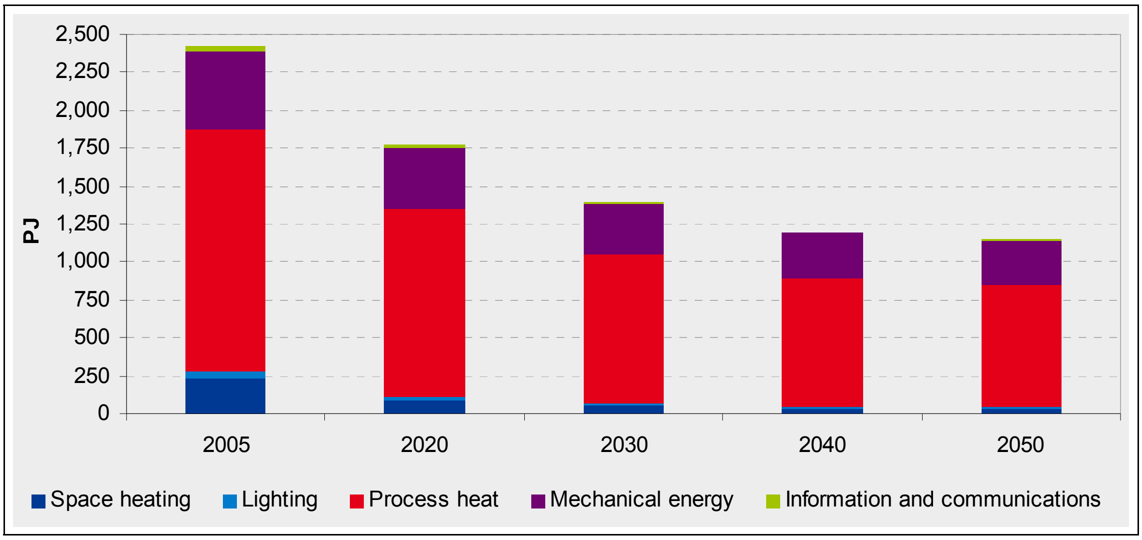
Table 5.3-24: Innovation scenario: Final energy consumption for industry, by type of use, 2005 – 2050, in PJ

		Innovation scenario			
	2005	2020	2030	2040	2050
Space heating	240	89	53	38	35
Process heat	1,597	1,239	983	844	801
Mechanical energy	516	403	329	295	293
Information and communications	33	18	12	10	10
Lighting	39	20	14	11	11
Total final energy consumption	2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

The change in the specific consumption for space heating is in line with developments in the service sector. Specific consumption will drop about 80% by 2050. This means that by that date, energy consumption would decrease to 35 PJ. In the reference scenario, the figure is still 138 PJ. An even further reduction in demand due to space heating would be possible in principle by way of further building insulation, but it would make little economic sense because generally industry generates low-temperature waste heat that can be used for space heating.

Figure 5.3-21: Innovation scenario: Final energy consumption for industry, by type of use, 2005 – 2050, in PJ



Source: Prognos 2009

The specific energy demand of the installations used to generate process heat will decrease an average of about 45% during the period under study. One exception is the metal production segment, where specific consumption for steel production will decrease only 20% by 2050.

The specific energy demand to provide mechanical force will decrease by as much as 50%. Here essentially the same measures as described in the reference scenario will be applied, and will be supported primarily by miniaturisation and process integration. Energy consumption will decrease 43% by 2050.

Heavier use of energy-efficient lighting systems will result in a substantial reduction in power consumption. In 2050, less than 1% of total energy consumption will be needed for this type of use. The figure in the reference scenario is 1.6%. Information and communication shows a similar development.

5.3.4 Energy consumption by the transport sector

5.3.4.1 Underlying assumptions about development in transport

In the innovation scenario, essentially three strategic requirements are tested out and implemented:

Transport volumes are examined as to whether and how they can be made more effective or reduced, while covering the same or similar degree of demand. This particularly applies to the base conditions for the organisation of merchandise streams and regional planning. No fundamental structural changes are assumed, for example in regard to consumption of leisure transport.

There is a significant modal shift to rail at every opportunity that transport studies support. The scenario shows how much such an option has to offer in terms of savings.

In terms of technology and energy sources, it is assumed that electric mobility will be systematically developed in a focused way for passenger transport, via the intermediate phases of hybrid and plug-in hybrid vehicles, and will replace all-combustion engines over time. The efficiency of drive technologies will be systematically optimised in this way. The development of natural-gas drives will advance likewise, and gas-fuelled vehicles will be introduced on the market with high intensity. Fuel cell drives will also be developed further. Because of the strategic orientation towards electric drives, this type of drive will remain a niche, as in the reference scenario, because we do not assume the establishment of a hydrogen infrastructure.

The employed liquid motor fuels will be systematically replaced with biofuels by 2050. This is particularly the case in freight transport, where there is currently believed to be no alternative to liquid fuels because of their energy density. Such a development will require a strategic setting of priorities in applying biomass for motor fuels as described in Sec. 2.5.2. This will be possible with the scope shown in this scenario only if the sustainability requirements described in Sec. 2.5.2 are met.

5.3.4.1.1 Passenger transport

Mobility, measured in kilometres per person per year, has steadily increased over the past years. There is no indication that this trend will reverse significantly. This is because travel times will remain constant, but technologically available speeds will continue to rise, so that greater distances can be covered in the same amount of time.

In the reference scenario, passenger mobility increases by 1,270 km between 2005 and 2030, and by another nearly 900 km by 2050. In the innovation scenario, mobility increases only 400 km over the same period to 2030, and then declines slightly by 65 km by 2050. This represents a break in the trend. Any greater reduction in passenger mobility does not seem imaginable from today’s perspective. The break in the trend is achieved by replacing longer trips with shorter ones, and by increased numbers of trips by slow transport.

The modal split also shows heavy dependence on passenger cars in the Innovation scenario. Although there is a greater adaptation of regional structures to price developments than in the Reference scenario (in part also due to energy policy), and longer trips are more extensively replaced with shorter ones, the share of passenger cars decreases only insignificantly. This highlights the immense dependence of the modal split on demographically induced shifts in travel purposes (leisure and shopping trips) and vehicles per capita.

5.3.4.1.2 Freight transport

The orientation of the determining factors for freight transport in the innovation scenario (modal split and transport distances) varies in the configurations from the reference scenario. It is configured in a way that aims in the direction of an ambitious CO_2 reduction. Two drivers will be controlling factors: first, a shift from road to rail (and sometimes to inland waterways), depending on the goods to be shipped and the available connections, and second, a reduction in mean transport distances compared to the reference scenario. The reduction in transport distances might be triggered, for example, by efficiency enhancements induced by energy prices, and a tendency towards moving more shipments over smaller average distances.

This will be countered by system-induced detours over less close-meshed rail and waterway networks, and more feeder trips (both to and from) on the road. The shift to rail and inland waterway boats as the most heavily used modes of long-haul transport will mean longer trips overall, so that freight transport volume rises in the innovation scenario. The shift in the modal split will be more than offset by transport distances specific to various modes of transport.

Heavy goods vehicles have an advantage in short-haul trips and last-mile delivery, and in local supply deliveries to the manufacturing sector. In the innovation scenario, the share of transportation by heavy goods vehicle is reduced by:

- Lower demand for fossil energy sources, which therefore do not need as extensive a local distribution network (filling stations, heating oil);
- A greater shift of parcel freight to combined transport, so that heavy goods vehicles no longer cover the entire distance from source to destination, and instead primarily perform feeder trips to and from transshipment terminals;
- An adaptation of logistics and transport processes in last-mile delivery for purposes of supplying and taking back food and consumer goods to and from retailers;
- A partial shift of road transport to rail, by optimising transit connections (but this is not always to the point, since rail capacity may be lacking, and moreover many transit shipments create value added and jobs by way of logistics services).

5.3.4.2 Development of framework data for the transport sector

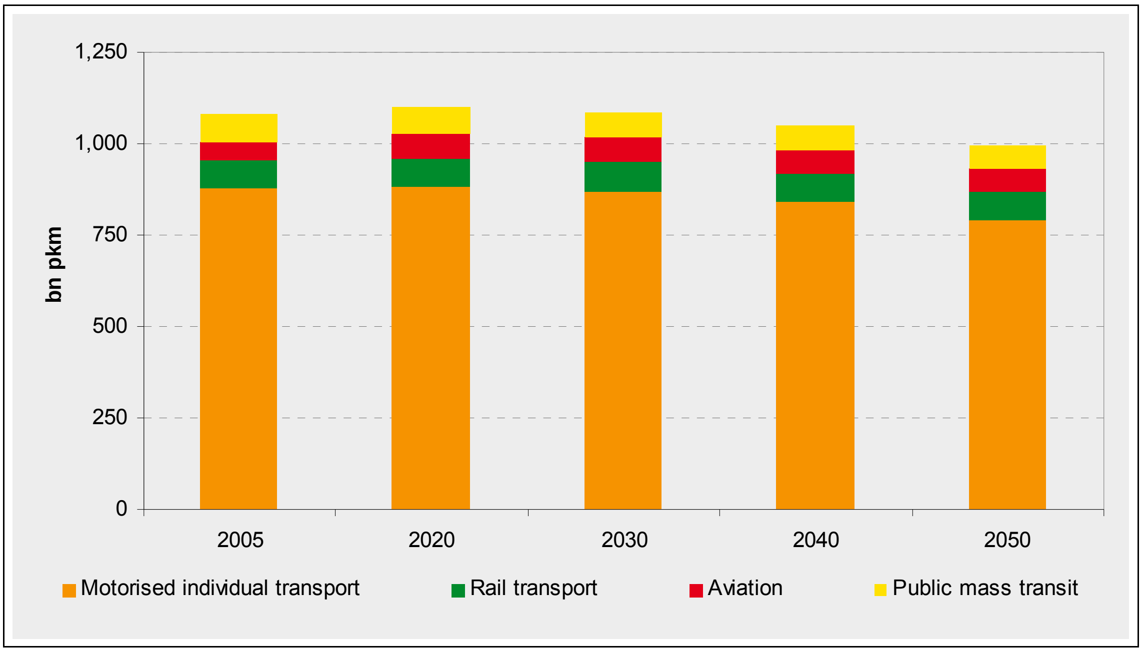
Based on the underlying socio-economic changes and the assumptions described above, the innovation scenario includes the following changes in **passenger transport.** Transport volume, as measured in passenger kilometres, will stagnate to 2020, then begin to decrease slightly, and decrease more sharply after 2030. Passenger transport volume will decrease 8% during the period under study (Table 5.3-25). The various modes of transport develop differently. Transport volume will decrease in passenger cars (–9%), rail transport (–1%), and public mass transit (–16%). But aviation will increase 19%. The shares that the various modes of transport hold in passenger transport volume will shift only slightly. The shares of aviation and rail transport will increase slightly, while the shares of passenger cars and public mass transit will decrease slightly. Passenger cars will remain the dominant form, with slightly less than 80%.

Table 5.3-25: Innovation scenario: Passenger transport volume, 2005 – 2050, in billion passenger kilometres

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Motorised individual transport	**876**	**880**	**867**	**839**	**793**
Passenger cars	857	862	851	824	781
Two-wheeled	19	18	16	14	13
Rail transport	**77**	**81**	**81**	**79**	**76**
Local transport by rail	43	44	44	43	41
Long-distance transport by rail	34	36	37	36	35
Public mass transit	**79**	**74**	**70**	**68**	**66**
Trams, urban rapid railways, underground	15	16	15	15	14
Buses	63	58	55	53	51
Aviation	**53**	**67**	**68**	**66**	**63**
Total passenger transport volume	**1,084**	**1,101**	**1,087**	**1,052**	**998**
Share in %					
Motorised individual transport	80.8	79.9	79.8	79.7	79.5
Rail transport	7.1	7.3	7.5	7.5	7.6
Public mass transit	7.2	6.7	6.5	6.5	6.6
Aviation	4.9	6.1	6.2	6.3	6.3

Source: ProgTrans / Prognos

Figure 5.3-22: Innovation scenario: Passenger transport volume, by mode of transport, 2005 – 2050, in billion passenger kilometres



Source: ProgTrans /Prognos 2009

According to the innovation scenario, **freight transport volume**, measured in ton-kilometres, will increase 86% in the period under study (Table 5.3-26). Thus freight transport volume increases slightly more in the innovation scenario than in the reference scenario, due to system-induced detours (rail, inland navigation).

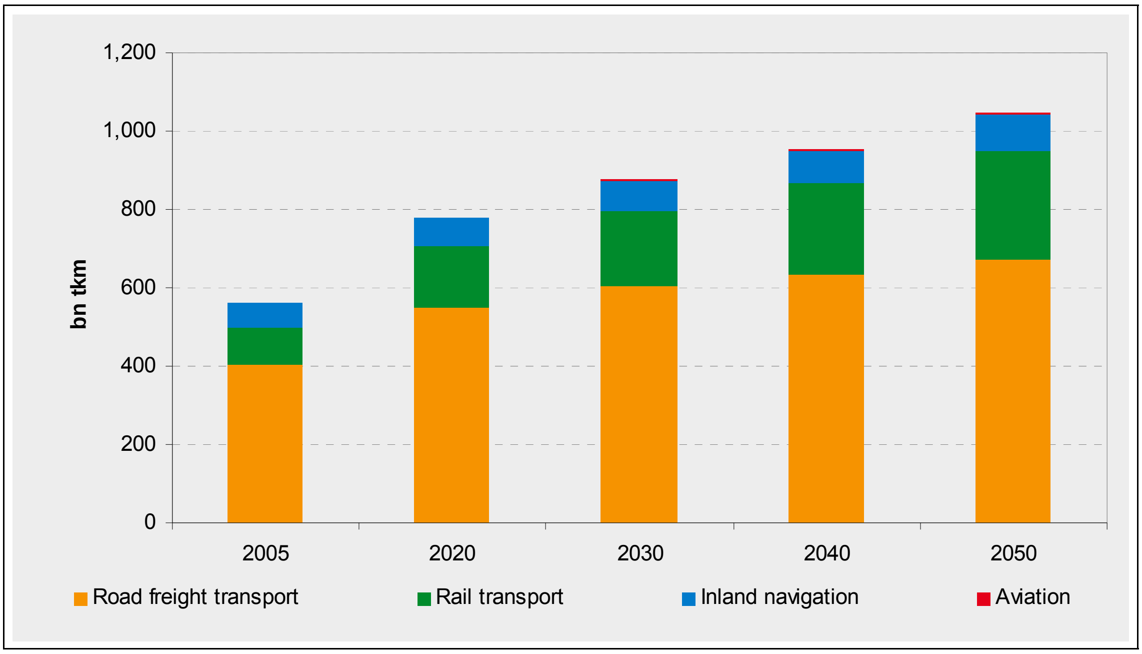
The volume of freight transport by rail will nearly triple; rail's share of the mix will increase by nearly 10 percentage points. Inland navigation, increasing 48%, will grow substantially more than in the reference scenario. Nevertheless, freight transport by road (67% growth) will retain its dominance of transport during the period. Despite vigorous growth (tripling) air will on the whole remain of minor significance for freight transport.

Table 5.3-26: Innovation scenario: Freight transport volume, 2005 – 2050, in billion (metric) ton-kilometres

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Freight transport by road	**403**	**550**	**604**	**635**	**671**
German heavy goods vehicles/road tractors	272	355	387	409	434
Long-distance transport	196	275	307	328	353
Local/regional transport	75	80	80	80	81
Foreign heavy goods vehicles/road tractors	131	195	217	226	237
Rail transport	**95**	**156**	**192**	**232**	**278**
Inland navigation	**64**	**71**	**78**	**85**	**95**
Aviation	**1**	**2**	**2**	**3**	**3**
Total freight transport volume	**563**	**779**	**876**	**953**	**1,047**
Share in %					
Road transport	71.5	70.6	69.0	66.6	64.1
Rail transport	16.9	20.1	21.9	24.3	26.5
Inland navigation	11.4	9.1	8.9	8.9	9.1
Aviation	0.2	0.2	0.2	0.3	0.3

Source: ProgTrans /Prognos 2009

Figure 5.3-23: Innovation scenario: Freight transport volume, by mode of transport, 2005 – 2050, in billion (metric) ton-kilometres



Source: ProgTrans / Prognos 2009

5.3.4.3 Final energy consumption of road transport

In **passenger transport,** the declining transport volumes, the significant change in the fleet of vehicles, and the substantial decrease in specific energy consumption for various types of drives have an even bigger effect than in the reference scenario ; the reduction in energy consumption totals 67%.

Vehicles with pure gasoline-engine drives will increasingly be replaced by hybrid and diesel vehicles, and no new ones will be permitted as of 2030 or 2035 at the latest. They will vanish from the fleet of vehicles by 2050 (Table 5.3-27). Hybrid vehicles will be systematically developed and introduced into the fleet. While they will number only 47,000 in 2010, by 2015 there will be nearly 500,000 on the road, and 4.1 million in 2020. By 2028 the numbers will reach a maximum, at nearly 20 million, and then recede slowly because at that point the next wave in the vehicle revolution will begin having an impact on the market: plug-in hybrids will number more than a million by 2026, nearly two million in 2035, and finally 12.6 million in 2050. All-electric vehicles will enter the fleet after a slight time lag, reaching a million in 2028, five million in 2039, and more than 8.1 million by 2050. Diesel vehicles, numbering 16.2 million, will at first continue the “diesel trend” that has been evident for years until 2018. After that their numbers will begin decreasing, and diesel drives will lose market share massively to all other forms. Fuel-cell vehicles will be developed to the large-scale pilot phase, and will number about 1 million vehicles by 2050.

In 2050 nearly two-thirds of all vehicles will be hybrids, and one-fifth will be all-electric-powered. Hybrid and electric vehicles will offer considerable efficiency advantages over all-gasoline or all-diesel passenger cars at the level of specific final energy consumption. Fifteen percent of vehicles will be gas-fuelled (Table 5.3-27).

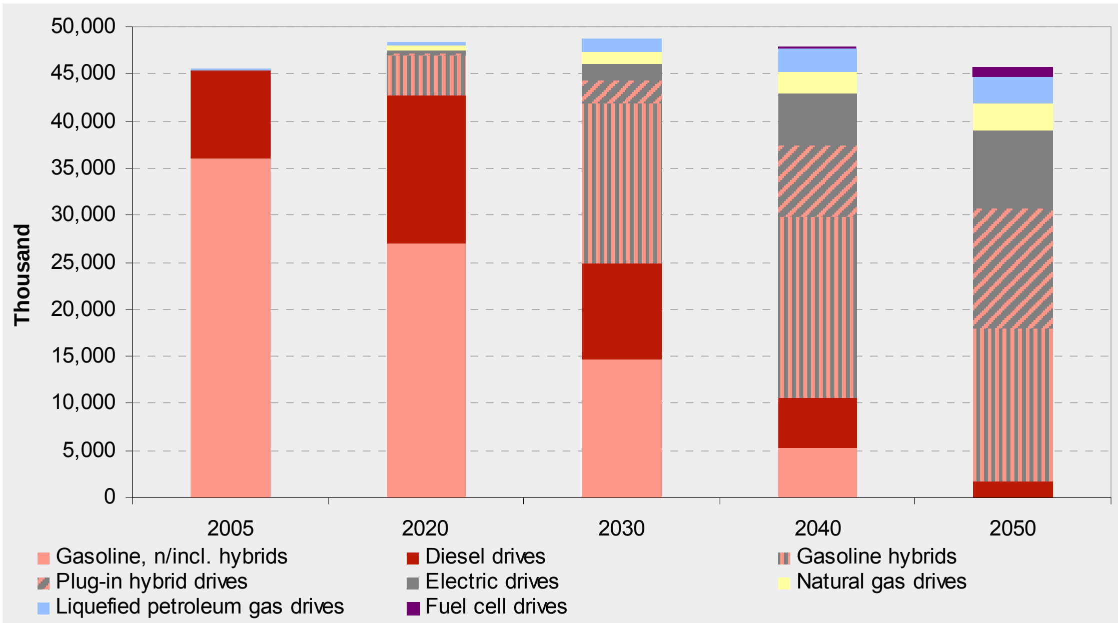
Specific consumption by vehicles will decrease significantly further compared to the reference scenario. In gasoline and gas-fuelled vehicles, specific consumption by the entire fleet will decrease an average of nearly 50% (up to 60% for new cars by 2050). It should be noted in Table 5.3-27 that these are average figures for the entire fleet, not for new vehicles alone. Referred to the entire fleet, energy efficiency improves 64%. This is connected primarily with the advance of electric vehicles, since their final energy efficiency is higher by a factor of at least 2 or 2.5 than for cars powered by internal combustion engines.

Table 5.3-27: Innovation scenario: Determinants for energy consumption by passenger cars and station wagons, averaged for the entire existing vehicle fleet, 2005 – 2050

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Total vehicles in use (000)	**45,521**	**48,491**	**48,739**	**47,835**	**45,828**
Gasoline, n/incl. hybrids	36,050	26,999	14,624	5,253	0
Gasoline hybrids	25	4,134	17,033	19,223	16,288
Diesel drives	9,392	15,840	10,255	5,401	1,739
Natural gas drives	20	507	1,330	2,429	2,805
Liquefied petroleum gas drives	32	510	1,312	2,423	2,800
Electric drives	2	212	1,824	5,456	8,401
Plug-in hybrid drives	0	287	2,358	7,519	12,640
Fuel cell drives	0	2	3	132	1,154
Annual kilometres travelled (000 vkm/vehicle)	**12.8**	**12.3**	**12.2**	**12.0**	**11.9**
Gasoline, n/incl. hybrids	10.9	9.7	11.1	11.5	11.8
Gasoline hybrids	8.1	8.6	11.0	11.5	11.8
Diesel drives	19.9	17.5	16.3	14.7	13.2
Natural gas drives	15.7	16.5	16.3	14.7	13.2
Liquefied petroleum gas drives	15.7	16.5	16.3	14.7	13.2
Electric drives	3.2	4.7	8.2	10.9	11.7
Plug-in hybrid drives	0.0	4.7	8.2	10.9	11.7
Fuel cell drives	1.5	2.8	4.3	5.6	7.0
Total kilometres travelled (bn vkm)	**581.7**	**595.0**	**592.5**	**573.8**	**543.4**
Gasoline, n/incl. hybrids	393.9	262.4	161.9	60.3	0.0
Gasoline hybrids	0.2	35.8	186.7	220.7	191.9
Diesel drives	186.7	277.8	166.8	79.7	22.9
Natural gas drives	0.3	8.4	21.6	35.8	37.0
Liquefied petroleum gas drives	0.5	8.4	21.3	35.7	37.0
Electric drives	0.0	1.0	14.9	59.2	98.5
Plug-in hybrid drives	0.0	1.4	19.2	81.6	148.1
Fuel cell drives	0.0	0.0	0.0	0.7	8.0
Specific consumption					
Cars (gasoline, diesel, hybrid; L/100 km)	7.8	5.8	4.6	4.1	3.9
Gasoline, n/incl. hybrids (L/100 km)	8.3	6.4	5.2	4.7	4.2
Gasoline hybrids (L/100 km)	6.2	4.8	3.9	3.5	3.2
Diesel drives (L/100 km)	6.8	5.4	4.8	4.4	4.3
Natural gas drives (kg/100 km)	5.6	4.3	3.5	3.2	2.9
Liquefied petroleum gas drives (kg/100 km)	6.1	4.7	3.8	3.4	3.1
Electric drives (kWh/100 km)	20.6	16.5	14.5	14.0	13.9
Plug-in hybrid drives (kWh/100 km)		23.5	20.0	18.6	17.7
Fuel cells (kg H2/100 km)	1.8	1.4	1.2	1.2	1.1
Occupancy (pkm/vkm)	**1.5**	**1.4**	**1.4**	**1.4**	**1.4**

Source: ProgTrans / Prognos 2009

Figure 5.3-24: Innovation scenario: Existing vehicle fleet of passenger cars and station wagons by type of drive, 2005 – 2050, in thousand



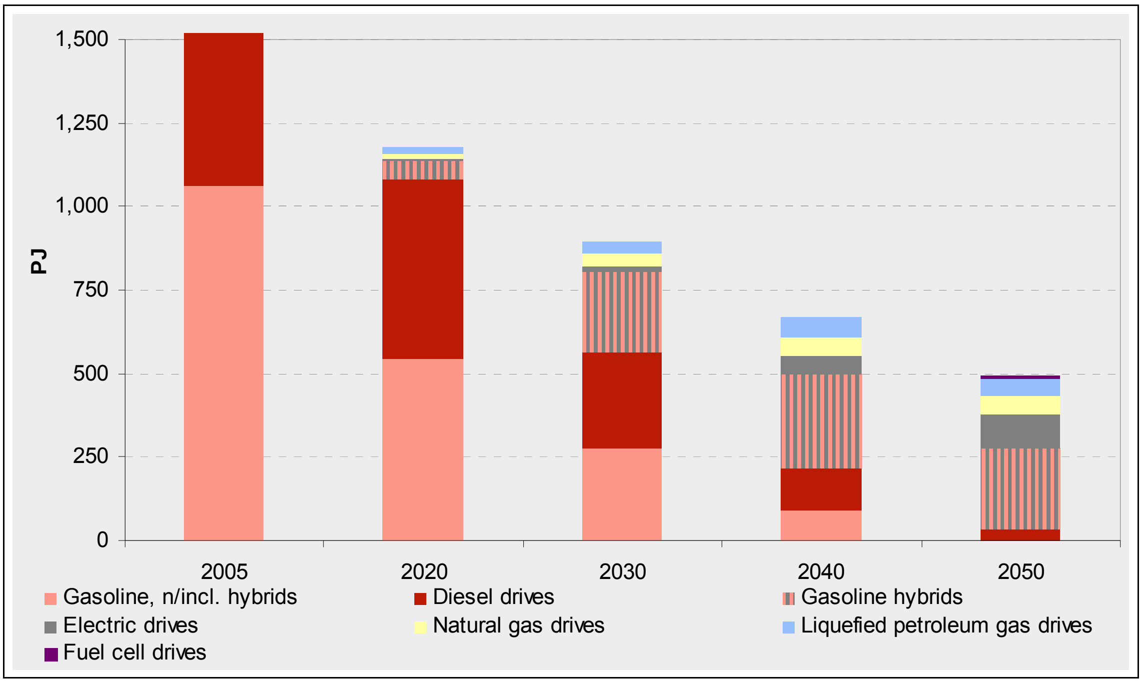
Source: ProgTrans / Prognos 2009

Table 5.3-28: Innovation scenario: Energy consumption of passenger cars and station wagons by type of drive, 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids	1,062	546	276	92	0
Gasoline hybrids	0	56	245	278	242
Diesel drives	457	538	286	126	35
Natural gas drives	1	18	38	57	53
Liquefied petroleum gas drives	1	18	38	56	53
Electric drives	0	1	15	59	101
Fuel cell drives	0	0	0	1	10
Total energy consumption	1,521	1,177	898	669	495
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids		-4.5	-7.7	-10.4	-100.0
Gasoline hybrids		52.6	9.7	1.3	-1.4
Diesel drives		-2.1	-6.8	-7.9	-11.9
Natural gas drives		9.8	7.2	4.0	-0.6
Liquefied petroleum gas drives		5.9	7.1	4.1	-0.6
Electric drives		-	26.4	14.8	5.6
Fuel cell drives		-	5.0	48.9	25.9
Total energy consumption		-2.2	-2.7	-2.9	-3.0

Source: ProgTrans / Prognos 2009

Figure 5.3-25: Innovation scenario: Energy consumption by passenger cars and station wagons by type of drive, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

All in all, energy consumption by cars and station wagons will decrease by 67% between 2005 and 2050.

Gasoline consumption will decrease 77%, and diesel consumption 92%. The fossil shares of gasoline and diesel will be replaced entirely by second and third-generation biofuels by 2050. Biofuels will account for somewhat more than half the energy consumption by passenger cars and station wagons in 2050. Another roughly 20% each will be powered by electricity and gas (natural gas and liquid gas; Table 5.3-28, Figure 5.3-25).

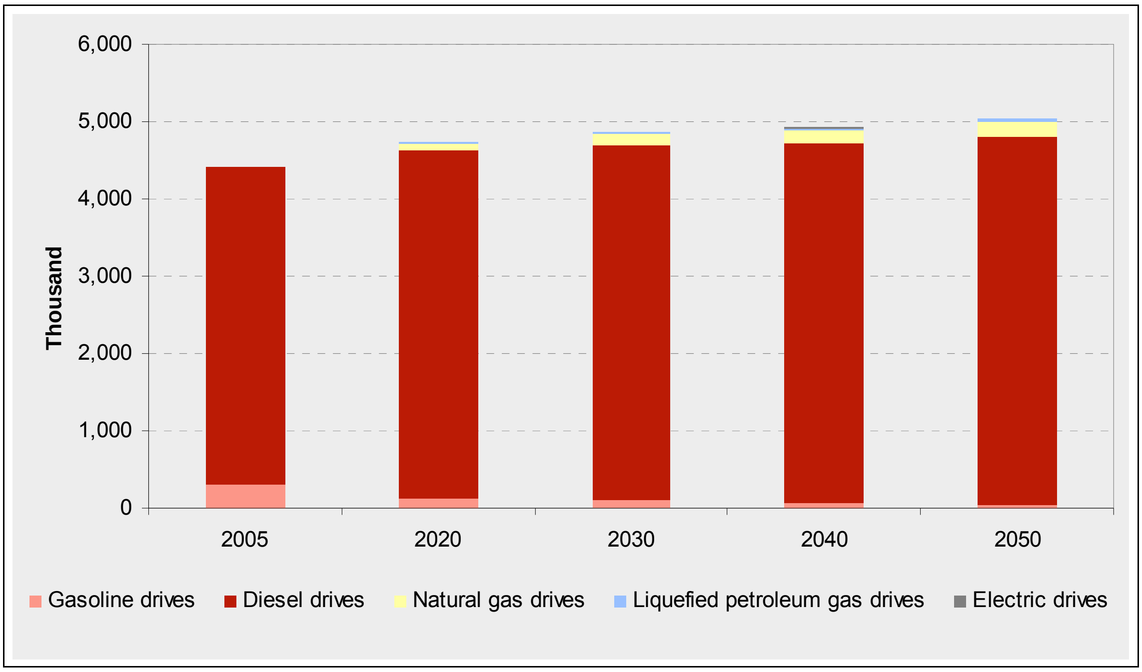
In motorised **freight transport**, rising transport volume is the dominant variable in the innovation scenario as well. This transport service will be provided by a rising number of vehicles (+14%). Utilisation of vehicle capacity will be improved 41% by 2050, compared to 2005 (Table 5.3-29). This improvement is less than in the reference scenario, because more extensive rail transport means that there will be more short-haul small-parcel distribution transport nationwide. In terms of vehicle technology, in the innovation scenario we assume that all types of drives employed will undergo substantial further increases in efficiency compared to the reference scenario. Specific consumption will decrease 28% by 2050 for diesel vehicles, and 30% for gasoline vehicles. Here as well we generally assume that few alternatives to liquid-fuel drives will develop to maturity for the market. As in the reference scenario, gas and electric vehicles will find a niche in delivery heavy goods vehicles and in urban and local transport.

Table 5.3-29: Innovation scenario: Determinants for energy consumption in freight transport by road, 2005 – 2050, averaged for the entire existing vehicle fleet

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Total vehicles in use (000)	**4,424**	**4,742**	**4,873**	**4,936**	**5,053**
Gasoline drives	308	139	100	74	50
Diesel drives	4,107	4,499	4,603	4,652	4,753
Natural gas drives	6	86	141	171	201
Liquefied petroleum gas drives	2	11	17	24	30
Electric drives	2	7	11	15	20
Annual kilometres travelled (000 vkm/vehicle)	**19.3**	**20.4**	**20.5**	**20.5**	**20.5**
Gasoline drives	10.4	10.6	10.4	9.4	7.3
Diesel drives	20.0	20.9	21.0	21.1	21.1
Natural gas drives	10.9	12.0	12.1	12.1	12.2
Liquefied petroleum gas drives	9.5	11.4	11.7	11.9	12.0
Electric drives	8.6	9.0	9.2	9.2	9.2
Total kilometres travelled (bn vkm)	**85.5**	**96.8**	**99.9**	**101.4**	**103.7**
Gasoline drives	3.2	1.5	1.0	0.7	0.4
Diesel drives	82.2	94.1	96.9	98.2	100.4
Natural gas drives	0.1	1.0	1.7	2.1	2.5
Liquefied petroleum gas drives	0.0	0.1	0.2	0.3	0.4
Electric drives	0.0	0.1	0.1	0.1	0.2
Specific consumption (PJ/bn km)					
Gasoline drives (L/100 km)	13.7	11.4	10.0	9.4	9.5
Diesel drives (L/100 km)	23.5	20.1	18.6	17.5	16.8
Natural gas drives (kg/100 km)	15.8	13.8	12.4	11.5	11.1
Liquefied petroleum gas drives (kg/100 km)	16.6	14.9	13.5	12.5	12.2
Electric drives (kWh/100 km)	56.0	49.6	46.1	43.0	41.2
Mean load factor (tkm/vkm)	**4.3**	**5.0**	**5.4**	**5.7**	**6.0**

Source: ProgTrans / Prognos 2009

Figure 5.3-26: Innovation scenario: Vehicle fleets in freight transport by road, by type of drive, 2005 – 2050, in thousands



Source: ProgTrans / Prognos 2009

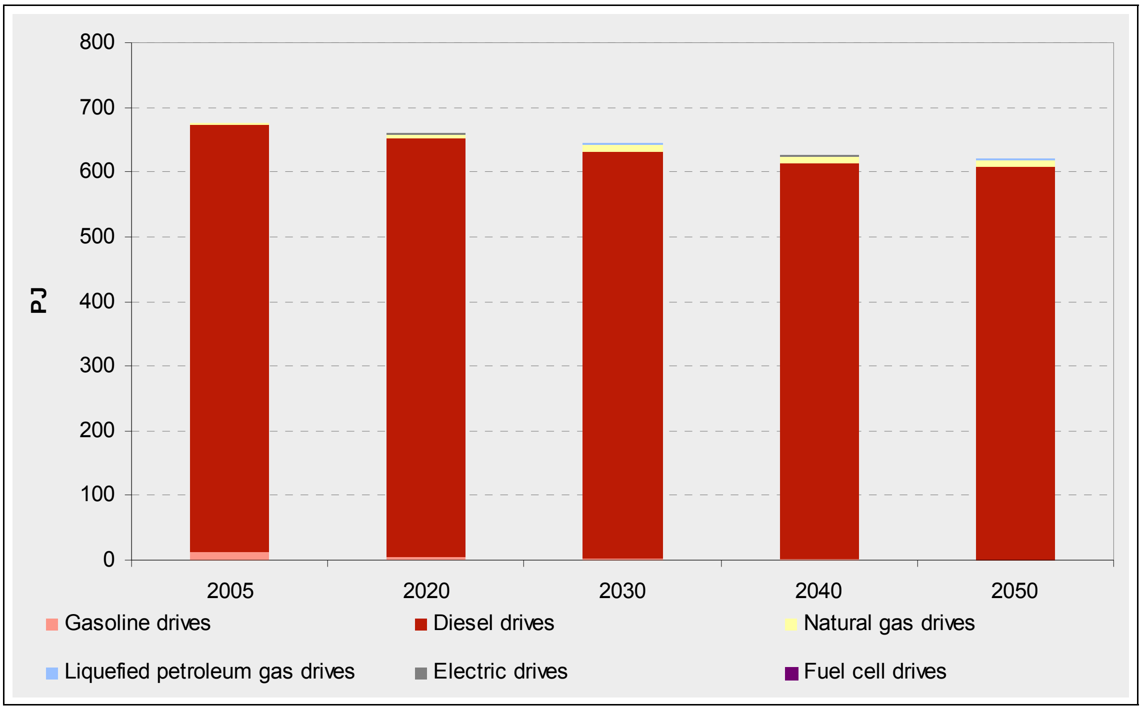
Total consumption for freight transport by road will decrease 8% during the period, as a consequence of cumulative effects. Almost all of this reduction will come from efficiency enhancements in diesel drives. As in the reference scenario, energy consumption of gasoline engines, as they vanish from the fleet, will roughly be compensated by the rising numbers of gas and electric vehicles.

Table 5.3-30: Innovation scenario: Energy consumption for freight transport by road by energy source, 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Gasoline drives	13.8	5.2	3.3	2.1	1.1
Diesel drives	660.6	646.2	629.0	610.5	606.4
Natural gas drives	0.5	6.5	9.7	10.9	12.5
LPG drives	0.1	1.0	1.4	1.8	2.2
Electric drives	0.0	0.1	0.2	0.2	0.3
Fuel cell drives	0.0	0.0	0.0	0.0	0.0
Total energy consumption	675.0	659.0	643.6	625.5	622.5
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Gasoline drives		-6.3	-3.6	-4.3	-6.1
Diesel drives		0.0	-0.5	-0.3	-0.1
Natural gas drives		7.9	3.1	1.1	1.4
LPG drives		6.4	3.2	2.4	2.2
Electric drives		-	3.3	2.5	2.2
Fuel cell drives		-	-	-	-
Total energy consumption		0.0	-0.5	-0.3	0.0

Source: ProgTrans / Prognos 2009

Figure 5.3-27: Innovation scenario: Energy consumption for freight transport by road by type of drive, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

For reasons of space and significance, developments in motorised two-wheeled vehicles and in public mass transit are not shown separately here. These are included in the total energy consumption for road transport, below. Public mass transit (currently mainly buses, prospectively group taxis and small buses) contributed to diesel consumption in 2005; prospectively, the consumption there will also be distributed among the other energy sources.

To match energy consumption against the system used in the energy balance sheet, the calculated levels must be adjusted for "tank-up tourism." This refers to the "import" of fuels, both by foreign vehicles and by tanking up outside the country, in border regions. This fuel importation came to some 74.5 PJ of gasoline in 2005 that was bought across the border because of the price difference from neighbouring countries; it will gradually decrease to about 20 PJ. The situation for diesel is the reverse; in some cases, there is minor "exporting" here.

Table 5.3-31: Innovation scenario: Final energy consumption of road transport, 2005 – 2050, in PJ

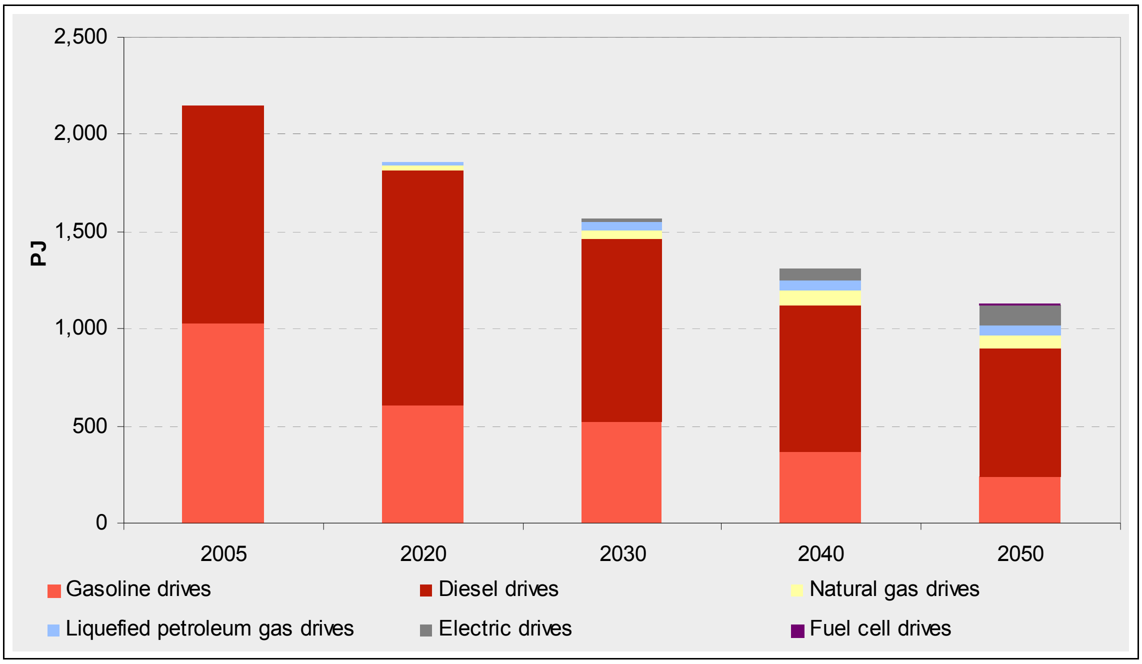
		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Gasoline drives	1,025	609	524	368	236
Diesel drives	1,124	1,207	937	757	661
CNG drives	2	26	50	69	68
LPG drives	2	19	39	59	56
Electric drives	0	1	15	59	101
Fuel cell drives	0	0	0	1	10
All road transport	2,152	1,862	1,565	1,313	1,133
For information only: Biofuel	9	255	494	617	732
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Gasoline drives		-2.8	-1.7	-3.5	-4.3
Diesel drives		-1.0	-2.7	-2.1	-1.3
CNG drives		9.0	6.1	3.4	-0.2
LPG drives		-	6.7	2.1	-1.4
Electric drives		-	25.2	10.5	4.0
Fuel cell drives		-	5.6	62.0	15.8
All road transport		-1.5	-1.8	-1.7	-1.4
For information only: Biofuel		6.6	4.6	1.3	3.3
Passenger transport	1,477	1,203	921	688	511
Freight transport	675	659	644	625	622

Source: ProgTrans / Prognos 2009

Total final energy consumption of road transport will decrease 47% during the period, from 2,152 PJ to 1,133 PJ (Table 5.3-31). Most of the decrease is because of the decrease in consumption for passenger transport during the period, from 1,477 PJ to 511 PJ (–65%, including buses and two-wheeled vehicles). Here again, the large share of diesel drives is primarily the consequence of freight transport.

Liquid fuels will gradually be replaced by biofuels over time, until by 2050 only second and third-generation biofuels will be used on the road. This is reflected in the summary of energy sources (Table 5.3-31).

Figure 5.3-28: Innovation scenario: Final energy consumption of road transport by type of drive, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

5.3.4.4 Final energy consumption of rail transport

In contrast to the reference scenario, the innovation scenario does not assume a decrease in the utilisation of public mass transit, but a slight increase. As a consequence of decreasing kilometres travelled, however, passenger transport volume on mass transit will still decrease 7% during the period. Specific consumption is projected to decrease 16% from the initial level by 2050, and total consumption 22% (Table 5.3-32).

Table 5.3-32: Innovation scenario: Determinants and energy consumption in rail mass transit (tram, urban rapid railways and underground rail lines), 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Transport volume (bn pkm)	15.3	15.7	15.4	15.0	14.4
Utilisation of capacity (pkm/vkm)	24.3	24.7	24.7	24.7	24.7
Kilometres travelled (million vkm)	629.1	633.6	623.7	606.7	583.5
Specific consumption (kWh/vkm)	2.9	2.6	2.5	2.5	2.4
Consumption (electricity, PJ)	**6.6**	**6.0**	**5.7**	**5.4**	**5.1**

Source: ProgTrans / Prognos 2009

Transport volume in rail passenger transport will decrease by about 1.3% during the period. The decrease will result primarily from changes in local travel, where transport volume will decrease 5%. In long-distance transport, transport volume will continue rising to 2030, then decrease slightly until it arrives at 4% above the initial level in 2050.

Because specific consumption will decrease even more sharply than in the reference scenario both in local transport (–15%) and in long-distance transport (–25%), energy consumption will decrease in both categories. All told, energy consumption for rail passenger transport will decrease by 20%, to about 29 PJ, during the period. Of this figure, about 70% will be in electricity. The remainder will be biofuel (Table 5.3-33).

Table 5.3-33: Innovation scenario: Determinants and energy consumption for rail passenger transport

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Local travel					
Transport volume (bn pkm)					
Electric traction	31.5	34.9	34.8	33.6	32.1
Diesel traction	11.6	9.6	9.5	9.2	8.8
Total transport volume	43.1	44.4	44.4	42.9	40.9
Specific consumption (kJ/pkm)					
Electric traction	486	442	433	426	422
Diesel traction	1,038	1,009	992	984	982
Total specific consumption	636	564	553	546	542
Energy consumption (PJ)					
Electricity	15.3	15.4	15.1	14.3	13.5
Diesel (incl. biofuel)	12.1	9.6	9.5	9.1	8.6
Total energy consumption	27.4	25.1	24.6	23.4	22.2
Long-distance travel					
Transport volume (bn pkm)					
Electric traction	32.9	35.6	35.9	35.2	34.2
Diesel traction	0.8	0.7	0.7	0.7	0.7
Total transport volume	33.7	36.3	36.6	35.9	34.9
Specific consumption (kJ/pkm)					
Electric traction	261	217	205	198	196
Diesel traction	715	669	652	643	639
Total specific consumption	272	226	213	207	205
Energy consumption (PJ)					
Electricity	8.6	7.7	7.3	7.0	6.7
Diesel (incl. biofuel)	0.6	0.5	0.5	0.4	0.4
Total energy consumption	9.2	8.2	7.8	7.4	7.1
Total passenger transport					
Energy consumption (PJ)					
Electricity	23.9	23.1	22.4	21.3	20.2
Diesel (incl. biofuel)	12.7	10.1	9.9	9.5	9.1
Total energy consumption	36.5	33.2	32.3	30.8	29.3

Source: ProgTrans / Prognos 2009

In freight transport by rail, transport volume will rise massively, almost trebling to nearly 280 billion tkm by 2050 (Table 5.3-34). As a consequence of the intensified shift from road to rail, rail transport volume is about 35% higher in the innovation scenario than in the reference scenario. The innovation scenario assumes a greater technical improvement in efficiency than in the reference scenario. Specific consumption decreases 34% from the original level.

All in all, energy consumption for freight transport by rail will increase to nearly 32 PJ (+91%). Diesel will decrease in significance; its share of consumption will decline from 22% to 6.5%. Fossil diesel will be almost entirely replaced with biofuel by 2050.

As a result energy consumption for local services (shunting, stationary installations) will increase from about 17 PJ in 2007 to 30 PJ in 2050. By the end of the period, only electricity will be used for these services.

Table 5.3-34: Innovation scenario: Determinants and energy consumption for rail freight transport

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Transport volume (bn tkm)					
Electric traction	83	147	183	224	271
Diesel traction	13	10	9	8	7
Total transport volume	95	156	192	232	278
Specific consumption (kJ/tkm)					
Electric traction	143	121	116	113	109
Diesel traction	368	319	309	303	297
Total specific consumption	173	133	125	119	114
Energy consumption (PJ)					
Electricity	11.8	17.7	21.2	25.2	29.6
Diesel (incl. biofuel)	4.7	3.2	2.8	2.4	2.0
Total specific consumption	16.5	20.9	24.0	27.6	31.7
Local services					
Energy consumption (PJ)					
Electricity	16.1	20.3	22.5	25.8	30.7
Diesel (incl. biofuel)	1.5	0.7	0.5	0.3	0.0
Total energy consumption	17.5	20.9	23.0	26.1	30.7

Source: ProgTrans / Prognos 2009

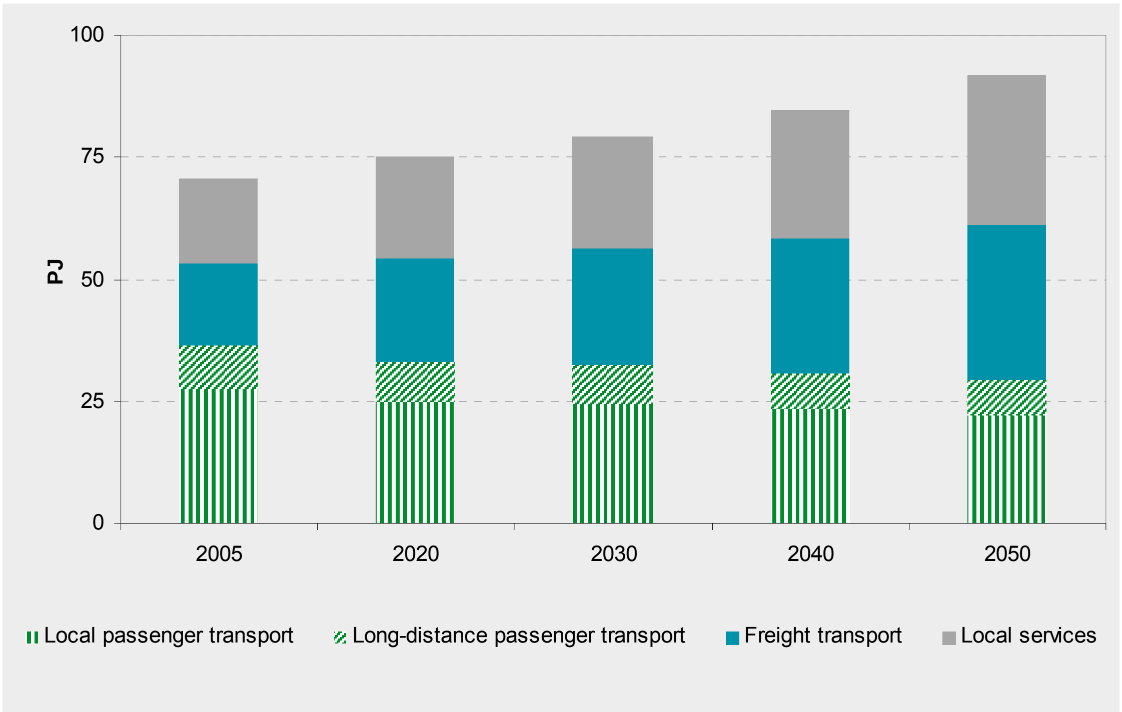
For all rail transport (passenger and freight), the final energy consumption is projected to increase by about 30% by 2050, to 92 PJ (Table 5.3-35). The share of electricity will rise from 73% to 89%. This increase is a consequence of greater consumption for freight transport and for local services. This is associated with a distinct shift in the different transport categories' shares of total consumption. The share consumed by passenger transport (local and long-distance) will decrease from more than 50% to 32% between 2005 and 2050; the share for freight transport will rise from 24% to 35%, and the share for local services will increase from 25% to 33% (Figure 5.3-29).

Table 5.3-35: Innovation scenario: Total energy consumption for rail transport, 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Electricity	51.7	61.1	66.2	72.3	80.5
Diesel (incl. biofuel)	18.9	13.9	13.2	12.2	11.1
Coal	0.0	0.0	0.0	0.0	0.0
All rail transport	70.6	75.0	79.3	84.5	91.7
Change in % p.a.		**2020**	**2030**	**2040**	**2050**
Electricity		1.0	0.8	0.8	0.7
Diesel (incl. biofuel)		-0.6	-0.1	-0.4	-0.9
Total energy consumption		0.7	0.6	0.6	0.5
Local passenger transport	27.4	25.1	24.6	23.4	22.2
Long-distance passenger transport	9.2	8.2	7.8	7.4	7.1
Freight transport	16.5	20.9	24.0	27.6	31.7
Local services	17.5	20.9	23.0	26.1	30.7
Total energy consumption	70.6	75.0	79.3	84.5	91.7
Memo item: Public mass transit	6.6	6.0	5.7	5.4	5.1

Source: ProgTrans / Prognos

Figure 5.3-29: Innovation scenario: Energy consumption for rail transport by type of use, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

5.3.4.5 Energy consumption by inland navigation and aviation

Due to the intensified replacement of road transport, transport volume via inland navigation grows more in the innovation scenario than in the reference scenario. Transport volume via inland navigation will rise 48% by 2050, to 95 billion tkm. But inland navigation's share of freight transport volume will remain limited, at 9%.

With a 31% decrease in specific consumption, and a domestic tank-up rate that rises again in the longer term, energy consumption by inland navigation will rise 43% by 2050, to about 18 PJ (Table 5.3-36).

Table 5.3-36: Innovation scenario: Determinants of energy consumption in inland navigation, 2005 – 2050

		Innovation scenario			
	2005	2020	2030	2040	2050
Transport volume (bn tkm)	64	71	78	85	95
Specific consumption (kJ/tkm)	172	145	132	123	119
Consumption (diesel incl. biofuels, PJ)	13	15	15	16	18

Source: ProgTrans / Prognos 2009

For aviation, passenger transport volume will rise 19% during the period. Air cargo volume will treble at the same time, but will still be of little significance in comparison to total freight transport volume. Technical efficiency will improve 40%. The interplay of these factors is projected to cause energy consumption for aviation to decrease 10% by 2050.

Table 5.3-37: Defining factors in energy consumption of aviation, 2005 – 2050

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Passenger transport volume (bn pkm)	53	67	68	66	63
Freight transport volume (bn tkm)	1	2	2	3	3
Specific consumption (PJ/bn pkm-equivalent[1)])	5	5	4	4	3
Consumption (aviation fuel, PJ)	345	383	354	336	312

[1)] 1 tkm=10 Pkm

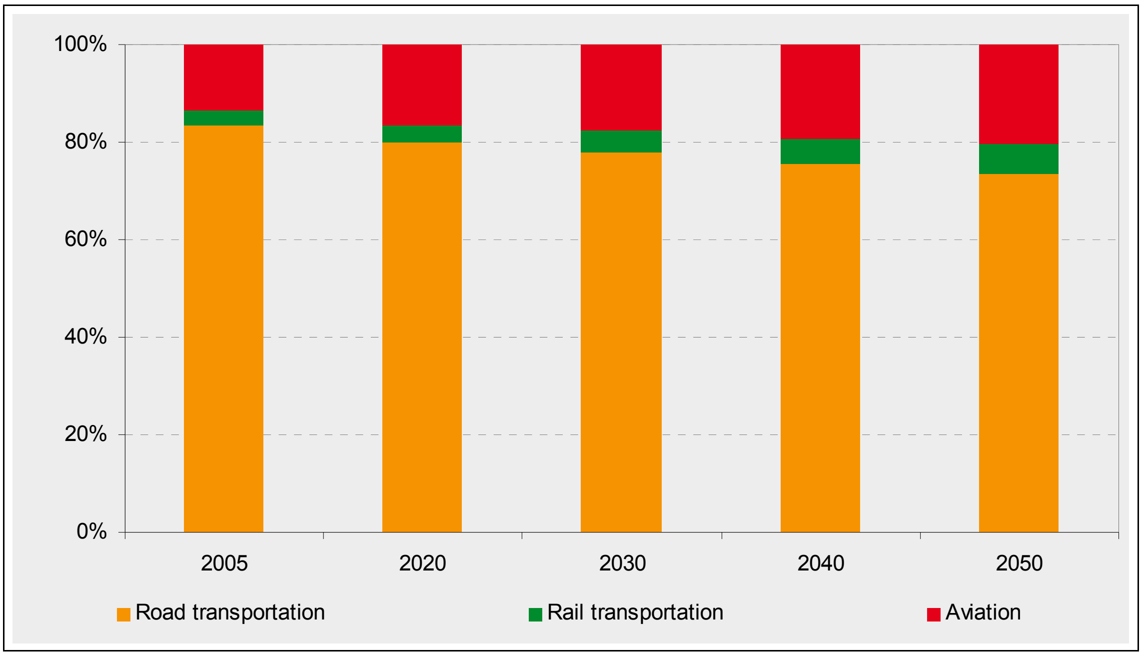
Source: ProgTrans / Prognos 2009

5.3.4.6 Final energy consumption: Total and by energy source

Energy consumption in the transport sector will decrease about 40% during the period, according to the innovation scenario.

The shares of energy consumption among the various mode of transport will shift significantly in some cases. The share consumed for road transport will decrease 11 percentage points, to 73%; the share for aviation will increase 7 percentage points to 20%; the share for rail transport will increase 3.2 percentage points to 6.2%. Although energy consumption for inland navigation will double, this mode of transport will still be of little significance (Figure 5.3-30).

Figure 5.3-30: *Innovation scenario: Share of mode in energy consumption by the transport sector, 2005 – 2050*



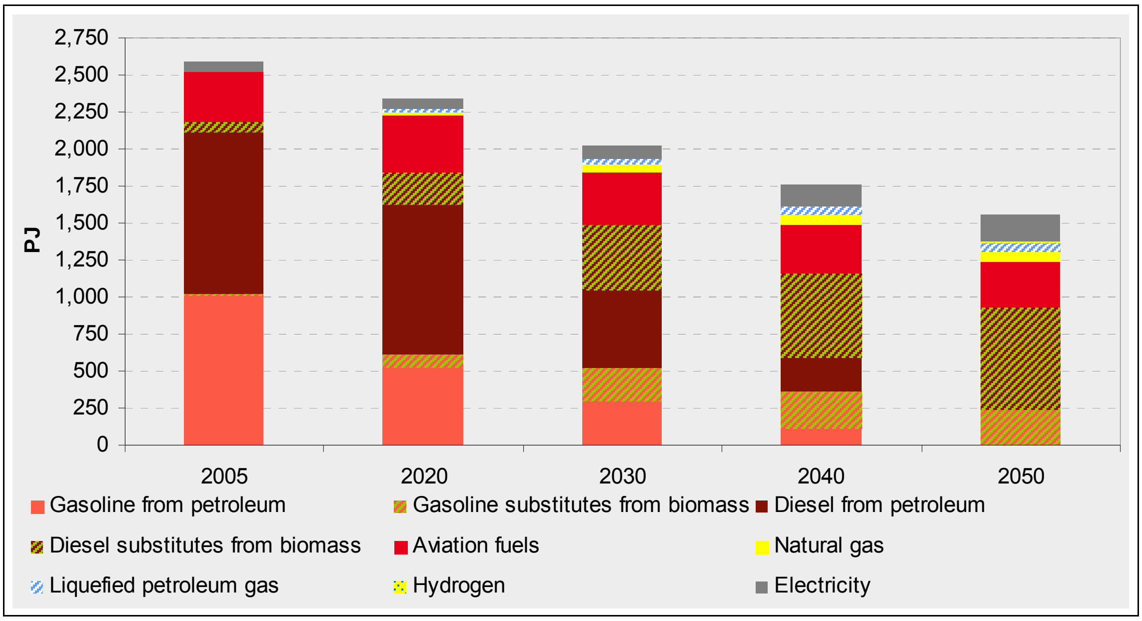
Source: ProgTrans / Prognos 2009

The various energy sources are projected to develop differently (Figure 5.3-31 and Table 5.3-38). As a consequence of more efficient vehicles and of replacement with other energy sources, consumption of liquid motor fuels will decrease substantially. Gasoline consumption will decrease 77% during the period, from 1,025 PJ to 236 PJ. Gasoline produced from petroleum will be entirely displaced from the market by 2050, initially by admixture with bioethanol; towards the end of the period under consideration, only second or even third-generation biofuels will be used.

Consumption of diesel fuel will keep increasing until 2015, but decrease to 661 PJ from 2015 to 2050 (–41% compared to 2005). Analogously to the change for gasoline, fossil diesel will initially be displaced by admixtures of biofuels, and will be replaced entirely by biofuel towards the end of the period.

Demand for natural gas and liquid natural gas will increase. With consumption of 124 PJ, these gases will account for 11% of the sector's total consumption. Hydrogen does not play an important rule as an energy source in the innovation scenario; its share remains below 1%.

Figure 5.3-31: Innovation scenario: Total final energy consumption of transport, by energy source, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

Electric power demand will increase about 221% during the period, and reach 187 PJ by 2050. Electric power demand is determined primarily by road passenger transport, followed closely by rail transport. Consumption of jet fuel (kerosene) will stagnate until 2025 and then decrease to 312 PJ by 2050 (–10%).

Table 5.3-38: Innovation scenario: Total final energy consumption of transport, 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
Road transport					
Gasoline	1,025	609	524	368	236
Gasoline substitutes from biomass	0	87	228	257	236
Gasoline from petroleum	1,025	521	296	112	0
Diesel	1,124	1,207	937	757	661
Diesel substitutes from biomass	0	209	430	540	661
Diesel from petroleum	1,124	998	507	217	0
Natural gas	2	26	50	69	68
Liquefied petroleum gas	2	19	39	59	56
Hydrogen	0	0	0	1	10
Electricity	0	1	15	59	101
Motor oil	1	0	0	0	0
All road transport	2,152	1,862	1,565	1,314	1,133
Rail transport					
Electricity	58	67	72	78	86
Diesel (incl. biofuel)	19	14	13	12	11
Coal	0	0	0	0	0
All rail transport	77	81	85	90	97
Inland navigation					
Diesel (incl. biofuel)	13	15	15	16	18
Aviation					
Aviation fuels	345	383	354	336	312
All transport	**2,587**	**2,341**	**2,019**	**1,756**	**1,560**
Gasoline (incl. biofuel)	1,025	609	524	368	236
Gasoline substitutes from biomass	9	87	228	257	236
Gasoline from petroleum	1,015	521	296	112	0
Diesel (incl. biofuel)	1,155	1,236	965	786	691
Diesel substitutes from biomass	62	214	443	561	691
Diesel from petroleum	1,093	1,021	522	225	0
Aviation fuels	345	383	354	336	312
Natural gas	2	26	50	69	68
Liquefied petroleum gas	2	19	39	59	56
Hydrogen	0	0	0	1	10
Electricity	58	68	87	137	187
Coal	0	0	0	0	0
Motor oil	1	0	0	0	0

Source: ProgTrans / Prognos 2009

5.3.5 Total final energy consumption

Final energy consumption, broken down by energy source, will develop as shown in Table 5.3-39 and Table 5.3-40, and in Figure 5.3-32 and Figure 5.3-33.

By 2050, final energy consumption will decrease steadily to 3,857 PJ (a 58% decrease against 2005), and thus by an average of 2.0% per year. The yearly decrease will grow to 2.3% until 2020, following crisis-induced fluctuations, and will then narrow to an average of 1.6% by 2050.

Apart from the substantial decrease in total energy consumption, there will be an extensive restructuring of the mix of energy sources.

To achieve the goals of CO_2 reduction, consumption of petroleum products will be reduced drastically. While they covered the largest share of final energy demand (41%) at the beginning of the period, their share will decrease to 9.4% by 2050. In 2050, petroleum will be used primarily as an aviation fuel, without which petroleum products will represent only 1.6% of energy consumption. Although the share of conventional gasoline and heating oil will decrease at an accelerating rate from the very start, the share of petroleum-based diesel fuel will rise by a further two percentage points until 2020, and begin falling at an accelerating rate after that.

The market share of **gases** will change only slightly, decreasing by 7 percentage points (from 27% to 20%).

In contrast to gas and petroleum products, the share of **electricity** will rise by 10 percentage points (from 20% to 30%). However, demand for electric power will decrease by nearly 38% between 2005 and 2050, from 1,832 PJ to 1,165 PJ.

Renewable energy sources will make an increasingly important contribution towards covering demand. From 2005 to 2050, their share will grow by a factor of 8.5 to 36.6%, a 257% gain against 2005. Biofuels will be the most important energy source among the renewables in 2050. By then, they alone will cover about one-quarter of total final energy demand.

Where the ratio of market shares of petroleum products to gases to electricity to renewable energy sources was approx. 4 : 3 : 2 : 1/8 in 2005, this structure will shift totally by 2050, to 1 : 2 : 3 : 3.5.

The final energy provided from **coal** will decrease more than average, by 82%, so that its market share will be only 2.0% by 2050.

Decreasing demand for heat is projected to reduce the share of **district heating** to 1.9%.

Table 5.3-39: Innovation scenario: Final energy consumption, by energy source and sector, 2005 – 2050, in PJ

		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
By energy source					
Coal	**400**	**262**	**168**	**110**	**77**
Hard coal	341	224	138	86	55
Lignite	59	38	29	24	22
Petroleum products	**3,798**	**2,627**	**1,504**	**809**	**363**
Heating oil, light	1,151	574	256	96	36
Heating oil, heavy	67	39	24	16	11
Gasoline from petroleum	1,033	534	303	115	0
Diesel from petroleum	1,202	1,097	566	246	4
Aviation fuels	345	383	354	336	312
Other petroleum products	**1**	**0**	**0**	**0**	**0**
Gases	2,482	1,705	1,142	880	766
Natural gas, other naturally occurring gases	2,359	1,606	1,050	783	671
Other gases	123	99	92	97	95
incl.: Blast furnace gas	77	49	33	24	18
Renewable energy sources	**396**	**804**	**1,297**	**1,409**	**1,412**
Biomass	178	189	171	122	66
Ambient heat	68	104	124	122	106
Solar energy	73	187	279	287	247
Biofuels	77	318	708	867	987
Biogas	0	7	16	11	5
Electricity	**1,832**	**1,517**	**1,320**	**1,224**	**1,165**
District heating	**300**	**229**	**165**	**113**	**74**
Total final energy consumption	9,208	7,144	5,596	4,546	3,857
By consumer sector					
Residential	2,735	2,003	1,465	1,017	662
Services	1,462	1,031	720	574	486
Industry	2,424	1,769	1,391	1,199	1,149
Transport	2,587	2,341	2,019	1,756	1,560

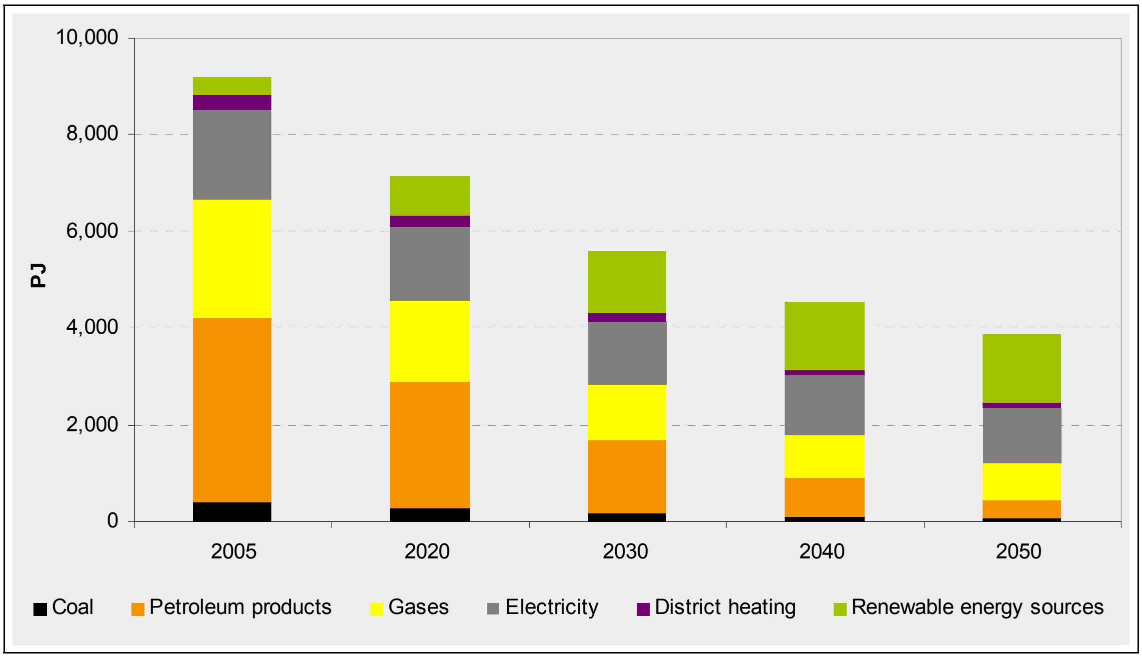
Source: ProgTrans / Prognos 2009

Table 5.3-40: Innovation scenario: Structure of final energy consumption by energy source and sector, 2005 – 2050, in %

Structure in %	2005	2020	2030	2040	2050
By energy source					
Coal	**4.3**	**3.7**	**3.0**	**2.4**	**2.0**
Hard coal	3.7	3.1	2.5	1.9	1.4
Lignite	0.6	0.5	0.5	0.5	0.6
Petroleum products	**41.2**	**36.8**	**26.9**	**17.8**	**9.4**
Heating oil, light	12.5	8.0	4.6	2.1	0.9
Heating oil, heavy	0.7	0.5	0.4	0.3	0.3
Gasoline from petroleum	11.2	7.5	5.4	2.5	0.0
Diesel from petroleum	13.1	15.4	10.1	5.4	0.1
Aviation fuels	3.7	5.4	6.3	7.4	8.1
Other petroleum products	0.0	0.0	0.0	0.0	0.0
Gases	27.0	23.9	20.4	19.4	19.9
Natural gas, other naturally occurring gases	25.6	22.5	18.8	17.2	17.4
Other gases	1.3	1.4	1.6	2.1	2.5
incl.: Blast furnace gas	0.8	0.7	0.6	0.5	0.5
Renewable energy sources	**4.3**	**11.3**	**23.2**	**31.0**	**36.6**
Biomass	1.9	2.6	3.0	2.7	1.7
Ambient heat	0.7	1.4	2.2	2.7	2.7
Solar energy	0.8	2.6	5.0	6.3	6.4
Biofuels	0.8	4.4	12.7	19.1	25.6
Biogas	0.0	0.1	0.3	0.2	0.1
Electricity	**19.9**	**21.2**	**23.6**	**26.9**	**30.2**
District heating	**3.3**	**3.2**	**2.9**	**2.5**	**1.9**
Total final energy consumption	100.0	100.0	100.0	100.0	100.0
By energy source					
Residential	29.7	28.0	26.2	22.4	17.2
Services	15.9	14.4	12.9	12.6	12.6
Industry	26.3	24.8	24.9	26.4	29.8
Transport	28.1	32.8	36.1	38.6	40.4

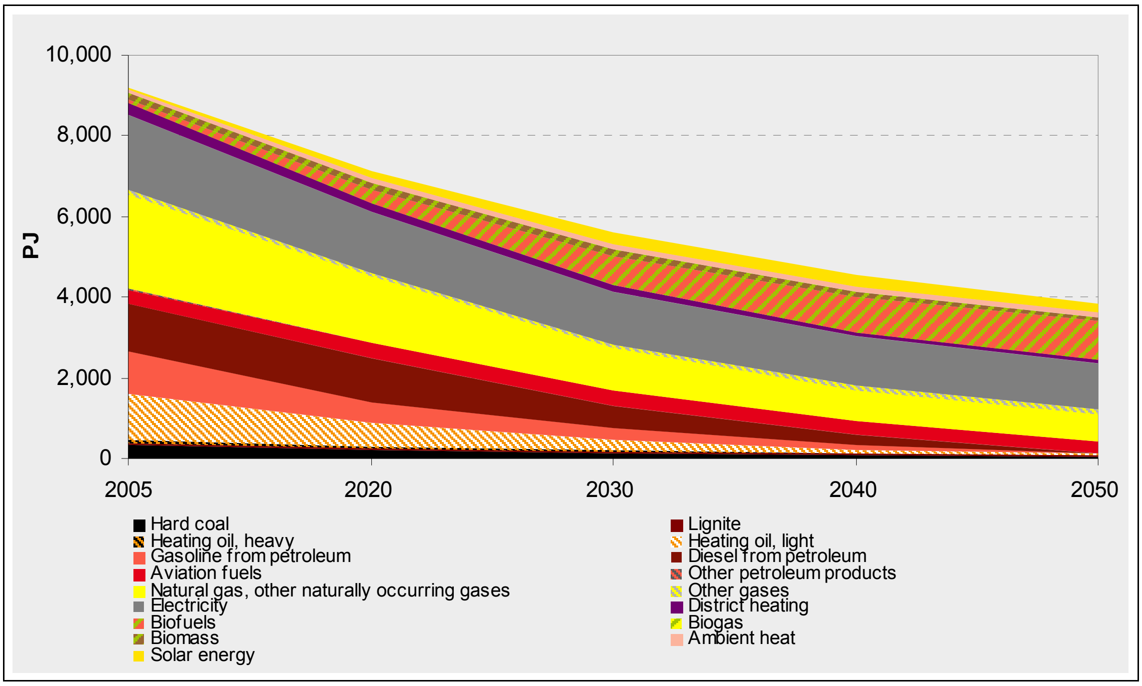
Source: ProgTrans /Prognos 2009

Figure 5.3-32: Innovation scenario: Final energy consumption by energy source group, 2005 – 2050, in PJ



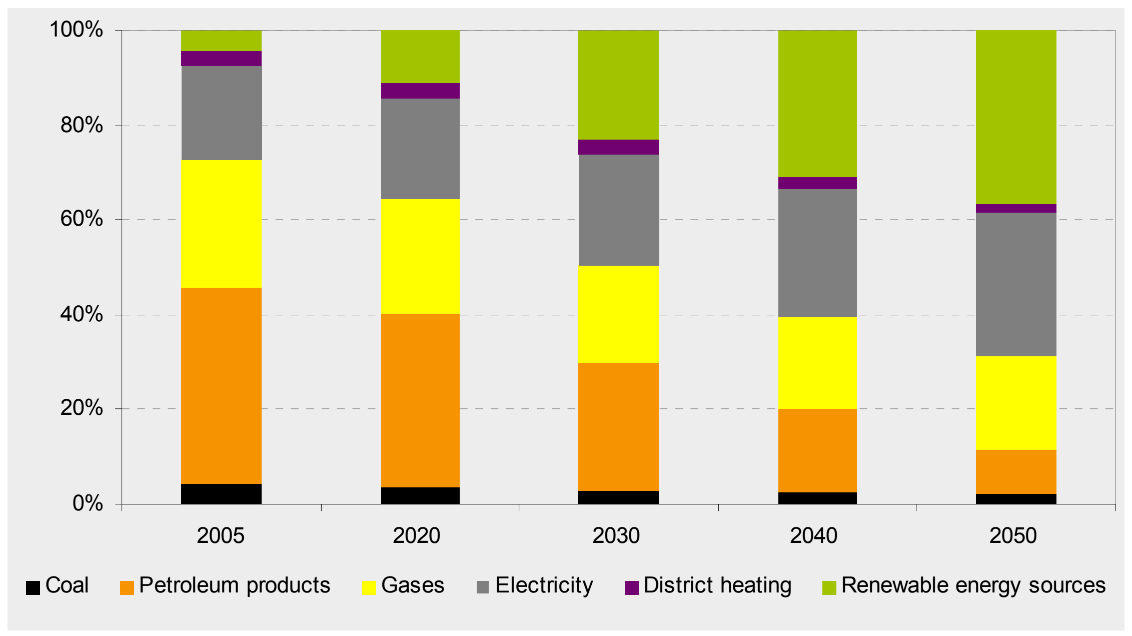
Source: ProgTrans/Prognos 2009

Figure 5.3-33: Innovation scenario: Final energy consumption by energy source, 2005 – 2050, in PJ



Source: ProgTrans /Prognos 2009

Figure 5.3-34: Innovation scenario: Structure of final energy consumption by energy source group, 2005 – 2050, in %

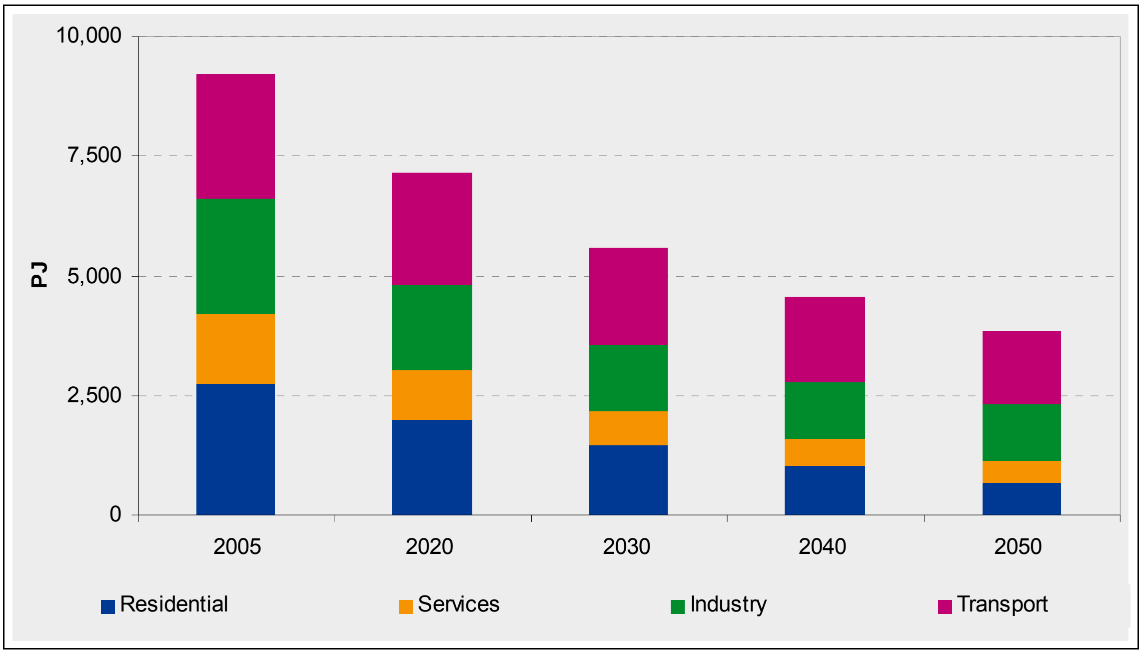


Source: ProgTrans / Prognos 2009

Final energy consumption will develop differently in the various sectors. The largest final energy savings between 2005 and 2050 will be in the residential sector, in both absolute (–2,073 PJ) and relative terms (76%). This is primarily the consequence of the systematic reduction in demand for space heating in virtually all new and existing buildings. Consumption by the service sector will decrease by 67%, for essentially the same reason. In addition, there will be process shifts there, especially in heating. The reduction of consumption will be 53% in industry and 47% in the transport sector.

These changes will cause a substantial shift in the relative weights of final energy consumption. Starting from a relatively uniform distribution in 2005 (the service sector having the lowest share, at 15%), industry (30%) and the transport sector (40%) will increase their shares, while the significance of the residential sector (17%) and services (13%) will recede.

Figure 5.3-35: Innovation scenario: Final energy consumption, by demand sector, 2005 – 2050, in PJ



Source: ProgTrans / Prognos 2009

5.3.6 Power generation

5.3.6.1 Development of the power plant fleet

The primary goal in the innovation scenarios with and without CCS is a reduction of CO_2 emissions. Renewables will continue to expand dynamically in Germany, and imports of renewably generated electricity, especially from solar thermal power plants, will grow significantly more than in the reference scenarios.

The innovation options likewise distinguish two development tracks in regard to the introduction of CCS technology for CO_2 separation. The option without CCS assumes that CCS technology will not be introduced into conventional electric power generation in Germany.

In the option with CCS, however, a technically mature form of this technology will be available by 2025, and will be cost-effective, assuming that CO_2 prices develop as projected.

Both options operate with the same assumptions in terms of expansion paths for centralised and decentralised combined heat and power generation, and for renewables. There are significant differences in the long-term structure of the fleet of conventional power plants, the expansion path for renewable energy sources, and power imports from renewable sources.

Power imports are a residual figure resulting from demand, development of renewables, development of the gas-fired and storage power plants needed for regulating energy, and in the case with CCS, the development of conventional power plants with CCS. It is assumed that the imports are electricity from renewable sources.

5.3.6.1.1 Combined heat and power

Power generation in central and decentralised combined heat and power plants will be heat-driven. Because of the significantly decreasing demand for heat and power in the final energy sectors, generation of electricity in combined heat and power plants will decrease by more than half in the Innovation options both with and without CCS, from 68 TWh in 2005 to 28 TWh in 2050. Installed capacity in the power plant model is categorised by energy source, primarily natural gas and biomass.

5.3.6.1.2 Expansion of renewable energy sources

The expansion path for renewable energy sources in power generation is drawn from the guideline scenario (Nitsch/DLR 2008) for the options both with and without CCS. However, the analyses by consumer sector show that for biomass use there is a conflict of goals as to the most suitable use.

Because of the limited possibilities for replacing liquid fossil motor fuels with electricity in the transport sector, especially in freight transport and aviation, the innovation scenario deviates from the guideline scenario’s expansion path for power generation from biomass. Although in energy terms biomass can be used most reasonably in coupled heat and power generation, a larger share of biofuels is attributed to the transport sector, so as to improve the overall balance of CO_2 emissions. For that reason, the Innovation options with and without CCS for 2050 deviate downward by about 12.5 TWh (23%) from the ambitious guideline scenario for power generation from biomass.

Because of the low net power consumption in the final energy demand sectors, the potential for the importation of renewably generated power, especially from solar thermal power plants, is not fully utilised in comparison to the guideline scenario. Instead, domestic potential is used first. In 2050 the Innovation option without CCS lags behind the levels from the guideline scenario by about 41 TWh (one-third); the option with CCS is behind by 70 TWh (58%).

In the Innovation option without CCS, installed capacity in Germany for power generation from renewable sources rises by a factor of 4.3 between 2005 and 2050, from 27.1 GW to 117.0 GW (see Table 5.3-41, Figure 5.3-36). Details of this development:

- Hydroelectric power will gain 13%, from 4.6 GW to 5.2 GW;

- Wind power will grow by a factor of almost 4, from 18.4 GW to 71.0 GW, 37.6 GW of this total in offshore installations alone;

- Photovoltaic power will increase by a factor of 15, from 1.9 GW to 29.0 GW;

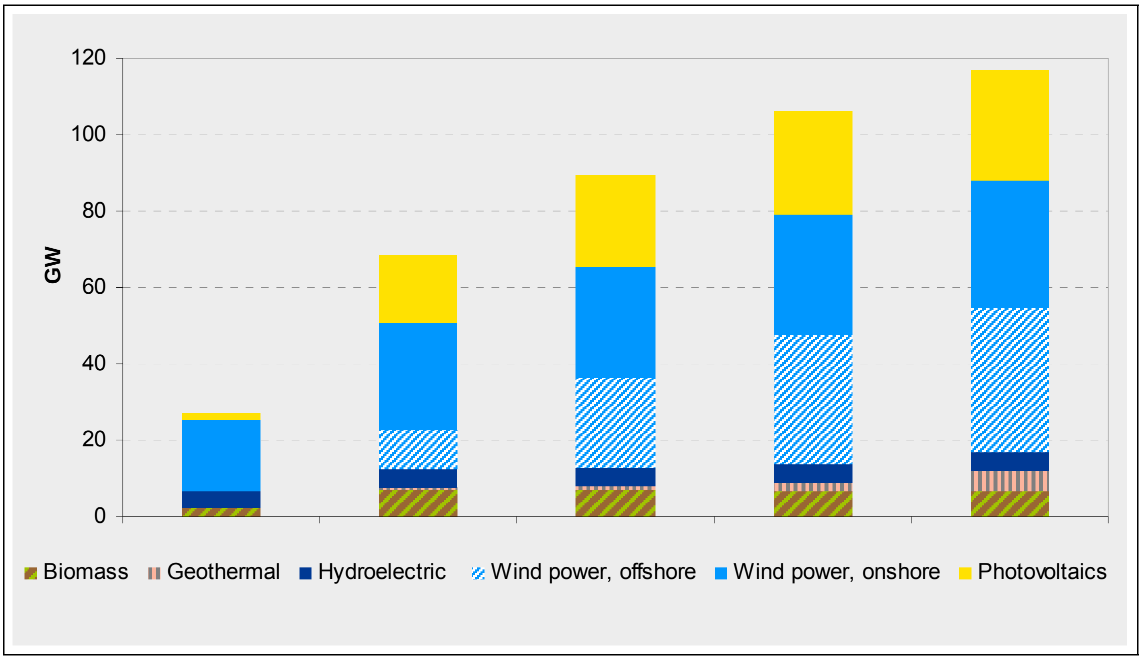
- Biomass will expand by a factor of 3, from 2.2 GW to 6.7 GW, and will thus be below the expansion path from the reference scenario ;

- Geothermal energy will reach an installed capacity of 5.1 GW.

Secured capacity from renewable sources will likewise increase during the projection period. However, this increase is limited because additional construction in renewable sources will emphasise wind and photovoltaic power, whose fluctuating generation contributes little to secured capacity. In the innovation option without CCS, power from these sources in Germany will rise by a factor of 3.5, from about 6.0 GW in 2005 to about 20 GW in 2050. Importation of 48.1 TWh of renewably generated power in 2050 will then increase secured capacity to 26.8 GW.

The great expansion of power generation from fluctuating renewable sources (wind, photovoltaics) will pose special challenges for the expansion of storage capacity as the need for balancing power rises.

Figure 5.3-36: Innovation scenario without CCS: Installed capacity of renewable energy sources, 2005 – 2050, in GW



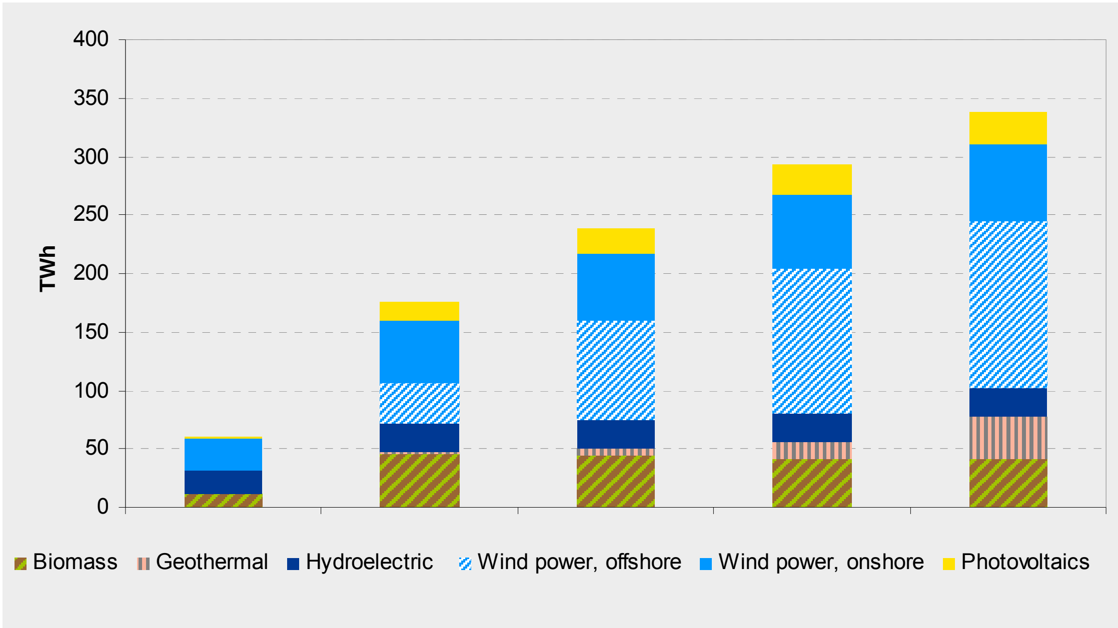
Source: Prognos 2009

In addition to the pumped storage units already in existence today, further capacity must be built to balance out the time gap between production and demand. Since the potential for pumped storage power plants in Germany is nearly exhausted, increasing use will be made of other power storage techniques, such as compressed-air storage systems. But as a rule these are less efficient than pumped storage systems – i.e., they have a poorer ratio between the power fed in and the power released. For that reason, the mean annual utilisation ratio of storage power plants will decline over the long term. All in all, in the Innovation option without CCS, the demand for storage capacity in Germany grows by a factor of 3.8 between 2005 and 2050, from 5.4 GW to 20.4 GW. The amount released (net power generation) by storage units rises from 7.1 TWh in 2005 to 54.7 TWh in 2050.

In the innovation option without CCS, power generation from renewable sources in Germany rises by a factor of 5.6 between 2005 and 2050, from 60 TWh to 339 TWh (see Table 5.3-41, Figure 5.3-37). Details of this development:

- Hydroelectric power will increase 27%, from 19.6 TWh to 24.8 TWh;
- Power generated from the wind will increase by a factor of 6.7, from 27.2 TWh to 209.3 TWh;
- Photovoltaic power will increase by a factor of 22, from 1.2 TWh to 27.7 TWh;
- Biomass conversion to electricity will grow by a factor of 2.4, from 12 TWh to 41.3 TWh; and
- Geothermal energy will contribute 35.7 TWh of generated power by 2050.

Figure 5.3-37: Innovation scenario without CCS: Net power generation from renewable energy sources, 2005 – 2050, in TWh



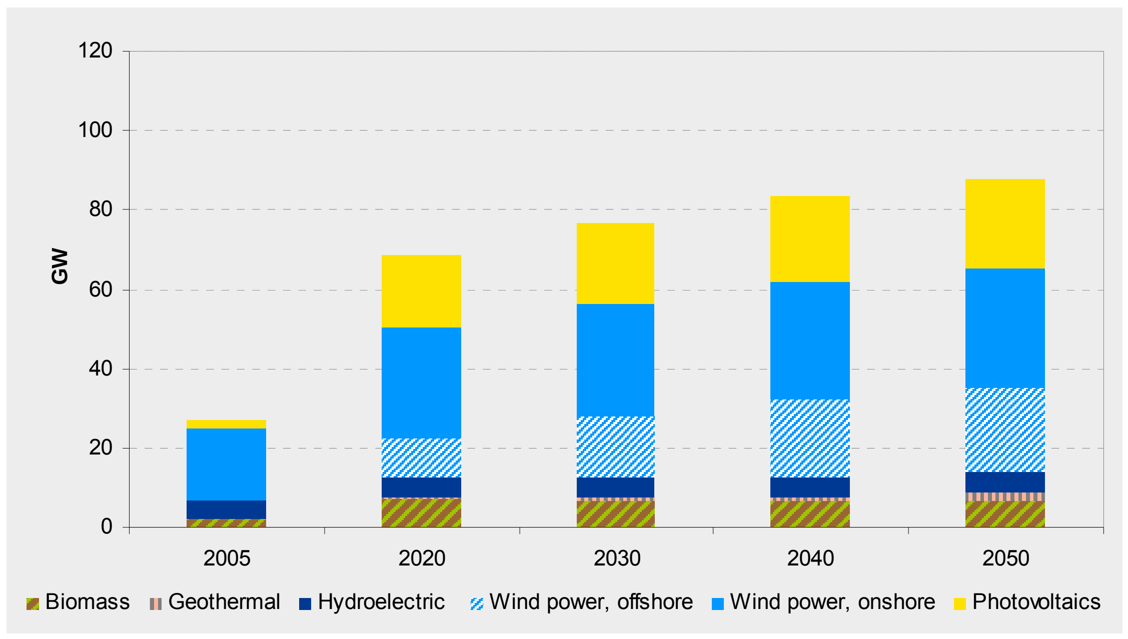
Source: Prognos 2009

Because of the implementation obstacles already discussed in the reference option without CCS, it is not certain that the ambitious goals that have largely been taken over from the expansion scenario [Nitsch/DLR 2008] into the innovation option without CCS will be achieved.

Thus in addition to the use of renewable energy sources with CCS technology, the innovation option with CCS includes a further possibility for producing low-emission electricity. All in all, the installed capacity for power generation from renewable sources in Germany rises by a factor of 4 in the innovation option with CCS, from 21.7 GW in 2005 to about 87.6 GW in 2050. Compared to the Innovation option without CCS, the expansion paths for wind power (offshore), photovoltaics, and geothermal energy are significantly lower. All in all, however, renewable energy sources will expand significantly faster than in either of the reference options, with or without CCS. Details of this development:

- Hydroelectric power will gain 12%, from 4.6 GW to nearly 5.2 GW;
- Wind power will expand by a factor of 2.8, from 22.2 GW to 51.2 GW, 21.0 GW of this in offshore installations;
- Photovoltaic capacity will be increased by a factor of 10, from 1.9 GW to 22.3 GW;
- Biomass will expand as in the innovation option without CCS, by a factor of 3, from 2.2 GW to 6.7 GW.
- Geothermal energy will reach an installed capacity of 2.2 GW.

Figure 5.3-38: Innovation scenario with CCS: Installed capacity of renewable energy sources, 2005 – 2050, in GW



Source: Prognos 2009

Secured capacity from renewable sources will likewise rise less in the innovation option with CCS, because of the smaller expansion of capacity. It will more than double from about 6 GW in 2005 to nearly 15.5 GW in 2050. Importation of 51 TWh of renewably generated power in 2050 will then increase secured capacity to 22.6 GW.

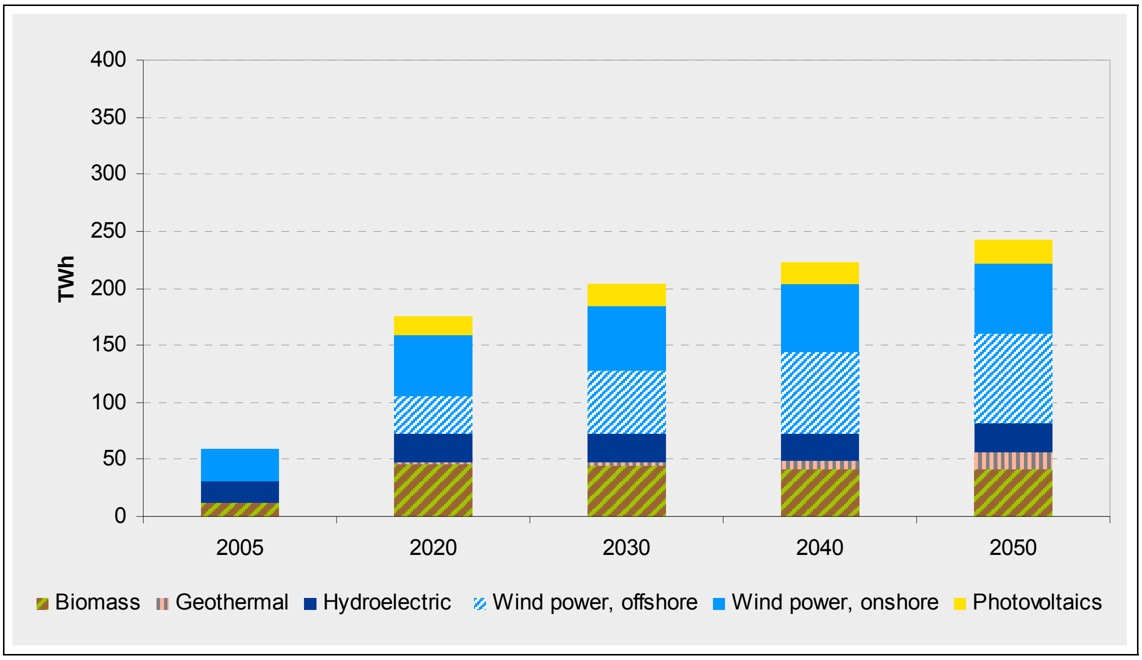
In the innovation option with CCS, the expansion of renewable energy sources is less than in the Innovation option without CCS. Accordingly, balancing power demand is less, and less expansion of storage capacity is needed. In this option as well, there is an increasing use of techniques other than pumped storage, such as compressed air storage. All in all, in the Innovation option with CCS, the demand for storage capacity in Germany grows by a factor of 2.4 between 2005 and 2050, from 5.4 GW to 12.9 GW. The amount released (net power generation) by storage units rises from 14.8 TWh to 36.5 TWh in 2050.

In the innovation option with CCS, power generation from renewable sources grows more slowly overall between 2005 and 2050 than in the option without CCS, because of the smaller growth in capacity. It increases by a factor of 4, from 60 TWh in 2005 to 243 TWh in 2050 (see Figure 5.3-39). Details of this development:

- Hydroelectric power will increase 25%, from 19.6 TWh to 24.6 TWh;
- Power generated from wind will increase by a factor of 5, from 27.2 TWh to 140.1 TWh;
- Photovoltaic power will increase by a factor of 17, from 1.2 TWh to 21.3 TWh;
- Biomass conversion to electricity will grow by a factor of 3.5, from 12 TWh to 41.3 TWh; and

- Geothermal energy will contribute 15.5 TWh in 2050, significantly less than in the innovation option without CCS.

Figure 5.3-39: Innovation scenario with CCS: Net power generation from renewable energy sources, 2005 – 2050, in TWh



Source: Prognos 2009

5.3.6.1.3 Construction of new conventional power plants

Construction of new conventional power plants in the innovation options with and without CCS is based on coverage of annual peak loads and on the goal of reducing CO_2. Additions and disposals of equipment follow the marginal cost logic used in current market mechanisms. The capacity factor of the conventional power plants to be used develops in accordance with capacity needs for the specified expansion path for renewable energy sources. The cost-effectiveness of using power plants depends crucially on this. The power plants already under construction today (see Chapter 2) are included in the new power plant capacity built under both options below.

In the innovation option without CCS, a total of 24.2 GW of new conventional power plant capacity is built between 2008 and 2050. Natural gas power plants, at 12.4 GW, represent more than half of the new installed capacity. Conventional hard coal power plants account for another 6.6 GW, and lignite power plants account for 5.3 GW. Nine of these – block-unit power plants – are already planned or under construction with a total capacity of approx. 9.4 GW. Additionally, following the marginal cost logic, the model calculates an additional construction of lignite-fired power plants for a total of nearly 4 GW in the period from 2013 to 2029. These additional power plants will emit up to 22.5 million metric tons of CO_2 per year during their service life until they are shut down for reasons of cost-effectiveness; cumulatively they will emit close to 600 million metric tons of CO_2 during their service life, and will thus burden the carbon budget that Germany aspires to. If this kind of capacity and energy were provided by gas-fired power plants, the CO_2 emissions during the plants' service lives would be reduced by 350 million metric tons, to 250 million.

In the innovation option with CCS, significantly more conventional power plants are built, for a total of 34.8 GW. These are primarily additional lignite-fired CCS plants (10 GW) and hard coal-fired CCS plants (3 GW), which help reduce CO_2 in this scenario. On the other hand, fewer gas-fired power plants are built, at 9.7 GW, in part also because the demand for balancing power is less.

5.3.6.2 Results for the innovation option without CCS

5.3.6.2.1 Energy

Net power consumption in the innovation option without CCS decreases by 20% between 2005 and 2050, to 453 TWh. The crucial factor here is the decline in final energy consumption to 330 TWh in the residential, service, industry and transport sectors (see Sec. 5.3.5). Consumption also decreases in the conversion sector (refineries, district heat generation, lignite open pit mining, etc.). Transport losses from the power grid (line losses) likewise decrease slightly because of the smaller volumes transported. Power consumed by storage units rises sharply.

Imports of renewably generated electricity will increase considerably. From 2021 onwards, electricity imports will exceed electricity exports, which still predominated in the starting year, 2005. Net imports will reach 48 TWh in 2050.

Based on this development, the necessary net power generation in Germany will decrease one-third between 2005 and 2050, from 583 TWh to 405 TWh.

Table 5.3-41: Innovation scenario without CCS: Net power consumption and generation, 2005 – 2050, in TWh

		Innovation w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Final energy consumption – Electricity	517	423	370	345	330
Consumption for conversion	16	14	13	10	8
Line losses	29	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	35	56	90
Net power consumption	573	485	443	436	453
Net imports*	-9	0	15	33	48
Net power generation	583	485	428	403	405

**Imported electricity is from renewable sources from 2021 onwards* *Source: Prognos 2009*

In the “Innovation without CCS” option, the overall net power generation of Germany's entire power plant fleet including storage units will have decreased by a third by the year 2050. Renewables are able to expand their share in Germany's net power generation eightfold. Off-shore wind power in particular contributes to this growth essentially (for detailed results, also refer to Table 5.2-3).

- In 2050 electricity will no longer be generated from hard coal and lignite-fired power plants. As explained above, the last lignite power plant will be decommissioned in 2047 after a service life of 18 years.

- Power generation from natural gas will decrease 83% between 2005 and 2050. Its share, which will be used primarily as balancing power and to a small extent for combined heat and power generation, will shrink from 11.5% to 2.8%.

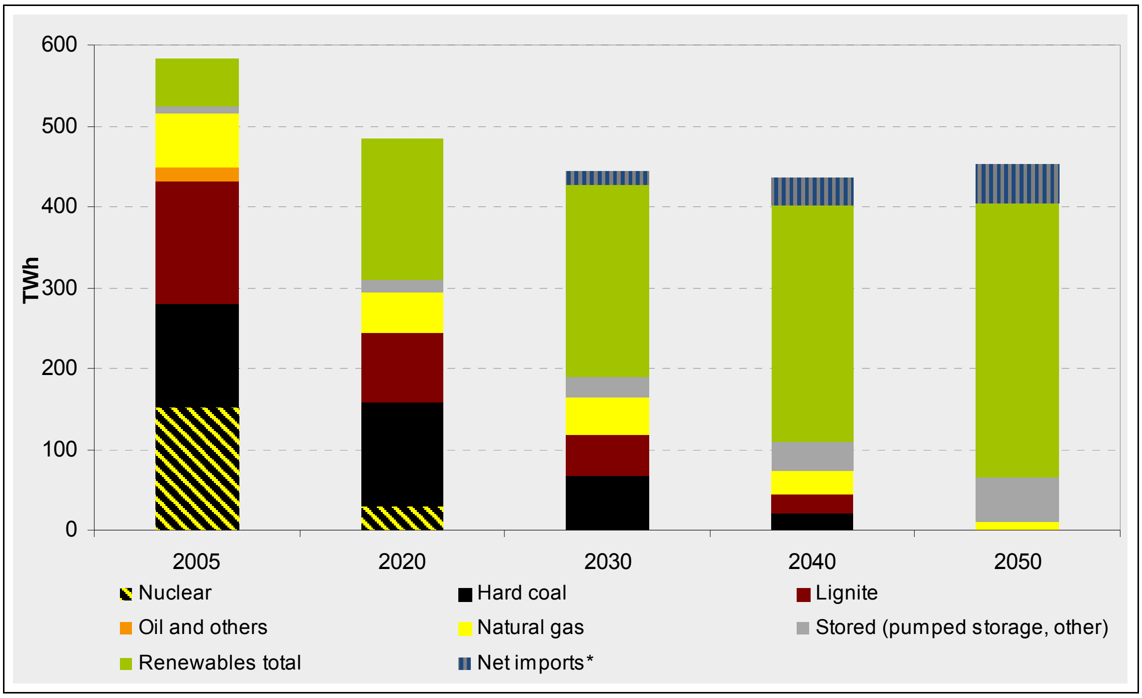
- Storage units will take on a leading role in balancing fluctuating feed-ins from renewable sources. Their share of net power generation will grow from 1.2% to 13.5%.

- In 2050, 83.7% of the power generated in Germany will be from renewable energy sources. This represents an increase by a factor of 8 from the 14.5% share in 2005.

In the net power generation described above, if we consider only primary power generation and omit interim storage units as secondary generation plants, the share of renewable sources increases substantially further.

A total of 96.7% of total primary power generation in Germany will be based on renewable energy sources in 2050.

Figure 5.3-40: Innovation scenario without CCS: Net power generated by German power plant fleet, 2005 – 2050, in TWh



**Imported electricity is from renewable sources from 2021 onwards* *Source: Prognos 2009*

5.3.6.2.2 Capacity

Declining net power consumption over the long term will also decrease the annual peak load on the German power grid that must be covered by firm generating capacity based on renewables (with imports), storage units, and conventional power plants (see Table 5.3-47). Among renewables, the low secured capacity relative to annual power generated will have a negative effect on the coverage of peak loads. Increases in renewable wind and photovoltaics will mean that more balancing power capacity must be built, especially storage units. This effect was taken into account in modelling the power plant fleet.

Table 5.3-42: Innovation scenario without CCS: Peak load and secured capacity, 2005 – 2050, in GW

		Innovation w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Peak load	84	68	60	56	54
Secured capacity	96	80	69	69	61
Renewables (incl. imports)	6	13	17	22	27
Conventional and stored	89	67	52	47	34

Source: Prognos 2009

In the innovation option without CCS, the installed net capacity of the German power plant fleet rises 12.8% overall by 2050, from 139.4 GW to 157.3 GW, in spite of a distinct decrease in net power demand. Since CCS technology is not available here, the power plant fleet in 2050 will have only a few conventional natural gas-fired power plants left. The chief characteristics of the fleet in 2050 will be generating systems that use renewable sources, and storage systems. For details of developments from 2005 to 2050, see also Table 5.3-50.

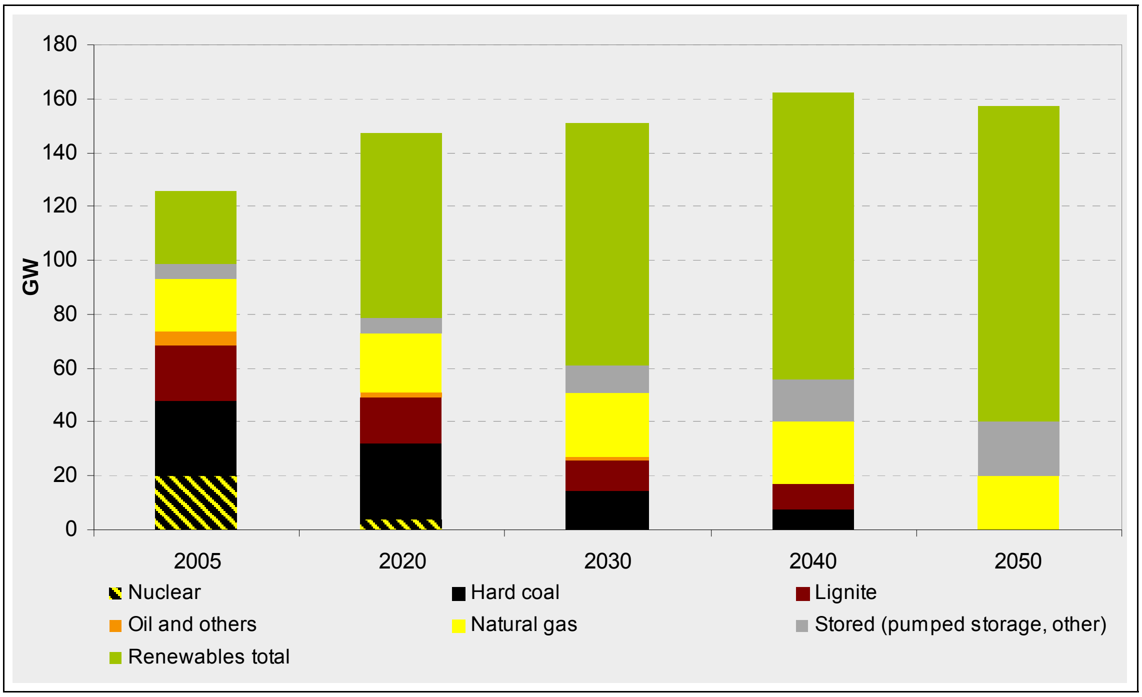
- The service lives of hard coal and lignite power plants will gradually shorten because of the additional construction of renewable-energy systems until it is no longer cost effective to operate the coal-fired plants after 2045 to 2047. By that point, all conventional power plants will be fully depreciated in business terms, although some will still be well short of their technical service lives. The "youngest" lignite-fired power plant will be 18 years old (service life 2029 to 2047, 1,250 MW); the rest will be 29-30 years old (built from 2013 to 2018, to be decommissioned gradually from 2043 to 2046). If these were replaced by gas-fired power plants, in contrast to the additional power plants currently under planning or under construction, the total gas used for power plants would increase slightly until 2030, compared to today (from 571 PJ to 629 PJ), and after that would decrease sharply to barely 150 PJ in 2050.

- Installed capacity of natural gas-fired power plants will remain nearly constant. Their share of the power plant fleet will decrease from 15.6% in 2005 to 12.6% by 2050.

- Storage capacity will expand substantially. Storage systems' share of installed capacity will grow from 4.3% in 2005 to 13.0% in 2050.

- Renewables' share of total capacity will expand steadily from 25% to nearly three-quarters of total installed capacity.

Figure 5.3-41: Innovation scenario without CCS: Installed capacity of the German power plant fleet, 2005 – 2050, in GW



Source: Prognos 2009

Utilisation of the capacity of the power plant fleet will decrease substantially compared to the reference options with and without CCS, even though availability of renewable sources will rise. The primary reason for declining mean annual capacity factors in the German power plant fleet is the elimination of the majority of the conventional power plants still in use for the base load today that generate their power from nuclear energy, hard coal and lignite.

Table 5.3-43: Innovation scenario without CCS: Net capacity, net power generated and annual capacity factors by input energy sources, 2005 – 2050

		Innovation w/o CCS			
	2005	2020	2030	2040	2050
Net capacity in GW					
Nuclear	19.9	4.1	0.0	0.0	0.0
Hard coal	27.9	28.1	14.7	7.5	0.0
Hard coal w/ CCS		0.0	0.0	0.0	0.0
Lignite	20.8	16.8	11.4	9.7	0.0
Lignite w/ CCS		0.0	0.0	0.0	0.0
Natural gas	19.6	22.6	23.9	23.0	19.8
Oil and others	5.2	1.7	0.7	0.0	0.0
Stored (pumped storage, other)	5.4	5.4	10.4	15.4	20.4
Hydroelectric	4.6	5.1	5.2	5.2	5.2
Wind power, total	18.4	38.1	52.8	65.3	71.0
Wind power, onshore	18.4	28.1	28.9	31.9	33.5
Wind power, offshore		10.0	23.2	33.5	37.6
Photovoltaics	1.9	17.9	24.0	27.1	29.0
Biomass	2.2	7.1	6.9	6.7	6.7
Geothermal		0.3	0.9	2.1	5.1
Total net capacity	125.9	147.2	150.3	162.1	157.3
Net power generation in TWh					
Nuclear	151.0	30.2	0.0	0.0	0.0
Hard coal	128.0	128.6	68.1	22.0	0.0
Hard coal w/ CCS		0.0	0.0	0.0	0.0
Lignite	152.0	85.9	49.6	23.0	0.0
Lignite w/ CCS		0.0	0.0	0.0	0.0
Natural gas	67.0	49.3	46.9	28.2	11.5
Oil and others	18.1	0.0	0.0	0.0	0.0
Stored (pumped storage, other)	7.1	15.8	24.4	36.9	54.7
Hydroelectric	19.6	24.3	24.6	24.8	24.8
Wind power, total	27.2	87.2	142.2	186.7	209.3
Wind power, onshore	27.2	53.5	58.1	63.7	66.9
Wind power, offshore		33.7	84.1	123.0	142.4
Photovoltaics	1.2	15.5	21.9	25.3	27.7
Biomass	12.0	46.2	44.7	41.3	41.3
Geothermal		1.8	6.0	14.7	35.7
Total net power generation	583.2	484.9	428.4	402.9	405.1
Annual capacity factors in hrs/yr					
Nuclear	7,588	7,428	-	-	-
Hard coal	4,588	4,572	4,626	2,923	-
Hard coal w/ CCS	-	-	-	-	-
Lignite	7,308	5,116	4,370	2,373	-
Lignite w/ CCS	-	-	-	-	-
Natural gas	3,418	2,183	1,962	1,222	581
Oil and others	3,481	3	3	-	-
Stored (pumped storage, other)	1,315	2,912	2,338	2,392	2,679
Hydroelectric	4,261	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,694	2,859	2,948
Wind power, onshore	1,478	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000
Average	4,632	3,294	2,851	2,486	2,576

Source: Prognos 2009

5.3.6.2.3 Fuel input and CO_2 emissions

The basis of calculation for CO_2 emissions is fuel input broken down by energy source. Fuel input is derived from net power generation and the associated mean annual fuel utilisation ratios of the generating plants (annual utilisation ratios). The long-term declining annual utilisation ratios of conventional power plants in this scenario are primarily the result of lower annual capacity factors and the associated more frequent start-up and shutdown procedures.

The results for the innovation option without CCS are shown in Table 5.3-45.

Table 5.3-44: Innovation scenario without CCS: Fuel input in PJ and annual utilisation ratio in %, 2005 – 2050

		Innovation w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input / Primary energy input					
Nuclear	1,658	331	0	0	0
Hard coal	1,182	1,128	615	219	0
Hard coal w/ CCS	0	0	0	0	0
Lignite	1,537	776	409	205	0
Lignite w/ CCS	0	0	0	0	0
Natural gas	571	380	356	221	95
Oil and others	314	0	0	0	0
Stored (pumped storage, other)	35	77	127	203	324
Hydroelectric	82	93	94	94	94
Wind power, total	98	314	512	672	753
Wind power, onshore	98	193	209	229	241
Wind power, offshore	0	121	303	443	513
Photovoltaics	4	56	79	91	100
Biomass	136	486	444	394	379
Geothermal	0	71	215	490	1,118
Total fuel input	5,617	3,711	2,850	2,591	2,863
Annual utilisation ratio in %					
Nuclear	32.8	32.8	0	-	-
Hard coal	39.0	41.0	39.9	36.2	-
Hard coal w/ CCS	-	-	-	-	-
Lignite	35.6	39.8	43.7	40.5	-
Lignite w/ CCS	-	-	-	-	-
Natural gas	42.2	46.8	47.4	45.8	43.5
Oil and others	20.8	20.8	22.2	-	-
Stored (pumped storage, other)	74.0	74.0	74.0	74.0	74.0
Hydroelectric	94.0	94.3	94.5	94.8	95.0
Wind power, total	100.0	100.0	100.0	100.0	100.0
Wind power, onshore	100.0	100.0	100.0	100.0	100.0
Wind power, offshore	-	100.0	100.0	100.0	100.0
Photovoltaics	100.0	100.0	100.0	100.0	100.0
Biomass	31.8	34.2	36.2	37.7	39.2
Geothermal	-	9.4	10.1	10.8	11.5
Average	36.9	47.0	54.1	56.0	50.9

Source: Prognos 2009

Total fuel input, or the use of renewable energy sources, as the case may be, will decrease 49% between 2005 and 2050. One reason, apart from decreasing net power generation, is the rising share of renewable energy sources; with the exception of power generated from geothermal energy and biomass, these have been defined as having a "fuel" utilisation ratio of 100%.

The use of renewable energy sources for power generation is treated as CO_2-emission neutral, in accordance with the generally applicable definition. For that reason, only fossil energy sources – hard coal, lignite, natural gas, oil, and other combustibles – are relevant for the calculation of CO_2 emissions from power generation. The quantities of biomass converted to electricity are made up about half of waste and residues, some of which are not considered renewable and therefore do have a low CO_2 factor. The calculation is based on fuel input broken down by energy source, and on the fuel-specific emission factors according to the greenhouse gas inventory.

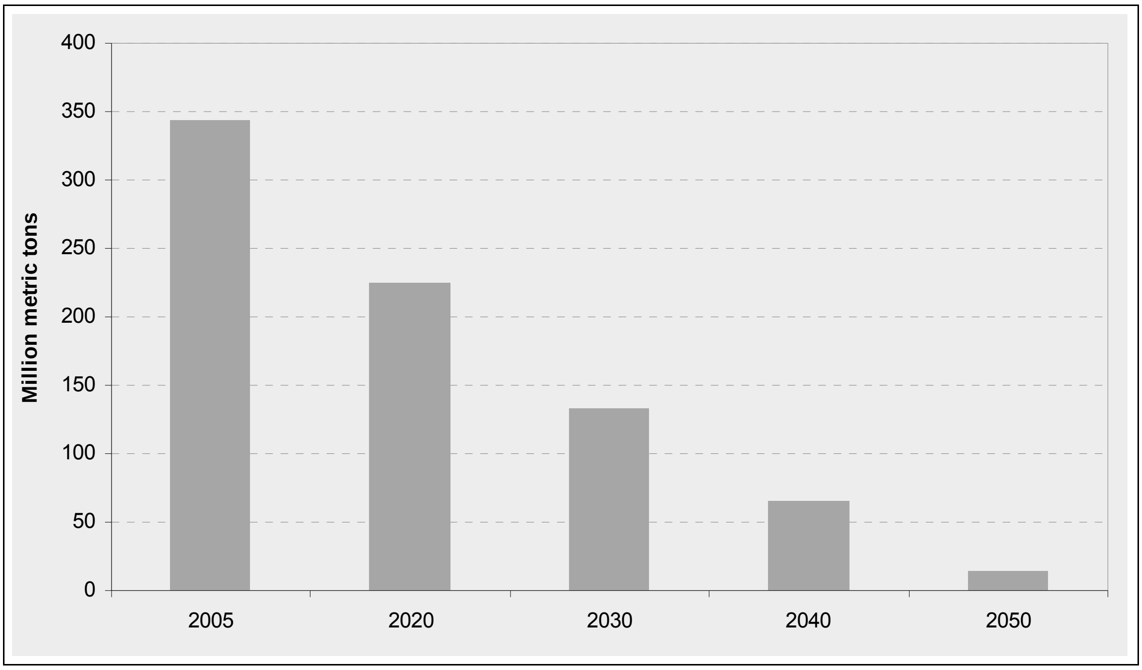
In the innovation option without CCS, CO_2 emissions from power generation in Germany decrease 96% between 2005 and 2050, to 14 million metric tons. The remaining emissions come from the remaining natural gas systems and from waste components in biomass.

Table 5.3-45: Innovation scenario without CCS: Fuel input in PJ and CO_2 emissions in million metric tons, 2005 – 2050

		Innovation w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input in PJ					
Hard coal	1,182	1,128	615	219	-
Hard coal w/ CCS	0	0	0	0	0
Lignite	1,537	776	409	205	-
Lignite w/ CCS	0	0	0	0	0
Natural gas	571	380	356	221	95
Oil and others	314	0	0	0	0
Biomass / Waste	136	486	444	394	379
CO_2 emission factors in kg/GJ					
Hard coal	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9
Lignite	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11
Natural gas	56	56	56	56	56
Oil and others	80	80	80	80	80
Biomass / Waste	23	23	23	23	23
CO_2 emissions in million metric tons					
Hard coal	111	106	58	21	-
Hard coal w/ CCS	0	0	0	0	0
Lignite	172	87	46	23	-
Lignite w/ CCS	0	0	0	0	0
Natural gas	32	21	20	12	5
Oil and others	25	0	0	0	0
Biomass / Waste	3	11	10	9	9
Total CO_2 emissions	344	225	134	65	14

Source: Prognos 2009

Figure 5.3-42: Innovation scenario without CCS: CO_2 emissions by the German power plant fleet, 2005 – 2050, in million metric tons



Source: Prognos 2009

If, for business reasons, the "youngest" lignite-fired power plants in particular, built in 2016 or later, were to be used at reduced capacity beyond 2037 (with equivalently reduced net feed-ins from renewables), then depending on the operating mode, in 2050 there would still be an emission base of about 8-11 million metric tons of CO_2 (direct emissions, not including emissions from flue gas cleaning) per year, or cumulatively an additional roughly 24-33 million metric tons of emissions by 2050.

5.3.6.2.4 Costs

The costs of the scenarios and options were compared on the basis of the full cost of power generation in Germany.

For domestic power generation, the full cost of power generation includes all costs incurred to build and operate power plants. These include investment costs, fuel costs (including CO_2 costs), and all costs for supplies, repair and maintenance, personnel, financing, and plant insurance. Costs of conventional power generation are based on the calculations from the Prognos AG power plant model. For renewable energy sources and power imports, own production costs are used, based on the guideline study [Nitsch/DLR 2008] (Table 5.3-47). Production costs per kWh rise 61% between 2005 and 2050. This is less than in the reference scenario, and is associated most of all with the sharp cost degression of renewable energy sources assumed by Nitsch [DLR 2008].
Compared to the reference scenario, only a small amount of gas capacity must be added, although it will be expensive; furthermore, only a few coal-fired power plants encumbered with CO_2 prices are still on the grid. Because of the sharp decrease in demand, full cost rises only 25% from 2005.

Table 5.3-46: Innovation scenario without CCS: Specific production cost and full cost of power generation, 2005 – 2050

		Innovation w/o CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Specific production cost of net power generation in euro cents/kWh (real, 2007)					
Average – Conventional generation	4.3	8.1	10.3	14.8	29.8
Nuclear	4.0	4.1	-	-	-
Hard coal	4.6	8.0	9.3	12.9	-
Hard coal w/ CCS		-	-	-	-
Lignite	3.3	6.8	7.2	10.2	-
Lignite w/ CCS		-	-	-	-
Natural gas	8.0	13.1	15.1	20.0	29.8
Oil and others		-	-	-	-
Stored (pumped storage, other)	10.3	11.5	11.9	11.1	9.4
Power imports	0.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	8.7	8.0	7.7
Hydroelectric	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	6.9	6.7
Onshore	11.1	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1
Average – Total	5.2	9.0	9.5	9.4	8.4
Full cost of power generation in EUR bn (real, 2007)					
Conventional generation – Total	22.3	23.8	17.0	10.8	3.4
Nuclear	6.0	1.2	0.0	0.0	0.0
Hard coal	5.9	10.3	6.3	2.8	-
Hard coal w/ CCS	-	-	-	-	-
Lignite	5.0	5.9	3.6	2.4	-
Lignite w/ CCS	-	-	-	-	-
Natural gas	5.3	6.5	7.1	5.6	3.4
Oil and others	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.8	2.9	4.1	5.1
Power imports	-	0.0	1.3	2.5	3.4
Average – Renewable generation	7.5	18.0	20.8	23.4	26.1
Hydroelectric	2.2	2.4	2.5	2.5	2.5
Wind power, total	3.0	7.5	10.4	13.0	14.1
Onshore	3.0	4.3	4.3	4.7	4.9
Offshore	-	3.2	6.1	8.3	9.3
Photovoltaics	0.7	2.3	2.4	2.5	2.6
Biomass	1.6	5.6	5.1	4.3	4.3
Geothermal	0.0	0.2	0.5	1.1	2.5
Total full cost of power generation	30.5	43.7	42.0	40.8	38.0

Source: Prognos 2009

5.3.6.3 Results for the innovation option with CCS

5.3.6.3.1 Energy

In terms of net power consumption in Germany, the Innovation option with CCS does not differ from the innovation option without CCS. But clear differences arise in stored power consumption, which is 33 TWh less here (2050), and in the slightly higher amounts of electricity imported. These effects reduce the necessary net power generation in Germany by a total of 36 TWh against the innovation option without CCS for 2050, to 369 TWh.

Table 5.3-47: Innovation scenario with CCS: Net power consumption and generation, 2005 – 2050, in TWh

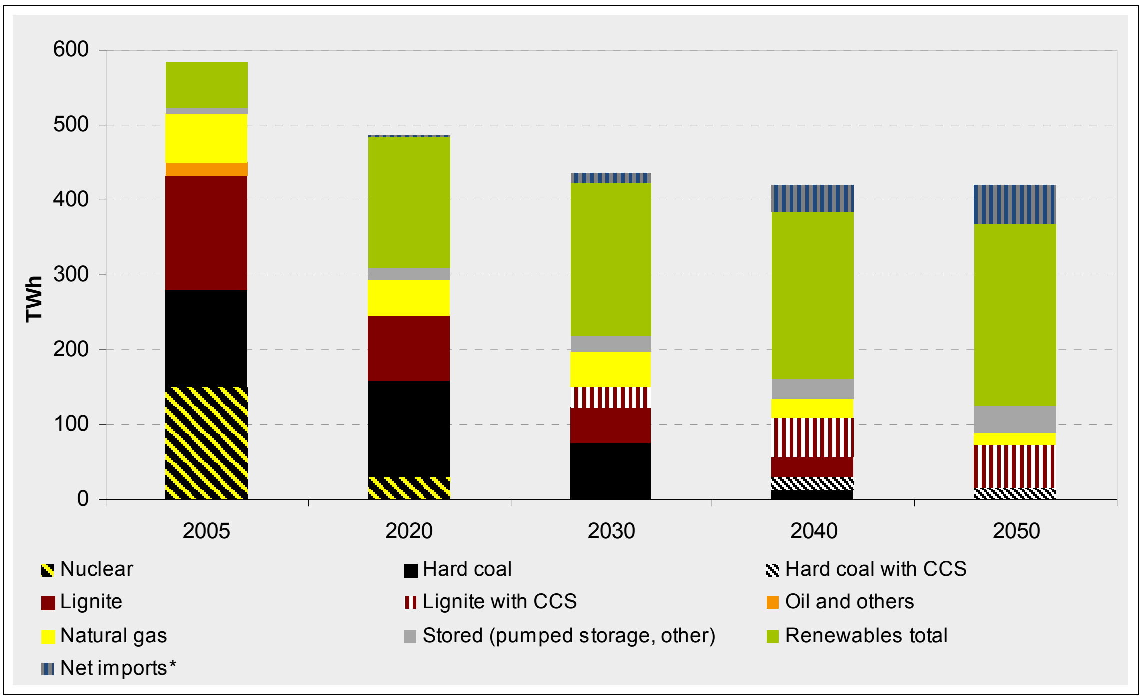
		Innovation w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Final energy consumption – Electricity	517	423	370	345	330
Consumption for conversion	16	14	13	10	8
Line losses	29	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	29	40	57
Net power consumption	573	485	436	420	420
Net imports*	-9	0	14	35	51
Net power generation	583	485	423	384	369

**Imported electricity is from renewable sources from 2020 onwards* *Source: Prognos 2009*

Net power generation by the power plant fleet, including storage units, will decrease 36% by 2050. The renewables in particular will then contribute heavily to power generation, but coal-fired power plants equipped with CO_2 separation will gain in significance (see Table 5.3-50 for detailed results).

- From 2045 onwards, power will no longer be generated in lignite and hard coal-fired power plants without CCS.
- CCS technology will be used in 4.4% of power generation from hard coal by 2050. Lignite-fired CCS power plants will then already be contributing a substantial 15.5% towards covering electricity demand.
- Power generation from natural gas, with a 76% decrease, will be down less sharply against 2005 than in the innovation option without CCS, but will still decrease more than average. The share of natural gas, which in this option will be used primarily as balancing power and in combined heat and power generation, will shrink from 11.5% to 4.4%.
- In this option too, storage units will take on a leading role in balancing fluctuating feed-ins from renewable sources. Because of the lower feed-in from renewables, however, storage units' share of net power generation will increase only from 1.2% to 9.9%.
- Renewable sources will contribute 65.8% of power generation in Germany by 2050. This represents an increase by a factor of 6.5 from their 10% share in 2005.

Figure 5.3-43: Innovation scenario with CCS: Net power generated by German power plant fleet, 2005 – 2050, in TWh



**Imported electricity is from renewable sources from 2021 onwards* *Source: Prognos 2009*

If, analogously to the approach in the Innovation option without CCS, one considers only primary power generation without intermediate storage, the share of renewables in the Innovation option with CCS increases significantly further. Primary power generation in Germany will then be based 73.1% on renewables in 2050.

5.3.6.3.2 Capacity

The Innovation options with and without CCS make different assumptions about the developmental path of renewables in Germany, and also about long-term electricity imports. Further differences between the scenarios arise because of the availability of CCS technology for hard coal and lignite fuels. In the Innovation option with CCS, CCS gradually becomes established in the German power plant fleet from 2025 onwards. Differences in the construction of new conventional power plant capacity and in the use of renewables also result in slight deviations in regard to secured capacity. All in all, the share of secured capacity from renewables is lower here.

Table 5.3-48: Innovation scenario with CCS: Peak load and secured capacity, 2005 – 2050, in GW

		Innovation w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Peak load	84	68	60	56	54
Secured capacity	96	80	67	69	59
Renewables (incl. imports)	6	13	16	19	23
Conventional and stored	89	67	51	50	36

Source: Prognos 2009

In contrast to the other options described here, the installed net capacity of the German power plant fleet to 2050 in the Innovation option with CCS rises only slightly, by 3.6%, from 125.9 GW in 2005 to 130.4 GW in 2050. In contrast to the Innovation option without CCS, for the long term the power plant fleet includes not only natural gas power plants, but also power plants to convert hard coal (with CCS) and lignite (with CCS) to electricity. From 2025 on, new coal-fired power plants will be built only with CCS technology, plus there will be additional systems for generating power from renewable sources. All nuclear power plants will leave the fleet after generating their individual remaining power outputs. For reasons of cost, no new oil-fired power plants will be built (for details of results see Table 5.3-50). Details of developments from 2005 to 2050:

- Hard-coal and lignite-fired power plants **without** CO_2 separation built before 2025 will no longer be cost effective by around 2045, and will be taken off the grid. No old coal-fired power plants will be retrofitted with CCS technology. At an age of at least 32, they will be fully depreciated in business terms.

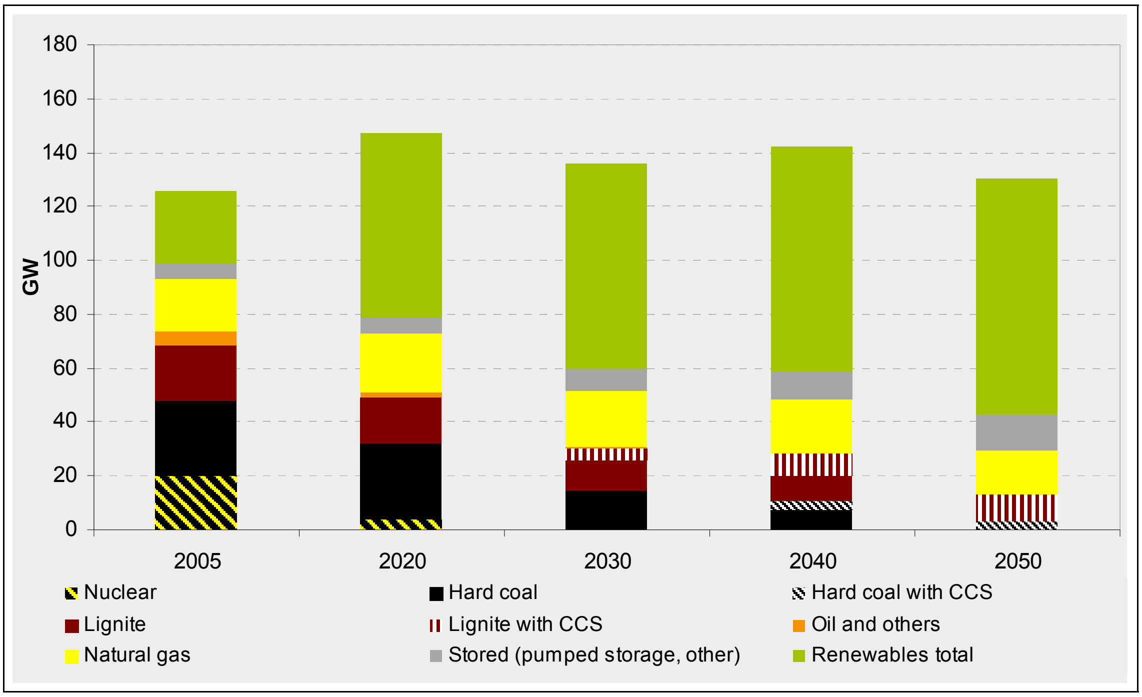
- **CCS power plants** for lignite will be built after 2025, and for hard coal as well after 2030. The installed capacity of these plants will represent 2.3% by 2050 for hard coal, and 7.7% for lignite.

- The installed capacity of natural gas power plants will decrease by nearly a quarter. Their share of the power plant fleet will decrease from 15.6% to 12.9%.

- Storage capacity will expand significantly, though less than in the Innovation option without CCS. Storage systems' share of installed capacity will grow from 3.9% in 2005 to 9.9% in 2050.

- Renewables' share of total capacity will expand steadily from 25% to about two-thirds.

Figure 5.3-44: Innovation scenario with CCS: Installed capacity of the German power plant fleet, 2005 – 2050, in GW



Source: Prognos 2009

The mean utilisation of power plant fleet capacity (full load hours per year) will decrease less in the Innovation option with CCS than in the option without CCS, because of the lower share of renewables and the construction of the CCS power plants operated for the base load. The mean annual utilisation of renewable sources, and especially storage power plants, will increase, while natural gas power plants will be used significantly less often on average.

Table 5.3-49: *Innovation scenario with CCS: Net capacity, net power generated and annual capacity factors by input energy sources, 2005 – 2050*

		Innovation w/ CCS			
	2005	2020	2030	2040	2050
Net capacity in GW					
Nuclear	19.9	4.1	0.0	0.0	0.0
Hard coal	27.9	28.1	14.7	7.5	0.0
Hard coal w/ CCS		0.0	0.0	3.0	3.0
Lignite	20.8	16.8	11.4	9.7	0.0
Lignite w/ CCS		0.0	4.0	8.0	10.0
Natural gas	19.6	22.6	20.9	20.0	16.8
Oil and others	5.2	1.7	0.7	0.0	0.0
Stored (pumped storage, other)	5.4	5.4	7.9	10.4	12.9
Hydroelectric	4.6	5.1	5.2	5.2	5.2
Wind power, total	18.4	38.1	43.7	49.0	51.2
Wind power, onshore	18.4	28.1	28.4	29.6	30.2
Wind power, offshore		10.0	15.3	19.4	21.0
Photovoltaics	1.9	17.9	20.3	21.6	22.3
Biomass	2.2	7.1	6.9	6.7	6.7
Geothermal		0.3	0.5	1.0	2.2
Total net capacity	125.9	147.2	136.2	142.1	130.4
Net power generation in TWh					
Nuclear	151.0	30.2	0.0	0.0	0.0
Hard coal	128.0	128.6	75.7	12.8	0.0
Hard coal w/ CCS		0.0	0.0	17.5	16.3
Lignite	152.0	85.9	46.9	26.9	0.0
Lignite w/ CCS		0.0	27.8	52.2	57.1
Natural gas	67.0	49.3	48.0	24.4	16.1
Oil and others	18.1	0.0	0.0	0.0	0.0
Stored (pumped storage, other)	7.1	15.8	20.5	27.2	36.5
Hydroelectric	19.6	24.3	24.4	24.6	24.6
Wind power, total	27.2	87.2	112.4	130.4	140.1
Wind power, onshore	27.2	53.5	57.0	59.1	60.4
Wind power, offshore		33.7	55.4	71.3	79.7
Photovoltaics	1.2	15.5	18.6	20.1	21.3
Biomass	12.0	46.2	44.7	41.3	41.3
Geothermal		1.8	3.5	7.1	15.5
Total net power generation	583.2	484.9	422.5	384.5	368.8
Annual capacity factors in hrs/yr					
Nuclear	7,588	7,428	-	-	-
Hard coal	4,588	4,572	5,145	1,704	-
Hard coal w/ CCS	-	-	-	5,843	5,418
Lignite	7,308	5,116	4,134	2,770	-
Lignite w/ CCS	-	-	6,959	6,521	5,710
Natural gas	3,418	2,183	2,295	1,216	956
Oil and others	3,481	3	18	-	-
Stored (pumped storage, other)	1,315	2,912	2,585	2,607	2,827
Hydroelectric	4,261	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,573	2,664	2,735
Wind power, onshore	1,478	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000
Average	4,632	3,294	3,102	2,706	2,829

Source: Prognos 2009

5.3.6.3.3 Fuel input and CO_2 emissions

As in the other options, CO_2 emissions are calculated by way of fuel input broken down by energy sources. Fuel input is derived from net power generation and the associated mean annual fuel utilisation ratios of the generating plants (annual utilisation ratios). The long-term declining annual utilisation ratios of conventional power plants in this option are primarily the result of declining annual capacity factors and the associated more frequent start-up and shutdown procedures.

The introduction of CCS technology means that significantly more fossil fuels will be used in 2050 (especially hard coal and lignite) than is the case in the Innovation option without CCS.

Table 5.3-50: Innovation scenario with CCS: Fuel input in PJ and annual utilisation ratio in %, 2005 – 2050

		Innovation w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Fuel input / Primary energy input					
Nuclear	1,658	331	0	0	0
Hard coal	1,182	1128	642	137	0
Hard coal w/ CCS	0	0	0	150	142
Lignite	1,537	776	390	249	0
Lignite w/ CCS	0	0	238	443	507
Natural gas	571	380	365	192	129
Oil and others	314	0	0	0	0
Stored (pumped storage, other)	35	77	104	144	207
Hydroelectric	82	93	93	93	93
Wind power, total	98	314	405	469	504
Wind power, onshore	98	193	205	213	218
Wind power, offshore	0	121	199	257	287
Photovoltaics	4	56	67	73	77
Biomass	136	486	444	394	379
Geothermal	0	71	126	235	484
Total fuel input	5,617	3,711	2,874	2,581	2,522
Annual utilisation ratio in %					
Nuclear	32.8	32.8	-	-	-
Hard coal	39.0	41.0	42.5	33.6	-
Hard coal w/ CCS	-	-	-	42.1	41.2
Lignite	35.6	39.8	43.3	38.9	-
Lignite w/ CCS	-	-	42.1	42.4	40.5
Natural gas	42.2	46.8	47.3	45.7	45.1
Oil and others	20.8	20.8	26.0	-	-
Stored (pumped storage, other)	74.0	74.0	74.0	74.0	74.0
Hydroelectric	94.0	94.3	94.5	94.8	95.0
Wind power, total	100.0	100.0	100.0	100.0	100.0
Wind power, onshore	100.0	100.0	100.0	100.0	100.0
Wind power, offshore	-	100.0	100.0	100.0	100.0
Photovoltaics	100.0	100.0	100.0	100.0	100.0
Biomass	31.8	34.2	36.2	37.7	39.2
Geothermal	-	9.4	10.1	10.8	11.5
Average	36.9	47.0	52.9	53.6	52.6

Source: Prognos 2009

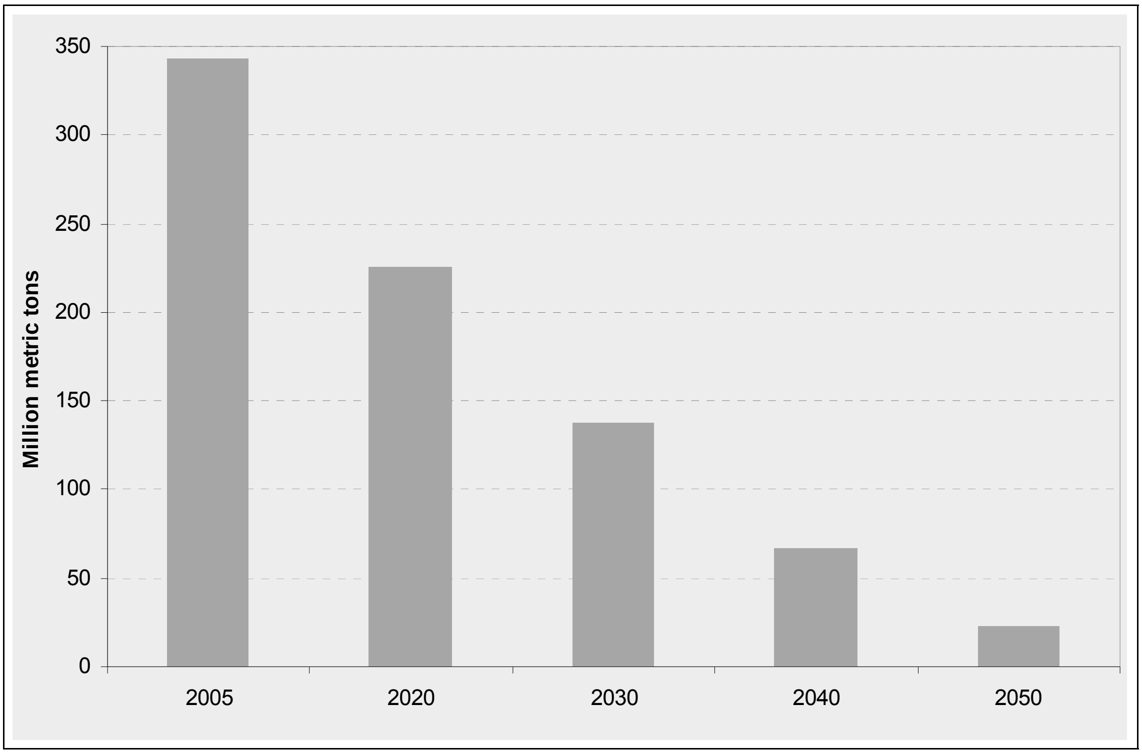
In the innovation scenario option with CCS, total fuel input, or the use of renewable energy sources, decreases 55.1% between 2005 and 2050. This decrease is greater than in the Innovation option without CCS. The reason is the significantly lower net power generation due to the reduction in demand for stored power.

The use of renewable energy sources for power generation is treated as CO_2-emission neutral, in accordance with the generally applicable definition. For that reason, only fossil energy sources – hard coal, lignite, natural gas, oil, and other combustibles – are considered in calculating CO_2 emissions from power generation. The calculation is based on fuel input broken down by energy source, and on the fuel-specific energy factors. A 90% separation rate was assumed for the CCS technology. The specific emission factors for fuel input in these plants were accordingly estimated at one-tenth of their value for conventional power plants using the same fuel.

In the Innovation option with CCS, CO_2 emissions from power generation in Germany decrease 93% between 2005 and 2050, to 23 million metric tons.

If, for economic reasons, especially the “youngest” power plants without CCS built in 2016 or after were still in use at reduced capacity (with equivalently reduced net feed-ins from renewables), then depending on the operating mode, there would still be an emission base of about 13 million metric tons of CO_2 per year in 2050 (direct emissions, not including emissions from flue gas cleaning).

Figure 5.3-45: Innovation scenario without CCS: CO_2 emissions by the German power plant fleet, 2005 – 2050, in million metric tons



**Emissions excluding component from flue gas desulfurization* *Source: Prognos 2009*

Table 5.3-51: Innovation scenario without CCS: Fossil fuel input, CO_2 emission factors and CO_2 emissions, 2005 - 2050

		Innovation w/ CCS			
	2005	2020	2030	2040	2050
Fuel input in PJ					
Hard coal	1,182	1,128	615	219	-
Hard coal w/ CCS	0	0	0	0	0
Lignite	1,537	776	409	205	-
Lignite w/ CCS	0	0	0	0	0
Natural gas	571	380	356	221	95
Oil and others	314	0	0	0	0
Biomass / Waste	136	486	444	394	379
CO2 emission factors in kg/GJ					
Hard coal	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9
Lignite	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11
Natural gas	56	56	56	56	56
Oil and others	80	80	80	80	80
Biomass / Waste	23	23	23	23	23
CO2 emissions in million metric tons					
Hard coal	111	106	58	21	-
Hard coal w/ CCS	0	0	0	0	0
Lignite	172	87	46	23	-
Lignite w/ CCS	0	0	0	0	0
Natural gas	32	21	20	12	5
Oil and others	25	0	0	0	0
Biomass / Waste	3	11	10	9	9
Total CO2 emissions	344	225	134	65	14

**Emissions excluding component from flue gas desulfurisation* *Source: Prognos 2009*

5.3.6.3.4 Costs

The production costs and full costs of power generation and power imports are calculated using the same principles as in Sections 4.3.6.2.4, 4.3.6.3.4, and 5.3.6.2.4.

Production costs develop very similarly to those in the Innovation option without CCS, while total costs are substantially less, primarily because of significantly less investment in storage systems. In real prices, total costs of power generation in 2050 are only 18% higher than in 2005 (Table 5.3-53).

Table 5.3-52: Innovation scenario with CCS: Production cost and full cost of power generation, 2005 – 2050

		Innovation w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**
Specific production cost of net power generation in euro cents/kWh (real, 2007)					
Average – Conventional generation	4.3	8.1	9.4	10.5	10.5
Nuclear	4.0	4.1	-	-	-
Hard coal	4.6	8.0	8.7	15.8	-
Hard coal w/ CCS		-	-	9.1	10.9
Lignite	3.3	6.8	7.4	9.8	-
Lignite w/ CCS		-	5.3	5.5	6.2
Natural gas	8.0	13.1	14.7	20.1	25.3
Oil and others		-	-	-	-
Stored (pumped storage, other)	10.3	11.5	11.5	10.8	9.7
Power imports	0.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	8.9	8.3	8.0
Hydroelectric	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	7.0	6.8
Onshore	11.1	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1
Average – Total	5.2	9.0	9.2	9.1	8.6
Full cost of power generation in EUR bn (real, 2007)					
Conventional generation – Total	22.3	23.8	18.6	14.0	9.4
Nuclear	6.0	1.2	0.0	0.0	0.0
Hard coal	5.9	10.3	6.6	2.0	0.0
Hard coal w/ CCS	-	-	-	1.6	1.8
Lignite	5.0	5.9	3.5	2.6	0.0
Lignite w/ CCS	-	-	1.5	2.9	3.5
Natural gas	5.3	6.5	7.1	4.9	4.1
Oil and others	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.8	2.4	2.9	3.5
Power imports	-	0.0	1.2	2.6	3.6
Average – Renewable generation	7.5	18.0	18.1	18.5	19.5
Hydroelectric	2.2	2.4	2.4	2.5	2.5
Wind power, total	3.0	7.5	8.2	9.1	9.6
Onshore	3.0	4.3	4.2	4.3	4.4
Offshore	-	3.2	4.0	4.8	5.2
Photovoltaics	0.7	2.3	2.0	2.0	2.0
Biomass	1.6	5.6	5.1	4.3	4.3
Geothermal	0.0	0.2	0.3	0.5	1.1
Total full cost of power generation	30.5	43.7	40.2	38.1	36.0

Source: Prognos 2009

5.3.7 District heat generation

In the innovation scenario, demand for district heating decreases from 300 PJ in 2005 to 70 PG in 2050, because of the reduction in demand for space heating. Accordingly the use of energy for district heating decreases from 306 PJ to 74 PJ. The mix of energy sources shifts from natural gas (nearly 50% in 2005) to renewable energy sources. Waste heat has the largest share in 2050, at 38 PJ (50%), followed by solar heat at 24 PJ (31%). Biomass plays a transient role but is reduced strategically from 2030 onwards, so as to free up the potential needed for the transport sector.

5.3.8 Other energy conversion

The sharp reduction in consumption of all conventional energy sources reduces the energy input to produce those sources in the conversion sector. However, producing second and third-generation biofuels (987 PJ) calls for a substantial input of primary biomass. Even assuming an optimistic increase in the efficiency of conversion processes to 62% by 2050, an input of 470 PJ for this purpose must still be expected. Accordingly, given the remaining conversion inputs for coal, gas and biogas, a total of 530 PJ of primary energy will be needed for other conversion.

5.3.9 Primary energy

As explained in Sec. 2.1, primary energy consumption (deviating from the convention in the energy balance sheet) is shown here without non-energy consumption.

5.3.9.1 Option without CCS

In the option of the innovation scenario without CCS, primary energy input is reduced by 57% between 2005 and 2050. In addition to efficiency gains, here technology shifts in the industry and transport sectors exert an effect, as do the conversion of power generation to renewable energy sources and the phase-out of coal.

The picture for energy sources is roughly as follows (Table 5.3-53, Figure 5.3-46). Among fossil energy fuels, the mix includes only residues of gas for providing process heat and for generating peak and balancing power, as well as aviation fuels and diesel (inland navigation). Demand, already reduced through systematic efficiency measures and process innovations, is systematically covered from renewable energy sources. Coal is reduced 98%, though a remainder of 77 PJ is used in metal production. This remainder requires an input of 82 PJ for conversion, which is still included in the mix in 2050. The input of petroleum products is reduced by 91%. Primary energy consumption for 2050 includes mainly aviation fuels and 73 PJ from (light and heavy) heating oil for process heat production in the industry and service sectors. Gasoline is no longer used in 2050; only 4 PJ of diesel is used (inland navigation, remainders for freight and rail transport). Gas sees the relatively smallest reduction, 73%. Of the remaining amount, 766 PJ is used primarily to generate process heat in industry and the service sector, and 95 PJ is used for power generation (in some cases at industrial power plants in combined heat and power mode). The increasing use of waste for energy (in combined heat and power generation) increases the use of this fuel by a factor of 2.5.

Table 5.3-53: Innovation scenario without CCS: Primary energy consumption (excluding non-energy consumption) by energy source and sector, 2005 – 2050, in PJ

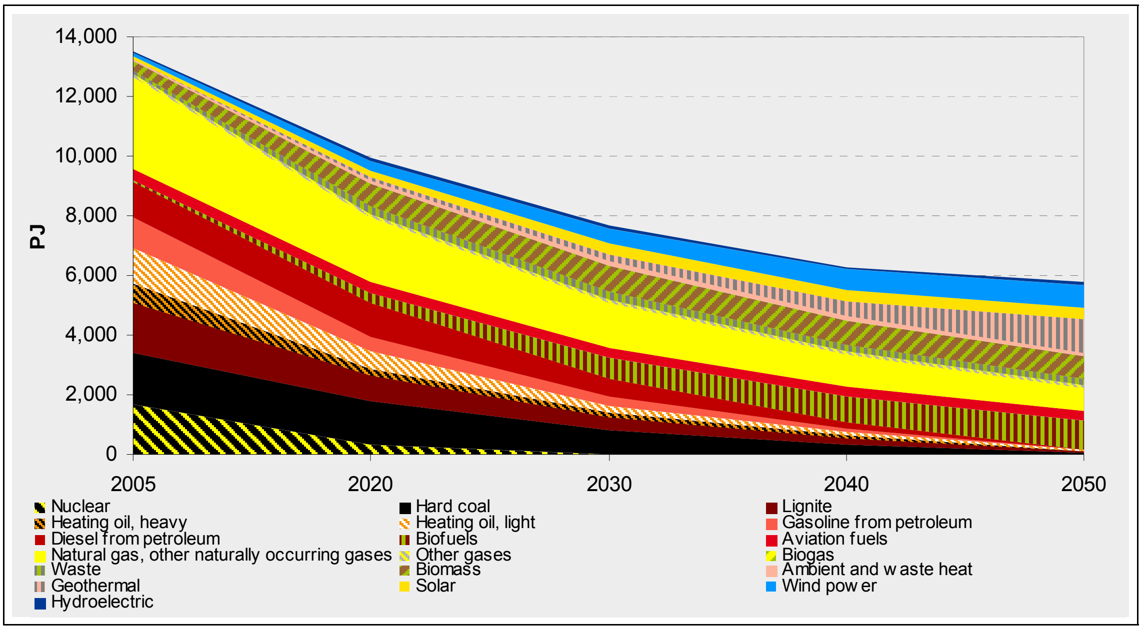
		Innovation scenario			
	2005	2020	2030	2040	2050
By energy source, without CCS					
Nuclear	**1,658**	**331**	**0**	**0**	**0**
Coal	**3,412**	**2,308**	**1,261**	**564**	**82**
Hard coal	1,749	1,476	814	330	59
Lignite	1,662	832	447	234	23
Petroleum products	**4,407**	**2,813**	**1,610**	**866**	**389**
Heating oil, light	1,151	574	256	96	36
Heating oil, heavy	675	225	130	72	37
Gasoline from petroleum	1,033	534	303	115	0
Diesel from petroleum	1,202	1,097	566	246	4
Aviation fuels	345	383	354	336	312
Other petroleum products	1	0	0	0	0
Gases	**3,228**	**2,269**	**1,611**	**1,150**	**875**
Natural gas, other naturally occurring gases	3,105	2,170	1,519	1,053	780
Other gases	123	99	92	97	95
Waste	**87**	**283**	**258**	**229**	**221**
Renewable energy sources	**741**	**1,932**	**2,939**	**3,484**	**4,200**
Biomass	337	765	874	791	726
Ambient and waste heat	69	112	149	164	144
Solar	77	246	362	388	371
Hydroelectric	82	93	94	94	94
Wind power	98	314	512	672	753
Biofuels	77	318	708	867	987
Biogas	0	14	26	17	7
Geothermal	0	71	215	490	1,118
Total primary energy consumption	13,532	9,936	7,680	6,294	5,766
By sector, without CCS					
Residential	2,069	1,391	949	605	341
Services	923	617	376	269	237
Industry	1,556	1,118	853	714	667
Transport	2,529	2,272	1,933	1,620	1,373
District heat generation	306	253	188	123	79
Power generation	5,583	3,634	2,723	2,387	2,539
Other energy conversion	567	651	658	575	530
Total primary energy consumption	13,532	9,936	7,680	6,294	5,766

Source: Prognos 2009

The contribution from renewable energy sources towards covering primary energy demand almost sextuples, but the various energy sources develop very differently. Geothermal energy has the strongest growth in both absolute and relative terms; it rises from zero to 1,118 PJ and is used entirely for power generation.

Biofuels increase by a factor of thirteen, with an absolute growth of 910 PJ. They account for almost all liquid motor fuels for road transport. They are associated with conversion losses of 470 PJ, which are accounted among biomass and represent a part of the growth there (115%). Wind energy expands by a factor of nearly eight; the use of solar energy (photovoltaics and solar thermal) nearly quintuples.

Figure 5.3-46: Innovation scenario without CCS: Primary energy consumption (excluding non-energy consumption) by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

5.3.9.2 Option with CCS

The option with CCS differs significantly from the option without CCS in terms of power generation, and consequently also differs slightly in other conversion (Table 5.3-54, Figure 5.3-47). Total primary energy input decreases 59% between 2005 and 2050.

Among energy sources, this pertains to coal and to renewable energy sources for power generation. The use of power plants with CO_2 separation means that hard coal and lignite will still be in use for base-load and intermediate-load CCS power plants until 2050, so that consumption of hard coal will decrease by 88% between 2005 and 2050, and lignite will decrease by 68%. Together they will still represent 753 PJ of the balance.

Table 5.3-54: Innovation scenario with CCS: Primary energy consumption (excluding non-energy consumption) by energy source and sector, 2005 – 2050, in PJ

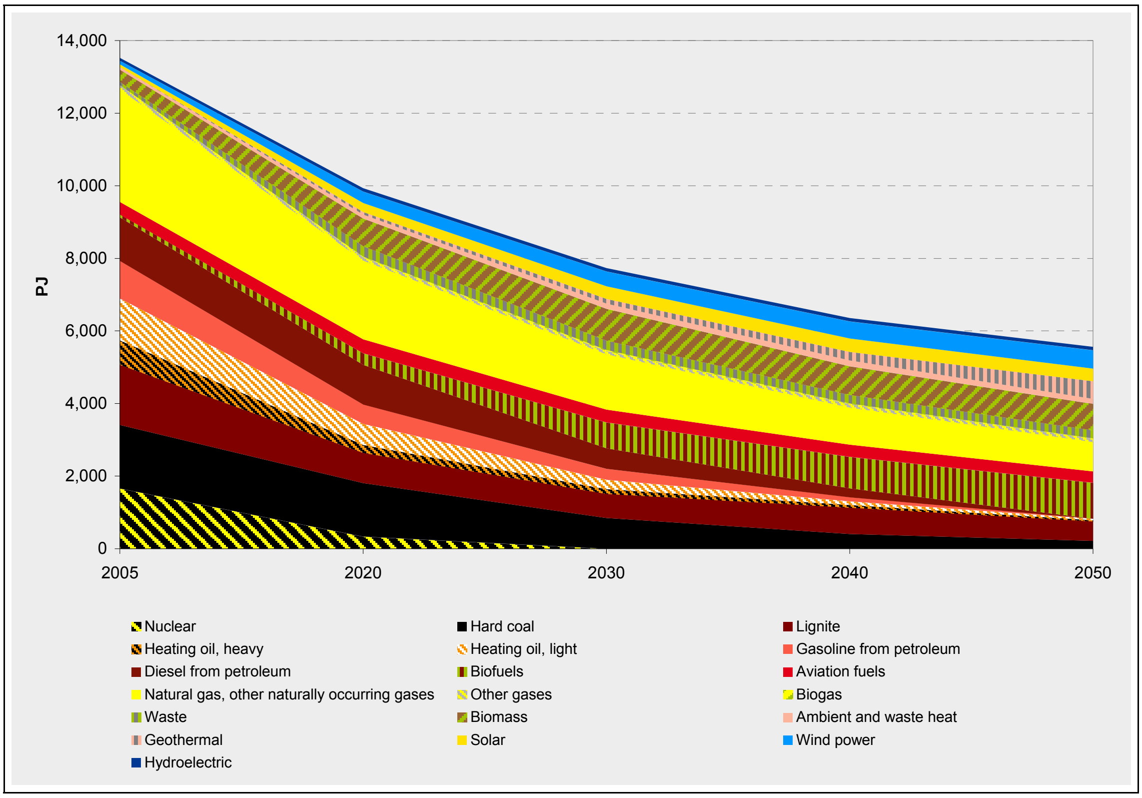
		Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**
By energy source, with CCS					
Nuclear	**1,658**	**331**	**0**	**0**	**0**
Coal	**3,412**	**2,308**	**1,514**	**1,135**	**753**
Hard coal	1,749	1,476	843	404	212
Lignite	1,662	832	671	731	540
Petroleum products	**4,407**	**2,813**	**1,611**	**866**	**389**
Heating oil, light	1,151	574	256	96	36
Heating oil, heavy	675	225	131	72	37
Gasoline from petroleum	1,033	534	303	115	0
Diesel from petroleum	1,202	1,097	566	246	4
Aviation fuels	345	383	354	336	312
Other petroleum products	1	0	0	0	0
Gases	3,228	2,269	1,620	1,121	908
Natural gas, other naturally occurring gases	3,105	2,170	1,528	1,024	813
Other gases	123	99	92	97	95
Waste	**87**	**283**	**258**	**229**	**221**
Renewable energy sources	**741**	**1,932**	**2,730**	**3,007**	**3,294**
Biomass	337	765	874	791	726
Ambient and waste heat	69	112	149	164	144
Solar	77	246	350	369	348
Hydroelectric	82	93	93	93	93
Wind power	98	314	405	469	504
Biofuels	77	318	708	867	987
Biogas	0	14	26	17	7
Geothermal	0	71	126	235	484
Total primary energy consumption	13,532	9,936	7,733	6,358	5,564
By sector, with CCS					
Residential	2,069	1,391	949	605	341
Services	923	617	376	269	237
Industry	1,556	1,118	853	714	667
Transport	2,529	2,272	1,933	1,620	1,373
District heat generation	306	253	188	123	79
Power generation	5,583	3,634	2,769	2,437	2,315
Other energy conversion	567	651	664	590	552
Total primary energy consumption	13,526	9,936	7,733	6,358	5,564

Source: Prognos 2009

Among renewable sources, the contribution of geothermal energy increases to 484 PJ (compared to 1,118 PJ in the option without CCS), wind energy use quintuples (compared to a factor of eight in the option without CCS), and solar energy increases 350% (379% in the option without CCS).

All told, primary energy input for power generation in the option with CCS decreases by 59% in the period from 2005 to 2050 (55% in the option without CCS). This result is counterintuitive, given the higher conversion losses at CCS coal-fired power plants, but it is the consequence of the load characteristics of power generation and the balance of imports. Because the base load and intermediate load are supplied by coal-fired power plants, the load and capacity characteristics of new renewable energy sources to be built are better, and less volume needs to be "re-stored" for load management. Thus there are also no storage losses (estimated at 30%), and the associated power does not need to be generated. Moreover, the balance of imports in the option with CCS is 3 TWh greater than in the option without CCS.

Figure 5.3-47: Innovation scenario with CCS: Primary energy consumption (excluding non-energy consumption) by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

5.3.10 Energy-related greenhouse gases

Energy-related greenhouse gases will decrease 91% between the reference year 1990 and 2050, and 89% between 2005 and 2050, in the innovation scenario option without CCS, and about 90% and 88%, respectively, in the option with CCS.

All sectors will contribute substantially to this result, but to different degrees. Residential and services, initially "high-room-heating" sectors, will reduce their energy-related CO_2 emissions by 98% and 85%, respectively, between 2005 and 2050 (adjusted for weather). The industry sector will achieve a 64% reduction. In this sector, apart from changes in efficiency and structure, little replacement of conventional fuels with renewable sources is possible. For that reason, the potential for reduction here remains "limited." In the transport sector, 83% of emissions can be saved from 2005 to 2050, especially by electrifying passenger transport and by replacing fossil motor fuels with biofuels in road transport. Power generation will produce the greatest reduction in emissions in absolute terms.

Table 5.3-55: Innovation scenario: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent

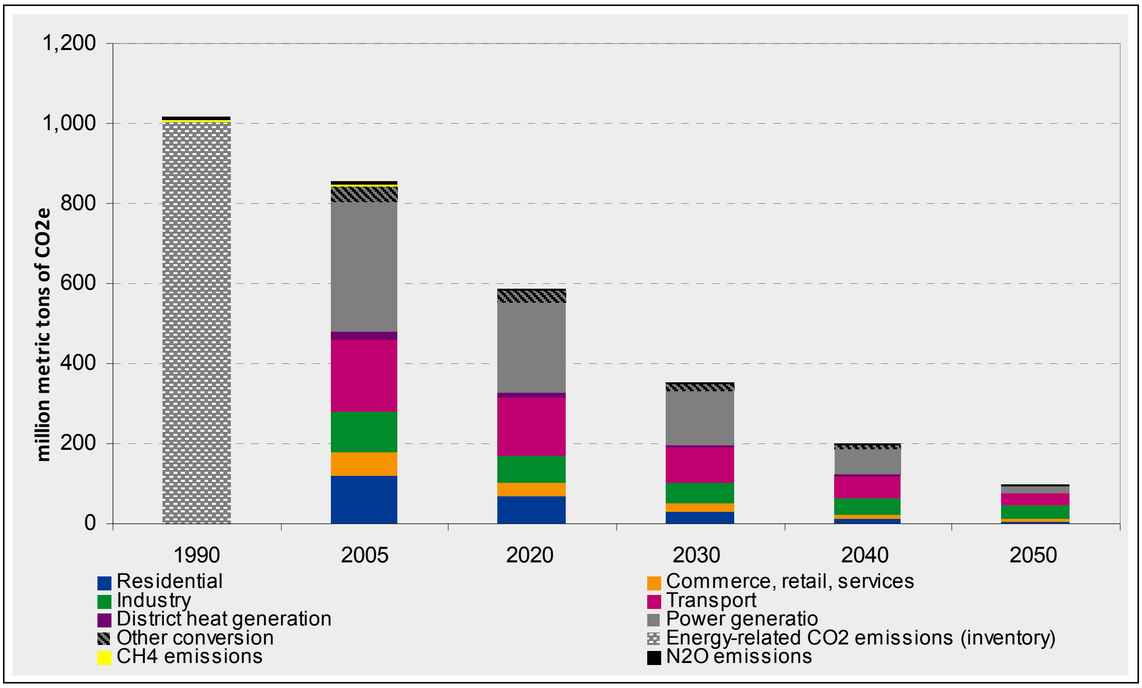
			Innovation scenario			
Million metric tons of CO_2 equivalent	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Residential		121.1	66.0	31.0	12.3	3.0
Commercial		58.0	35.7	18.7	10.8	8.4
Industry		100.7	70.2	51.2	40.6	36.0
Transport		179.5	143.9	91.3	57.0	30.3
Energy transformation sectors						
Public district heating		22.3	10.9	5.6	2.2	0.7
Power generation without CCS		323.4	226.3	134.1	65.0	14.0
Power generation with CCS		323.4	226.3	137.7	67.0	22.9
Other energy sectors without CCS		39.5	28.3	16.0	7.9	2.4
Other energy sectors with CCS		39.5	28.3	16.0	7.9	2.4
Total CO2 without CCS	1,005.4	844.5	581.3	347.9	195.8	94.8
Total CO2 with CCS	1,005.4	844.5	581.3	351.5	197.8	103.7
CH4 without CCS	4.5	1.3	1.0	0.7	0.5	0.3
CH4 with CCS	4.5	1.3	1.0	0.8	0.5	0.3
N2O without CCS	7.7	7.9	6.3	4.2	2.6	1.5
N2O with CCS	7.7	7.9	6.3	4.2	2.6	1.6
Total GHG without CCS	1,017.6	853.7	588.6	352.8	199.0	96.6
Total GHG with CCS	1,017.6	853.7	588.6	356.5	200.9	105.5
Total without CCS						
Change from 1990	-	-16.1%	-42.2%	-65.3%	-80.4%	-90.5%
Change from 2005	20.7%	1.3%	-30.2%	-58.1%	-76.4%	-88.5%
Total with CCS						
Change from 1990	-	-16.1%	-42.2%	-65.0%	-80.3%	-89.6%
Change from 2005	20.7%	1.3%	-30.2%	-57.7%	-76.2%	-87.5%
Notes: Emission data for 2005 have been adjusted; the change compared to 2005 refers to the emission level of the German GHG inventories (842.9 m tons of CO_2e); emissions of power production including CO_2 from flue gas desulfurization plants						

Source: Prognos 2009

From 2005 to 2050, the reduction in emissions from power generation is about 96% in the option without CCS, and about 93% in the option with CCS. The reduction in emissions in district heating comes to 97% in the same period, and that for the other conversion sectors is 94%. Though technologies and fuels vary, CH_4 emissions from combustion processes develop very similarly in the two options, and decrease by 94% from 1990. These emissions were already cut back substantially between 1990 and 2005, so that the reduction compared to 2005 is only 79%. Nitrous oxide emissions differ slightly in the two options, and decrease by about 80% compared to 1990 and 2005 levels.

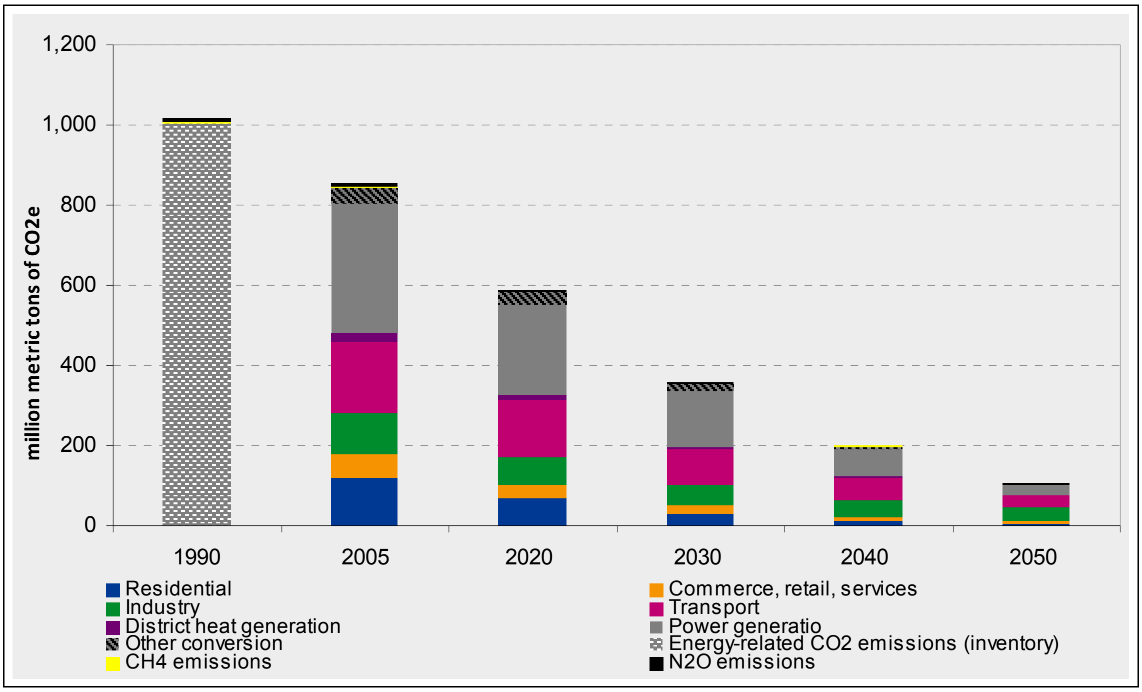
The relative reduction in total energy-related greenhouse gases generally parallels that of energy-related CO_2 emissions, with 90.5% in the option without CCS and just under 90% in the option with CCS. This small difference is due to the greater use of coal in power generation; its emissions cannot be entirely neutralised by CCS technologies. Compared to 2005 emission levels, the decreases are 88.5% (option without CCS) and 87.5% (option with CCS).

Figure 5.3-48: Innovation scenario without CCS: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

Figure 5.3-49: Innovation scenario with CCS: Energy-related greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

5.3.11 Fugitive emissions by the energy sector and non-energy-related emissions from the industry sector

5.3.11.1 Fugitive emissions from the energy sector

Although energy demand decreases substantially in the innovation scenario, the impact on fugitive CH_4 emissions by the energy sector remains rather low (Table 5.3-56). This is primarily the result of the dominant role of hard coal production for this source. Given that the production of hard coal phases out as in the reference scenario, there are no changes in the innovation scenario. The clearest change in emissions comes in the release of CH_4 emissions from the natural gas distribution system, which decreases substantially because of the considerable decline in the use of natural gas. In 2050, CH_4 emissions from natural gas production, natural gas transport and distribution, and other leakage come to about 1.4 million metric tons of CO_2 equivalent.

All in all, fugitive CH_4 emissions from the energy sector decrease about 90% during the period from 2005 to 2050 in the innovation scenario.

Table 5.3-56: Innovation scenario: Development of fugitive CH_4 emissions from energy sector, 2005 – 2050, in kt

		Innovation scenario			
kt CH_4	**2005**	**2020**	**2030**	**2040**	**2050**
CH_4 emissions					
Mining activities					
Underground mining activities	254.5	0.0	0.0	0.0	0.0
Handling of hard coal	14.3	0.0	0.0	0.0	0.0
Surface mining activities	2.0	0.9	0.5	0.2	0.0
Solid fuels transformation	0.4	0.2	0.1	0.0	0.0
Post-mining activities	2.9	2.9	2.9	2.9	2.9
Oil production and processing					
Production	3.9	1.9	0.6	0.0	0.0
Storage	2.3	1.4	0.8	0.4	0.2
Natural gas					
Production	53.1	50.6	41.8	34.1	25.9
Transport	40.1	28.5	20.4	14.6	11.0
Distribution	165.9	106.8	56.2	30.9	19.7
Other leakages	67.0	43.1	22.7	12.5	7.9
Total CH_4	606.3	236.4	146.0	95.7	67.6
Change from 1990	-54.1%	-82.1%	-88.9%	-92.8%	-94.9%
Change from 2005		-61.0%	-75.9%	-84.2%	-88.8%

Source: Öko-Institut 2009

5.3.11.2 Process-related CO_2 emissions

Projections for process-related CO_2 emissions come in three phases for the Innovation scenario.

1. For the most emission-intensive processes resulting in the highest emissions, it is assumed that ambitious mitigation options will be pursued.

2. For other processes where emissions are less extensive but still relevant, CO_2 emission trends can be deduced from developments in the energy industry (e.g., the sharp decrease in lignite production and the sharp decline in the use of petroleum).

3. The determinants of emissions from some (less relevant) sources were not analysed further, and emissions were kept constant at 2005 levels in the scenarios.

Looking at the especially relevant process-related CO_2 emissions that derive from projections for future production volumes, one must first look at the production of cement clinker and lime. It is assumed that the remaining emissions can be entirely eliminated with CCS. This is the case because the process-related emissions mean that the concentration of CO_2 in the flue gas of a cement or lime kiln is far greater than at a coal-fired power plant. For that reason, the specific energy demand for separating and compressing CO_2 in these processes is relatively low. By 2050, CO_2 emissions from cement and lime production will be reduced to zero.

In ammonia production, pure hydrogen is needed as an intermediate product. Hydrogen production is the highest-emission production step in ammonia production. Using hydrogen produced with renewable energy sources in ammonia production makes especially good sense, because no further conversion steps are needed that would result in energy losses. A similar situation arises in methanol production. Hitherto methanol, like ammonia, has been produced from natural gas. For the future, it would be conceivable to produce this basic material from hydrogen and CO_2. The necessary hydrogen for the purpose can be either produced using surplus wind power that would otherwise have to be throttled down, or it can be imported. All in all, process-related emissions from the production of ammonia and methanol will be reduced to zero by 2050.

With regard to process-related CO_2 emissions from glass production, it is assumed that higher ratios of recycling and a greater use of cullet will reduce emissions by 50% from their original levels.

The remaining process-related CO_2 emissions from the production of steel, brick, primary aluminium, carbide, ferroalloys, and carbon black are also kept constant in the innovation scenario.

Process-related CO_2 emissions from catalyst burn-off and from conversion losses at refineries will decrease considerably because of the sharp decline in the use of petroleum. In addition, it is assumed that the production of hydrogen at refineries, which is necessary for desulfurisation, will likewise be converted to regenerative hydrogen. Thus the emissions from conversion losses will decrease to zero.

Table 5.3-57: Innovation scenario: Development of process-related CO_2 emissions for selected industrial processes, 2005 – 2050, in kt

		Innovation scenario			
kt CO_2	**2005**	**2020**	**2030**	**2040**	**2050**
Process emissions					
Cement production	12,921	10,796	7,054	3,456	0
Limestone production	5,415	4,525	2,956	1,448	0
Glass production	894	759	655	551	447
Ceramics production	359	359	359	359	359
Ammonia production	5,253	4,503	3,002	1,501	0
Karbide production	16	16	16	16	16
Catalytic burning	2,883	1,969	1,127	606	272
Conversion loss	3,776	2,211	844	227	0
Methanol production	2,351	2,016	1,344	672	0
Carbon black production	589	589	589	589	589
Iron and steel production (limestone use only)	2,225	1,828	1,523	1,217	912
Ferroalloys production	3	3	3	3	3
(Primary) aluminium production	883	871	862	853	844
Total CO_2	37,569	30,444	20,334	11,498	3,442
Change from 1990	-1.8%	-20.4%	-46.8%	-69.9%	-91.0%
Change from 2005		-19.0%	-45.9%	-69.4%	-90.8%
Memo items:					
Iron and steel production (iron ore reduction)	40,330	33,132	27,594	22,057	16,520
Flue gas desulfurization	1,382	609	271	0	0

Source: Öko-Institut 2009

The result is that process-related CO_2 emissions in the innovation scenario decrease from 37.6 million metric tons of CO_2 in 2005 to 3.4 million metric tons in 2050.

CO_2 emissions from flue gas desulfurisation plants will decrease to zero by 2050 because of the sharp decline in the use of coal.

5.3.11.3 Process-related CH_4 and N_2O emissions

Since the contribution of process-related CH_4 emissions to total emissions is very small, they are kept constant for the projection period to 2050.

Projections for adipic acid and nitric acid production were based on the following assumptions:

- The intensified price signal from emission trading will cause a further improvement in available mitigation technology.
- For N_2O emissions from the production of nitric and adipic acid, the innovation scenario assumes that from 2025 onwards, all installations will achieve a catalytic breakdown of 99.5%.
- If CO_2 prices are high, among other conditions, it may be cost-effective to configure systems for the catalytic breakdown of N_2O in redundant form so that if one catalytic converter fails, N_2O emissions still can be prevented with a second converter.

Table 5.3-58: Innovation scenario: Development of CH_4 and N_2O emissions from industrial processes, 2005 – 2050, in kt of CO_2 equivalent

		Innovation scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
CH_4 emissions					
Industrial proceesses	2	2	2	2	2
Chemical industry	0.2	0.2	0.2	0.2	0.2
Metal production	2.0	1.9	1.9	1.9	1.9
N_2O emissions					
Chemical industry	14,194	1,751	244	244	244
Total CO_2 equivalents	14,197	1,753	246	246	246
Change from 1990	-40.3%	-92.6%	-99.0%	-99.0%	-99.0%
Change from 2005		-87.7%	-98.3%	-98.3%	-98.3%

Source: Öko-Institut 2009

Since the overall level of process-related CH_4 and N_2O emissions from industrial processes is determined primarily by N_2O emissions from adipic and nitric acid production, the measures taken in this area will have a substantial impact. Total process-related CH_4 and N_2O emissions will decrease 99% between 2005 and 2050 in the Innovation scenario (Table 5.3-58).

5.3.11.4 Emissions of HFCs, PFCs and SF_6

The innovation scenario assumes that administrative law to prevent the use of HFCs, PFCs and SF_6 will be tightened. Additionally, the assumption is that systematic pricing will provide further incentives to reduce the remaining emissions.

In terms of a further reduction of emissions of fluorinated greenhouse gases, the following (administrative) measures are taken into account.

First, it is assumed that regulators will ban the use of HFCs in mobile cooling systems for all types of vehicles and for private and commercial refrigeration. Here it is possible to replace HFCs with natural coolants. Furthermore, it assumes that the use of HFCs will be banned in producing polyurethane foam products, XPS hard foams, and aerosols (dispensing and technical aerosols), and that the use of fluorinated gases will be priced into the remaining areas (taxation, or inclusion in the EU emissions trading system). Strong greenhouse gas potential means that a price signal will have an especially strong effect, and result in technical innovations. This will make it cost-effective to find and use substitutes for these fluorine gases. Furthermore, it will create stronger incentives for recycling fluorinated gases. All in all, it is assumed that emissions can be reduced by 90% compared to 1990.

Table 5.3-59: Innovation scenario: Development of emissions of fluorinated greenhouse gases, 2005 – 2050, in kt of CO_2 equivalent

		Innovation scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Fluorinated GHG					
HFC emissions					
Refrigeration and air conditioning	7,491	8,399	5,849	3,299	749
Foam production	1,250	471	355	240	125
Other sources	1,155	1,210	845	480	116
Subtotal HFC	9,896	10,080	7,050	4,020	990
PFC emissions					
Aluminium production	338	167	123	78	34
Refrigeration and air conditioning	132	78	57	35	13
Semiconductor manufacture	249	125	92	58	25
Other sources	0	13	9	4	0
Zwischensumme FKW	718	383	280	176	72
SF_6 emissions					
Magnesium foundries	668	524	371	219	67
Electrical equipment	762	595	422	249	76
Car tyres	65	0	0	0	0
Double glas windows	1,348	1,904	1,314	724	135
Other sources	537	442	317	191	66
Subtotal SF_6	3,380	3,464	2,422	1,380	338
Total fluorinated GHG	13,994	13,927	9,751	5,575	1,399
Change from 1990	18.0%	17.4%	-17.8%	-53.0%	-88.2%
Change from 2005		-0.5%	-30.3%	-60.2%	-90.0%

Source: Öko-Institut 2009

5.3.11.5 Summary

From 2005 to 2050, the innovation scenario posits a 92% decrease in fugitive emissions from the energy sector, emissions from industrial processes, and emissions of fluorine gases.

Table 5.3-60: Innovation scenario: Development of emissions from industrial processes, fluorinated gases and fugitive emissions from the energy sector, 2005 – 2050, in kt of CO_2 equivalent

		Innovation scenario			
kt CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Process emissions CO_2	37,569	30,444	20,334	11,498	3,442
Fluorinated GHG	13,994	13,927	9,751	5,575	1,399
Fugitive CH_4 emissionen from energy sectors	12,732	4,964	3,067	2,009	1,420
CH_4 and N_2O from industrial processes	15,371	1,753	246	246	246
Total CO_2 equivalents	79,665	51,088	33,398	19,328	6,507
Change from 1990	-21.6%	-49.7%	-67.1%	-81.0%	-93.6%
Change from 2005		-35.9%	-58.1%	-75.7%	-91.8%
Memo items:					
Iron and steel production (iron ore reduction)	40,330	33,132	27,594	22,057	16,520
Flue gas desulphurization	1,382	609	271	0	0

Source: Öko-Institut 2009

In 2050, emissions will still amount to 6.5 million metric tons of CO_2 equivalent. Compared to the reference scenario, the additional reduction in emissions in 2050 will be about 43 million metric tons of CO_2 equivalent. This makes it clear that ambitious measures can still bring about substantial further reductions in emissions in these sectors.

5.3.12 Emissions from waste management

The measures and developments assumed in the innovation scenario are concerned entirely with emissions that arise apart from landfills. The measures taken for landfills are already so effective that no further reductions in emissions can be achieved beyond those described in the reference scenario.

In municipal sewage treatment, the innovation scenario studied what effect might result from a specific savings of water (and thus wastewater) on the order of one-quarter by 2050. This assumption is based on an active promotion of water-conserving valves, appliances and systems. Accordingly, N_2O emissions decrease from 2.3 million metric tons of CO_2 equivalent to about 1.6 million metric tons of CO_2 equivalent between 2005 and 2050.

Table 5.3-61: Innovation scenario: CH_4 and N_2O emissions from waste management, 2005 – 2050, in kt

		Innovation scenario			
kt	**2005**	**2020**	**2030**	**2040**	**2050**
Input quantities					
Solid waste disposal (biogenic material)	2,154	0	0	0	0
Composting installations	9,658	6,673	5,293	4,010	2,854
Waste fermentation installations	2,842	3,593	4,330	4,901	5,300
Mechanical-biological waste treatment	2,520	3,287	3,081	2,853	2,610
CH_4 emissions					
Waste disposal	464	149	84	50	30
Domestic & commercial waste water	6	5	4	4	4
Composting and waste fermantation	28	19	15	11	8
Mechanical-biological waste treatment	0.38	0.18	0.17	0.16	0.14
Subtotal CH_4	498	173	103	65	42
N_2O emissions					
Domestic & commercial waste water	7.57	6.69	6.27	5.81	5.31
Composting and waste fermentation	0.71	0.49	0.39	0.29	0.21
Mechanical-biological waste treatment	0.35	0.33	0.31	0.29	0.26
Subtotal N_2O	8.63	7.51	6.97	6.39	5.78
Total CH_4 + N_2O (kt CO_2 equivalents)	13,129	5,956	4,326	3,348	2,680
Change from 1990	-67.5%	-85.3%	-89.3%	-91.7%	-93.4%
Change from 2005	-	-54.6%	-67.0%	-74.5%	-79.6%

Source: Öko-Institut 2009

A specific 25% reduction was also studied in waste volume delivered up for composting and anaerobic digestion, and for waste treatment in mechanical-biological waste treatment systems – the consequence of reinforced measures for garbage reduction and recycling. In garbage composting, it was assumed that as part of a focused biogas strategy, the ratio of organic waste treated in composting and anaerobic digestion systems will shift significantly in the direction of installations for gas production. Instead of the 2.5 million metric tons of organic waste in the reference scenario, in the innovation scenario about 5.3 million metric tons of waste is used for biogas production in 2050. The combination of the two developments results in a decrease in CH_4 emissions by about 70%, or about 0.4 million metric tons of CO_2 equivalent. All told, a reduction of about two-thirds results for composting and mechanical biological treatment systems during the scenario period from 2005 to 2050, or an emission reduction from 0.9 million to 0.3 million metric tons of CO_2 equivalent. Greenhouse gas emissions in waste management from 2005 to 2050 will change substantially in terms of both their levels and their structure by source sectors or by type of gas.

Total greenhouse gas emissions from waste management will decrease nearly 80% between 2005 and 2050. This is equivalent to a reduction of about 93% from the original 1990 level.

The share of greenhouse gas emissions from composting and anaerobic digestion systems in 2050 will be 8% in the innovation scenario, compared to 19% in the reference scenario. In the innovation scenario as well, municipal sewage treatment plants remain the largest emission source in waste management, representing about one-third.

In the innovation scenario too, CH_4 emissions represent one-third of the total waste-management greenhouse gas emissions in 2050. Accordingly, N_2O emissions contribute about two-thirds in this sector.

5.3.13 Emissions from agriculture

Under the innovation scenario, CH_4 and N_2O emissions from **animal husbandry** are reduced by two key measures:

- A substantial reduction in livestock herds and
- Gas-tight storage of liquid animal waste and greater fermentation of such waste in biogas plants.

The German population is oversupplied with energy and protein from animal-based foods, and is exposed to high health risks as a consequence. Meat consumption is currently about 60 kg per person per year; by contrast, the optimum amount from the health perspective is about 20 kg per person per year. In the innovation scenario, appropriate policy tools (see Sec. 9.12) produce a gradual reduction in the consumption of animal products by 2050. In 2050, each person will consume an average of 20 kg of meat (instead of 60 kg), 260 kg of milk including milk products (instead of 330 kg), and 130 chicken eggs (instead of 220) (Woitowitz 2007). Lower consumption will significantly reduce livestock herds in Germany, while still ensuring that the population is able to meet its own needs. Only dairy cattle, beef cattle, and pigs are considered here.

Consumption of an optimum quantity of animal products from the health viewpoint will reduce herds of dairy cattle 13% between 2005 and 2050, beef cattle 57%, and pigs 62%, yielding corresponding reductions in GHG emissions from enteric fermentation and commercial manure management.

Table 5.3-62: Innovation scenario: Animal flocks in Germany, 2005 – 2050, in thousands.

		Innovation scenario			
Livestock (1,000)	**2005**	**2020**	**2030**	**2040**	**2050**
Dairy cattle	4,236	4,102	3,968	3,834	3,700
Cattle	8,799	7,553	6,307	5,061	3,815
Swine	26,858	22,693	18,529	14,364	10,200

Source: Öko-Institut 2009

Greenhouse gas emissions that have already been reduced due to smaller amounts of animal excrement as a result of cutbacks in livestock herds can be reduced further by changing methods of animal husbandry and commercial manure management. The most effective measure is gastight storage of liquid manure to prevent the release of CH_4 and N_2O during storage. At the same time, there will be more fermentation of liquid manure in biogas plants. Comparably to enteric fermentation in a ruminant's stomach, in biogas plants the nutrients contained in liquid manure are metabolized by microorganisms and converted to such products as methane. This methane is available for energy uses in combined heat and power plants, and can replace fossil energy fuel sources.

Another option for reducing GHG emissions from animal husbandry is a further increase in animal productivity, but this was not pursued further because of the associated health risks and species-appropriate farming.

The changes in N_2O emissions from **agricultural soil** in the innovation scenario are based on the same manipulated variables as in the reference scenario. Once again, the use of mineral fertilizers is the most significant source of N_2O emissions. In contrast to the reference scenario, the innovation scenario assumes specific measures and instruments that may affect N_2O emissions. These are measures that have already been discussed in various contexts (such as biodiversity strategy, sustainability strategy). It is considered realistic that they will be implemented in the coming decades. The individual measures take hold at different times (e.g., expansion of organic farming until 2030) and in some cases run in parallel (improved fertilizer management between 2005 and 2050). A detailed description of these measures is provided in Sec. 9.12.

Compared to the reference scenario, N_2O emissions from agricultural soils will decrease 35% between 2005 and 2050. The greatest emission reduction will be achieved with regulatory measures regarding the cultivation of marshland (–58% between 2005 and 2050). Expanded organic farming, the introduction of a tax on surplus nitrogen, and better fertilizer management will reduce the amount of applied synthetic fertilizers 38% by 2050. As the number of livestock decreases, especially beef and dairy cattle, the rate of excrement excretion in pasturage will decrease 36%.

The least potential for mitigation lies in the use of commercial manure and harvest residues. Accurate forecasts for usage rates to 2050 are difficult because of the possible greater usage of liquid manure and harvest residue as input substrates in biogas plants, and the need to use them to maintain fertility and carbon content in the soil. For that reason, the innovation scenario assumes a rather conservative mitigation rate.

Total greenhouse gas emissions from agriculture will decrease 43% between 2005 and 2050. Compared to 1990 emission levels, this is equivalent to a decrease of about 51%, as shown in Table 5.3-63.

Table 5.3-63: Innovation scenario: CH_4 and N_2O emissions from agriculture, 2005 – 2050, in million metric tons of CO_2 equivalent

		Innovation scenario			
mln t CO_2 equivalents	**2005**	**2020**	**2030**	**2040**	**2050**
Source category					
CH_4 emissions					
Enteric fermentation	17.2	12.3	10.8	9.2	7.7
Manure management	5.5	4.8	4.4	4.0	3.7
Agricultural soils	-0.6	-0.6	-0.6	-0.6	-0.6
Summe CH_4	22.0	16.5	14.6	12.7	10.8
N_2O emissions					
Manure management	2.4	2.1	1.8	1.5	1.3
Agricultural soils	28.4	20.7	19.4	18.7	18.0
Summe N_2O	30.8	22.8	21.2	20.2	19.3
Total CH_4 + N_2O	52.8	39.3	35.8	32.9	30.1
Change from 1990	-14.3%	-36.3%	-41.9%	-46.6%	-51.2%
Change from 2005		-25.6%	-32.1%	-37.7%	-43.0%

Source: Öko-Institut 2009

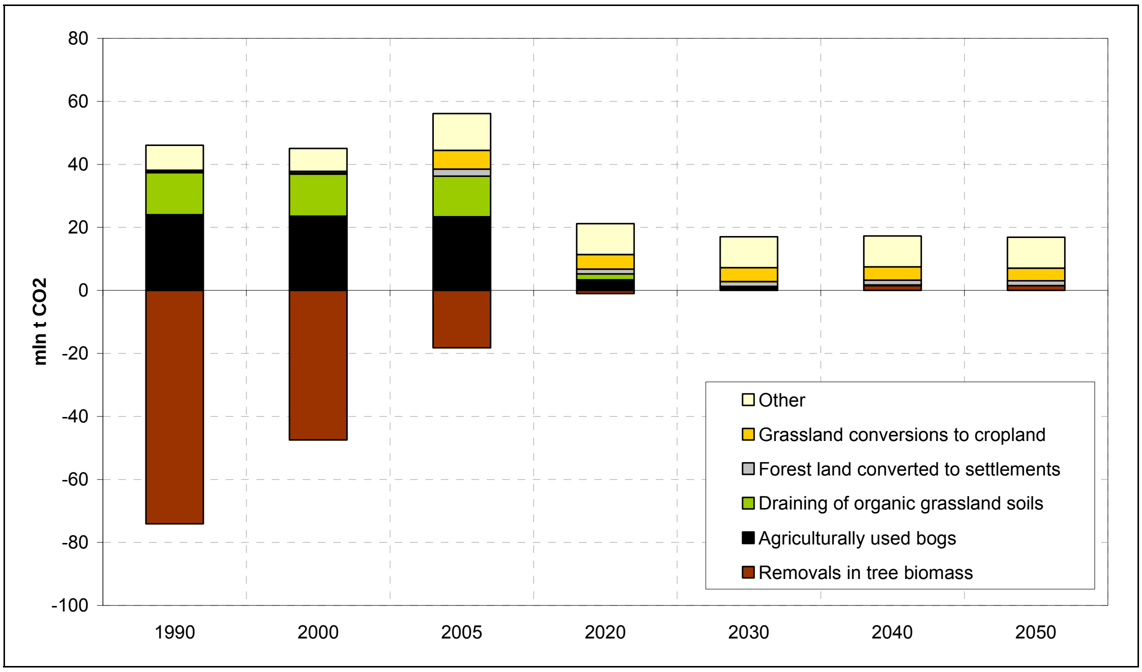
5.3.14 Emissions from land use, land use change and forestry

The measures assumed under the innovation scenario are primarily aimed at CO_2 emissions from emitter categories of land use. It is assumed that silviculture will be managed sustainably and with a strong awareness of nature. The aim is to preserve and enhance both the effect of forests as sinks and the store of carbon retained in forest biomass. This is to be done by stabilizing forest inventories, through techniques like forest conversion (including more broadleaf trees in place of conifers, diverse silviculture measures, etc.), adaptation to changing climate conditions, and encouraging natural forest communities. Preserving the inventory has greater climate benefit than afforestation, since afforestation measures for the existing forest sink will not produce growth in the inventory for 20 years or so.

The goal of preserving the inventory will be countered by pressure to use this resource, especially for greater biomass use. The innovation scenario assumes that in spite of sustainable forestry, the area of harvestable forests will decrease because of the age group structure of the forest and the associated management. This particularly affects the inventory of broadleaf trees, since the current trunk diameter of beeches and oaks in the dominant age group structures will grow above the guideline levels for harvesting over the next few decades.

For that reason, in the innovation scenario the measures for CO_2 reduction in the LULUCF sector intervene in the four identified main sources that can no longer be compensated by an extensive forest sink capacity, and whose emissions must therefore be reduced. The decrease in uses and changes of space that cause emissions will reduce CO_2 emissions 73% between 2005 and 2050. If CO_2 retention in forest biomass is taken into account, this decrease is lowered to 56%, since in 2005 forest sinks were still able to compensate for 32% of emissions from land use and land use changes (Figure 5.3-50).

Figure 5.3-50: Innovation scenario: Carbon dioxide emissions and retention from land use, land use change and forestry, 1990 – 2050, in million metric tons of CO_2



Source: Öko-Institut 2009

The underlying measures have already been discussed in a variety of contexts (e.g., biodiversity strategy, cross compliance). It is considered realistic that they will be implemented in the coming decades. A detailed description of these measures is provided in Sec. 9.13.

The area of grassland broken up for cultivation will be reduced 33% through protection of grassland as part of cross compliance, as well as by the implementation of the federal government's biodiversity strategy goals. Hardscaping can be reduced along the same order of magnitude by way of regulatory measures.

The greatest mitigation effect will come from the reduction of land use changes involving a substantial carbon release (areas with organic soils that are under cultivation or that are drained for use as pasture or hay fields). Studies have shown that marsh conversion has high potential for savings (McKinsey 2009; Freibauer und Drösler 2009) that by 2050 can be exploited almost entirely by way of incentives (promotion of marshland restoration, allowance of paludiculture as an alternative use for EU direct payment entitlements) (Table 5.3-64).

Table 5.3-64: Innovation scenario: CO_2 emissions and retention from land use, land use change and forestry, 1990 – 2050, in million metric tons of CO_2

			Innovation scenario			
kha	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Land use change						
Area of agriculturally used bogs	596	579	83	19	4	1
Area subject to draining of organic grassland soils	726	704	101	23	5	1
Area of forest land converted to settlements	1	7	4	4	4	4
Area subject to grassland conversions to cropland	6	79	61	58	55	53
mln t CO_2						
CO_2 emissions and removals						
Removals in tree biomass	-74.1	-18.2	-1.0	0.1	1.5	1.5
Agriculturally used bogs	24.0	23.4	3.4	0.8	0.2	0.0
Draining of organic grassland soils	13.3	12.9	1.9	0.4	0.1	0.0
Forest land converted to settlements	0.3	2.2	1.5	1.5	1.5	1.5
Grassland conversions to cropland	0.5	6.0	4.6	4.4	4.2	4.0
Other	7.9	11.7	9.8	9.8	9.8	9.8
Total CO_2 emissions (w/o removals)	46.1	56.1	21.2	16.9	15.8	15.4
Total CO_2 emissions and removals	-28.0	37.9	20.2	17.0	17.3	16.9
Change of CO_2 emissions from 1990		21.8%	-54.0%	-63.3%	-65.7%	-66.6%
Change of CO_2 emissions and removals from 1990		235.6%	172.2%	160.9%	161.8%	160.3%
Change of CO_2 emissions from 2005			-62.2%	-69.9%	-71.9%	-72.6%
Change of CO_2 emissions and removals from 2005			-46.8%	-55.1%	-54.4%	-55.5%

Source: Öko-Institut 2009

The large reduction of emissions due to cultivation of soils and the drainage of grassland soil means that although CO_2 retention in forestry will decline, in the innovation scenario CO_2 emissions from the LULUCF sector will decrease 56% between 2005 and 2050 and 67% between 1990 and 2050.

5.3.15 Total greenhouse gas emissions

In the innovation scenario, total greenhouse gas emissions decrease 87% from 1990 to 2050 for the option without CCS, and 86% for the option with CCS. Compared to 2005 – as the base year for scenario development – the emission reductions are respectively about 85% and 84%.

Table 5.3-65: Innovation scenario: Total greenhouse gas emissions, 1990 – 2050, in million metric tons of CO_2 equivalent

			Innovation scenario			
Million metric tons of CO_2 equivalent	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Energy-related emissions (without CCS)						
CO_2	1,005	835	581	348	196	95
CH_4	5	1	1	1	0	0
N_2O	8	7	6	4	3	2
Energy-related emissions (with CCS)						
CO_2	1,005	835	581	352	198	104
CH_4	5	1	1	1	0	0
N_2O	8	7	6	4	3	2
Fugitive and process-related emissions						
CO_2	38	37	30	20	11	3
CH_4	28	13	5	3	2	1
N_2O	24	14	2	0	0	0
HFC	4	10	10	7	4	1
PFC	3	1	0	0	0	0
SF_6	5	5	3	2	1	0
Product use						
CO_2	3	2	2	2	2	2
CH_4	0	0	0	0	0	0
N_2O	2	1	1	1	1	1
Agriculture						
CH_4	27	22	17	15	13	11
N_2O	34	31	23	21	20	19
Land use, land use change and forestry						
CO_2	-28	38	20	17	17	17
N_2O	0	1	1	1	1	1
Waste sector						
CH_4	38	10	4	2	1	1
N_2O	2	3	2	2	2	2
Total withoutCCS	**1,199**	**1,031**	**709**	**447**	**276**	**157**
Total with CCS	**1,199**	**1,031**	**709**	**451**	**278**	**166**
Total without CCS						
Change from 1990	-	-14.0%	-40.8%	-62.7%	-77.0%	-86.9%
Change from 2005	16.3%	-	-31.2%	-56.6%	-73.3%	-84.8%
Total with CCS						
Change from 1990	-	-14.0%	-40.8%	-62.4%	-76.8%	-86.2%
Change from 2005	16.3%	-	-31.2%	-56.3%	-73.1%	-83.9%
Note: Emissions data for 2005 is inventory data; energy-related emissions include CO_2 from flue gas desulfurization						

Source: Prognos and Öko-Institut 2009

The major drivers here are the drastic decreases in energy-related emissions, especially in power generation and transport, in the service sector and in the residential sector. Industry's contribution is considerably less. Process-related greenhouse gas emissions also decrease substantially. Compared to 1990 (and also to 2005), reductions here come to about 93%.

The structure of greenhouse gas emissions also changes dramatically. In 2050, energy-related emissions will only represent slightly less than 63%. By contrast, the shares of emissions from sectors with only limited actual or potential emission reductions will grow considerably. In the innovation scenario, about 19% of total greenhouse gas emissions will come from agriculture in 2050, and about 11% from the land use and forestry sector.

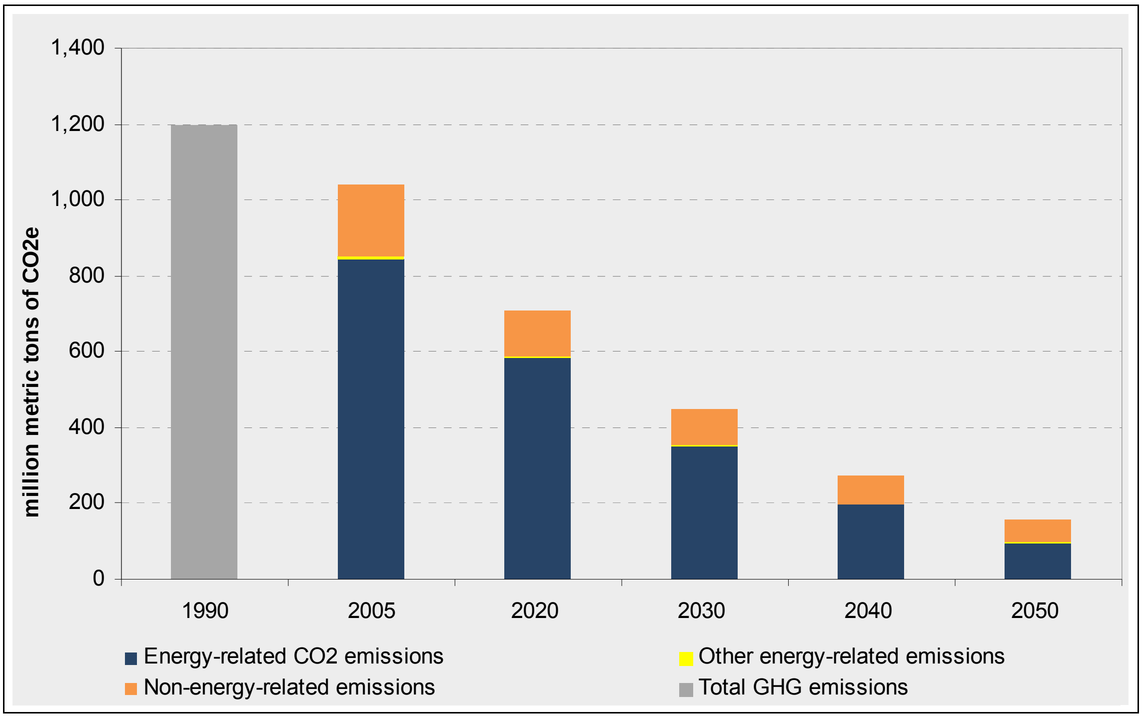
Despite these decreases, the measures taken into account in the innovation scenario still do not achieve the goal of a 95% reduction in emissions. The gap to be made up comes to about 97 million metric tons of CO_2 equivalent.

A major reason for falling short of the goal is the situation in land use and forestry. From 1990 to 2050 this sector will develop from a net CO_2 sink to a significant CO_2 source. If the target reduction of 95% is referred to greenhouse emissions not including land use, land use change and forestry, the resulting target level for 2050 is only slightly higher (61 million metric tons of CO_2 equivalent instead of 60 million). At the same time, if this sector is excluded, the reduction potential addressable there is also eliminated, so that although the emission level in the end year of the innovation scenario is somewhat lower (139 million metric tons of CO_2 equivalent, instead of 157 million), the gap that must still be filled to achieve the 95% reduction goal narrows only a little less than 19 million metric tons of CO_2 equivalent, to 78 million metric tons.

Per capita emissions in the innovation scenario (in the option without CCS – the levels in the option with CCS differ only marginally) decrease from 12.5 metric tons of CO_2 equivalent or 11.1 metric tons of CO_2 in 2005, to 5.7 metric tons of CO_2 equivalent or 4.9 metric tons of CO_2 in 2030, and 2.2 metric tons of CO_2 equivalent (all greenhouse gases) or 1.6 metric tons of CO_2 in 2050. Consequently, allowing for developments from 1990 to 2005, a per capita reduction of 86% is achieved.

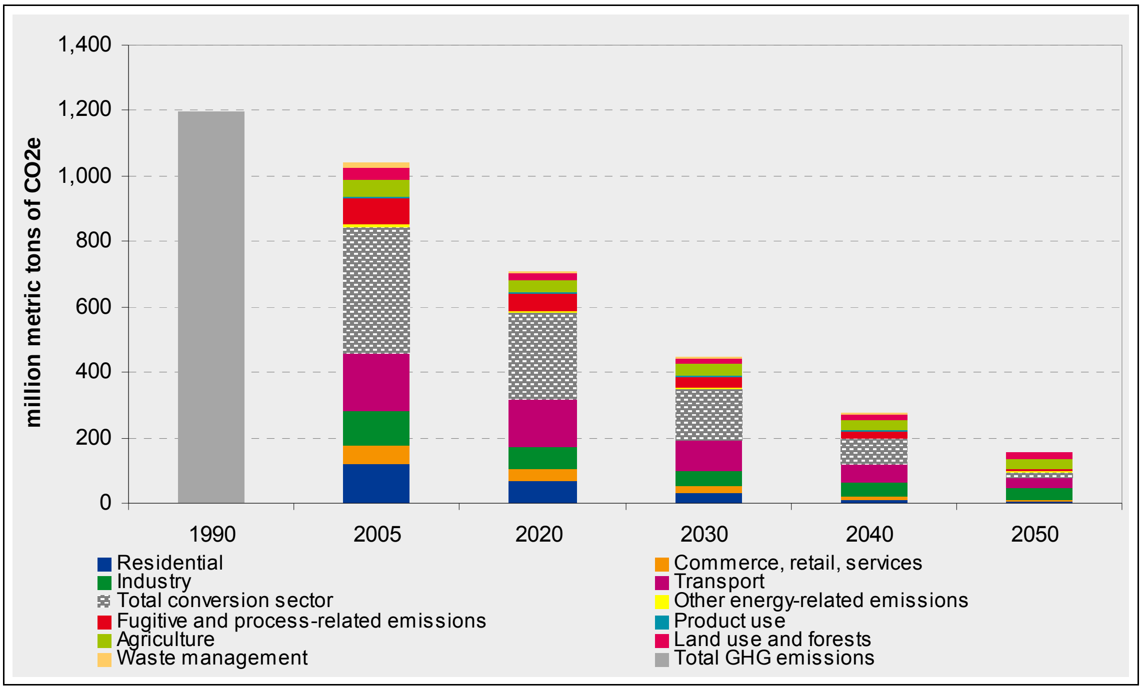
The calculation of cumulative emissions (from 2005 onwards) yields 20 billion metric tons of CO_2 equivalent (all greenhouse gases) for 2030, or just under 18 billion metric tons of CO_2. The massive emission cuts in the innovation scenario result in a total increase of only 5 billion metric tons of CO_2 equivalent (all greenhouse gases), or 4 billion metric tons of CO_2, by 2050, so that cumulative emissions for the full period from 2005 to 2050 are about 22 billion metric tons of CO_2 or 25.5 billion metric tons of CO_2 equivalent (all greenhouse gases). Thus the amounts of greenhouse gases emitted up to 2030 represent about 80% of the cumulative total emissions for 2005 to 2050. The equivalent share up to 2020 is well above 50%.

Figure 5.3-51: *Innovation scenario without CCS: Total greenhouse gas emissions by gas, 1990 – 2050, in million metric tons of CO_2 equivalent*



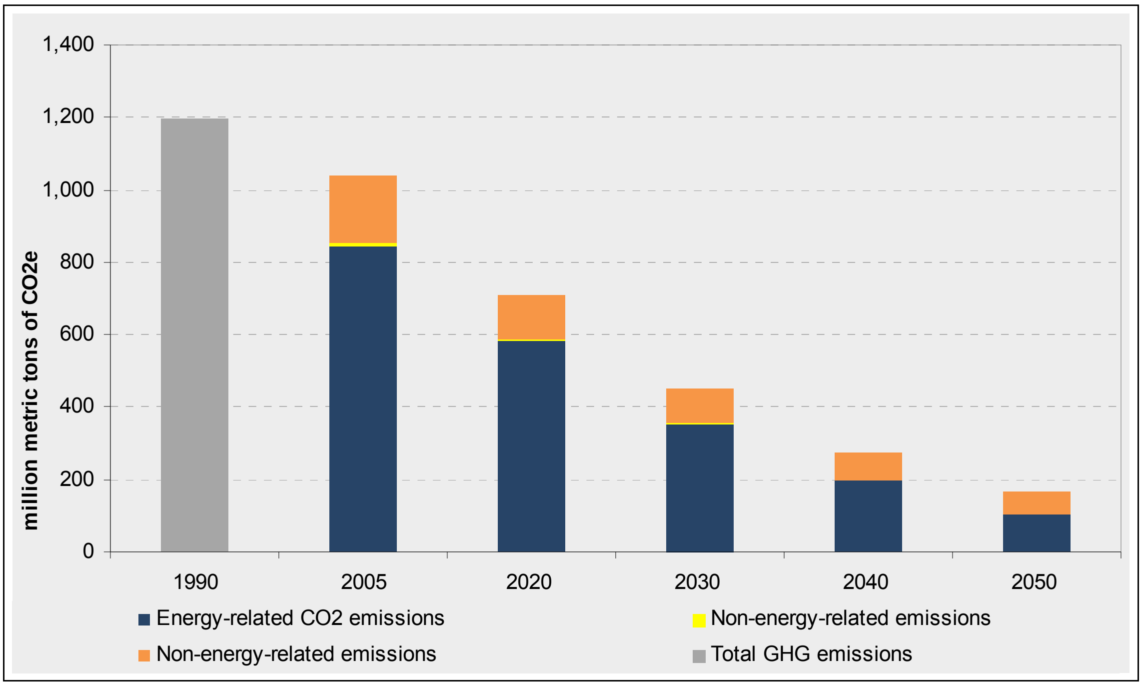
Source: Prognos and Öko-Institut 2009

Figure 5.3-52: *Innovation scenario without CCS: Total greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent*



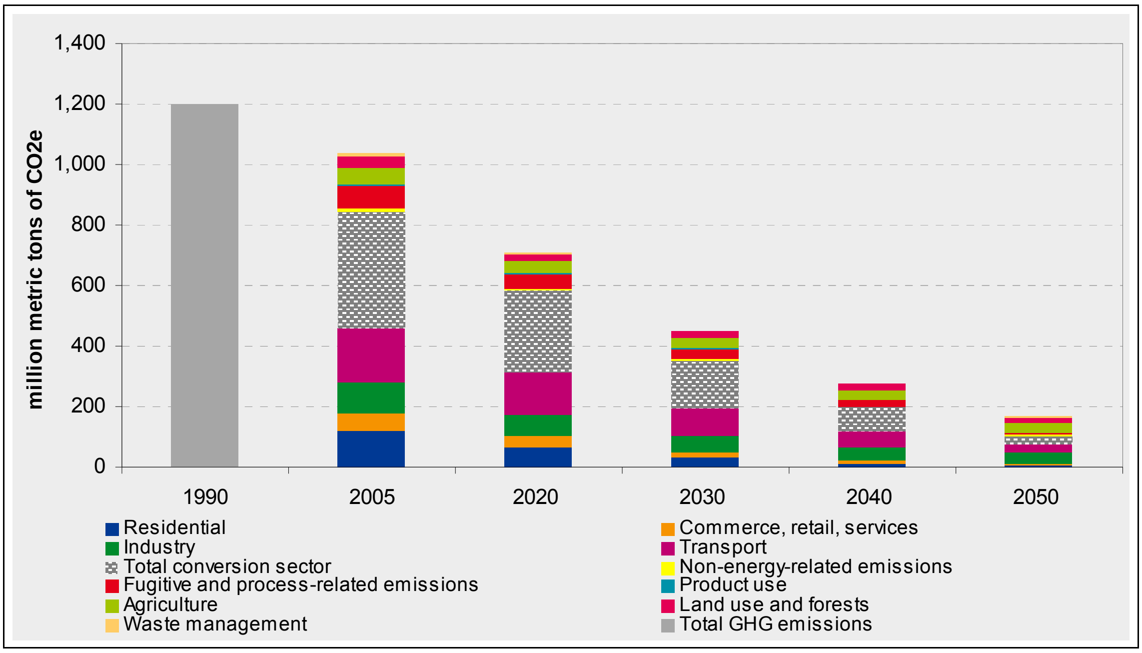
Source: Prognos and Öko-Institut 2009

Figure 5.3-53: Innovation scenario with CCS: Total greenhouse gas emissions by gas, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

Figure 5.3-54: Innovation scenario without CCS: Total greenhouse gas emissions by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos and Öko-Institut 2009

6 Comparison of scenarios

Table 6-1: Numerical assumptions and results of innovation scenario without CCS

	Unit	2005	Reference scenario (without CCS)				Innovation scenario (w/o CCS)				Inn. / Ref. Difference 2050
			2020	2030	2040	2050	2020	2030	2040	2050	
Price of oil (real) (2007 price base)	USD (2007) / bbl	54	100	125	160	210	100	125	160	210	
Price of CO_2 certificates (real) (2007 price base)	EUR (2007) / t	-	20	30	40	50	20	30	40	50	
Socio-economic framework data / Germany											
Population	m	82.5	79.8	78.6	76.0	72.2	79.8	78.6	76.0	72.2	
Residential	m	39.3	40.3	40.7	40.6	38.8	40.3	40.7	40.6	38.8	
GDP (real) (2000 price base)	EUR bn (2000)	2,124	2,457	2,598	2,743	2,981	2,457	2,598	2,743	2,981	
Industrial production (real) (2000 price base)	EUR bn (2000)	430	522	538	553	581	521	537	551	578	
Passenger cars	M	45.5	48.5	48.7	47.8	45.8	48.5	48.7	47.8	45.8	
Passenger transport volume	bn pkm	1,084	1,111	1,104	1,075	1,023	1,101	1,087	1,052	998	98%
Freight transport volume	bn tkm	563	775	869	944	1,033	779	876	953	1,047	101%
Household prices (incl. VAT), real (2005 price base)											
Heating oil, light	EUR cents (2005) / l	53.6	92.5	131.3	191.9	287.3	92.5	131.3	191.9	287.3	
Natural gas	EUR cents (2005) / kWh	5.3	8.8	11.8	16.1	22.7	8.8	11.8	16.1	22.7	
Electricity	EUR cents (2005) / kWh	18.2	28.9	34.3	41.8	50.3	28.9	34.3	41.8	50.3	
Regular gasoline	EUR cents (2005) / l	120.0	186.9	244.2	327.9	450.9	186.9	244.2	327.9	450.9	
Wholesale prices (not incl. VAT), real (2005 price base)											
Heating oil, light (industry)	EUR(2005) / t	499	884	1,244	1,802	2,694	884	1,244	1,802	2,694	
Natural gas (industry)	EUR cents (2005) / kWh	2.5	5.1	7.0	10.0	14.6	5.1	7.0	10.0	14.6	
Electricity (industry)	EUR cents (2005) / kWh	6.8	13.2	15.6	19.5	23.9	13.2	15.6	19.5	23.9	
Primary energy consumption	**PJ**	**13,532**	**11,298**	**9,808**	**9,024**	**8,330**	**9,936**	**7,680**	**6,294**	**5,766**	**69%**
Petroleum	%	32.6	29.2	28.1	25.4	22.4	28.3	21.0	13.8	6.7	30%
Gases	%	23.9	24.9	23.6	21.4	21.5	22.8	21.0	18.3	15.2	71%
Hard coal	%	12.9	16.7	13.0	14.1	12.8	14.9	10.6	5.2	1.0	8%
Lignite	%	12.3	8.9	12.8	13.2	14.6	8.4	5.8	3.7	0.4	3%
Nuclear energy	%	12.3	2.9	0.0	0.0	0.0	3.3	0.0	0.0	0.0	
Biomass	%	3.1	8.0	10.6	12.1	13.1	11.0	20.9	26.6	29.8	228%
Other renewable	%	3.1	9.3	11.9	13.8	15.6	11.3	20.7	32.4	46.8	300%
Final energy consumption	**PJ**	**9,208**	**8,178**	**7,291**	**6,644**	**6,099**	**7,144**	**5,596**	**4,546**	**3,857**	**63%**
Residential	%	29.7	27.9	27.6	26.7	25.7	28.0	26.2	22.4	17.2	67%
Commerce, retail, services	%	15.9	14.3	12.8	12.3	12.0	14.4	12.9	12.6	12.6	105%
Industry	%	26.3	28.1	28.7	29.5	31.3	24.8	24.9	26.4	29.8	95%
Transport	%	28.1	29.7	30.9	31.5	31.0	32.8	36.1	38.6	40.4	130%
Petroleum products	%	41.2	37.6	35.2	32.3	28.6	36.8	26.9	17.8	9.4	33%
Natural gases	%	27.0	26.2	24.1	22.5	22.7	23.9	20.4	19.4	19.9	88%
Coal	%	4.3	3.9	3.4	3.1	2.9	3.7	3.0	2.4	2.0	68%
Electricity	%	19.9	21.6	23.3	25.6	27.5	21.2	23.6	26.9	30.2	110%
District heating	%	3.3	3.2	3.1	2.9	2.7	3.2	2.9	2.5	1.9	70%
Renewables	%	4.3	7.5	10.9	13.7	15.6	11.3	23.2	31.0	36.6	235%
Renewables incl. share for conversion	%	5.6	12.9	17.9	21.6	24.4	18.1	36.2	52.3	67.2	276%
Net power generation	**TWh**	**583**	**554**	**530**	**529**	**520**	**485**	**428**	**403**	**405**	**78%**
Nuclear	%	25.9	5.5	0.0	0.0	0.0	6.2	0.0	0.0	0.0	
Hard coal	%	21.9	30.6	22.8	25.8	21.0	26.5	15.9	5.5	0.0	0%
Lignite	%	26.1	18.4	29.9	28.8	31.9	17.7	11.6	5.7	0.0	0%
Natural gas	%	11.5	11.1	9.3	6.8	7.0	10.2	10.9	7.0	2.8	41%
Renewable energy sources	%	9.8	29.5	32.6	33.1	34.4	33.7	53.3	70.1	81.1	236%
Other	%	4.8	4.9	5.3	5.4	5.7	5.6	8.3	11.7	16.1	283%
PEC per capita	GJ per capita	164	142	125	119	115	125	98	83	80	69%
GDP (real) 2000 / PEC	EUR / GJ	157	217	265	304	358	247	338	436	517	144%
Industrial prod. / FEC ind.	EUR / GJ	177	227	257	282	305	295	386	460	503	165%
Passenger km. / FEC passenger transp.	pkm / GJ	576	648	722	787	891	669	813	968	1,124	126%
Metric ton-km / FEC freight transp.	tkm / GJ	800	1,088	1,204	1,303	1,391	1,121	1,282	1,424	1,557	112%
Total GHG emissions	million t	1,042	888	785	717	658	709	447	276	157	24%
Cumulative GHG emissions from 2005 on	million t	1,042	15,607	23,992	31,395	38,214	14,924	20,620	24,066	26,083	68%
Total CO_2 emissions	million t	913	803	703	638	581	634	387	227	117	20%
Cumulative CO_2 emissions from 2005 on	million t	913	13,988	21,539	28,140	34,176	12,796	17,828	20,737	22,318	65%
Energy-related CO_2 emissions	million t	844	705	606	542	486	580	347	196	95	20%
Energy-related GHG emissions	million t	852	714	614	549	492	588	352	199	97	20%
Other GHG emissions	million t	190	175	171	168	166	121	95	77	60	36%
GHG emissions / GDP (real)	g / EUR(2000)	490	362	302	261	221	289	172	101	53	24%
CO_2 emissions / GDP (real)	g / EUR(2000)	430	327	271	232	195	258	149	83	39	20%
Energy-related GHG emissions / GDP (real)	g / EUR(2000)	401	290	236	200	165	239	136	73	32	20%
GHG emissions per capita	t per capita	12.6	11.1	10.0	9.4	9.1	8.9	5.7	3.6	2.2	24%
CO_2 emissions per capita	t per capita	11.1	10.1	8.9	8.4	8.0	7.9	4.9	3.0	1.6	20%
Energy-related GHG emissions per capita	t per capita	10.3	8.9	7.8	7.2	6.8	7.4	4.5	2.6	1.3	20%

Source: Prognos and Öko-Institut 2009

6.1 Final energy demand

6.1.1 Final energy demand in the residential sector

6.1.1.1 Framework data

The basic assumptions about the residential sector are the same in both scenarios, as described in Chapter 3. Energy consumption of the residential sector depends primarily on living space, residential population (and to some degree, that population's age distribution), distribution among size categories (persons per household or per residential unit) and distribution among building sizes. The framework data will not be detailed again further here, but because of their importance as a base quantity, total living space and net additions as summarised in Table 3.1-3 are repeated here:

Table 6.1-1: Additions of living space (net) and occupied living space, 2005 – 2050 (million m^2)

	2005	2020	2030	2040	2050
Net addition of living space					
Total	54.8	11.5	3.2	-3.9	-6.6
Single-family homes and duplexes (1+2)	45.2	10.6	8.4	2.6	0.5
Three-family and multi-unit buildings (3+)	9.1	0.9	-5.0	-6.3	-6.9
Non-residential buildings	0.4	0.0	-0.1	-0.2	-0.2
Living space (occupied)					
Total	3,223	3,485	3,583	3,576	3,525
Single-family homes + duplexes	1,856	2,069	2,171	2,220	2,235
Multi-unit buildings/non-residential	1,367	1,415	1,412	1,356	1,290
Vacancy rate	4.2%	3.6%	3.2%	3.1%	3.1%

Source: Prognos 2009

Due to the declining population, the figure for net additions towards the end of the period is negative – in other words, more space is closed down or demolished than new space is built. This is not unfavourable for the development of heat demand from the viewpoint of cutting back energy use and CO_2, because it also means that more old buildings, which tend to have higher specific heating demands, are being taken out of use.

Climate conditions (gradually rising average temperatures with an increasing frequency of extreme events) are also the same, as is mean user behaviour, as quantified by hours of full use of heating systems.

6.1.1.2 Final energy demand for space heating and hot water in the residential sector

For a given amount of living space and given building and household structures, the following factors govern demand for space heating and the energy consumption associated with meeting demand, the structure of that consumption, and its CO_2 emissions:

- Heating structure, broken down by energy source and heating system;
- The condition of insulation and other heat-related factors in the building shell and the resulting specific heating needs referred to living space;
- The efficiency of heating systems.

The first two parameters are varied differently in the two scenarios. Both scenarios assume the same development over time for efficiency in heating systems. Even today, conventional heating systems are already very close to the upper limits of possible efficiency, and heat pumps are under serious pressure even today to improve their utilisation ratios. We therefore assume that policy choices will result in an optimisation of heating systems even in the reference scenario.

Table 6.1-2: Comparison of scenarios: Heating structure of housing stock, by living space, 2005 – 2050, in million m^2

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
All homes									
District heating	307	358	391	410	425	381	441	486	524
Oil	1,082	1,010	959	895	829	833	569	288	13
Gas	1,537	1,733	1,765	1,732	1,677	1,500	1,309	1,078	842
Coal	60	35	32	31	29	36	25	12	1
Wood	41	73	103	129	150	160	279	391	494
Electricity (n/incl. heat pumps)	175	147	119	89	59	133	91	46	2
Heat pumps	18	114	181	238	286	142	248	348	440
Solar	2	15	32	51	70	300	621	926	1,207
All homes	3,223	3,485	3,583	3,576	3,525	3,484	3,582	3,574	3,524
Of which: single-family and duplex									
District heating	49	72	86	98	108	94	135	172	205
Oil	761	716	687	651	612	585	399	202	9
Gas	867	1,012	1,049	1,052	1,039	803	634	448	262
Coal	33	20	18	18	17	21	14	7	0
Wood	29	58	84	107	127	134	239	339	430
Electricity (n/incl. heat pumps)	100	84	69	53	36	76	52	26	1
Heat pumps	15	97	155	204	246	119	208	292	369
Solar	1	11	23	37	50	237	491	733	957
All single-family and duplex	1,856	2,069	2,171	2,220	2,235	2,069	2,171	2,220	2,235

Source: Prognos 2009

In the comparison between scenarios, the heating structure changes significantly in the innovation scenario compared to the reference scenario. In the innovation scenario, only “remainders” of residences will be heated with oil or coal. These “remainders” must reasonably be expected; they will exist, for example, in vacation homes in remote areas, but also in buildings for mixed commercial and residential use. The innovation scenario posits a reduction of nearly 100% in these energy sources compared to the reference scenario ; the same holds true for residences heated directly with electricity. The decrease in gas-heated living space is 50%. Renewable energy sources – wood, ambient heat and solar heat – are the winners in the substitution process (see Table 6.1-2).

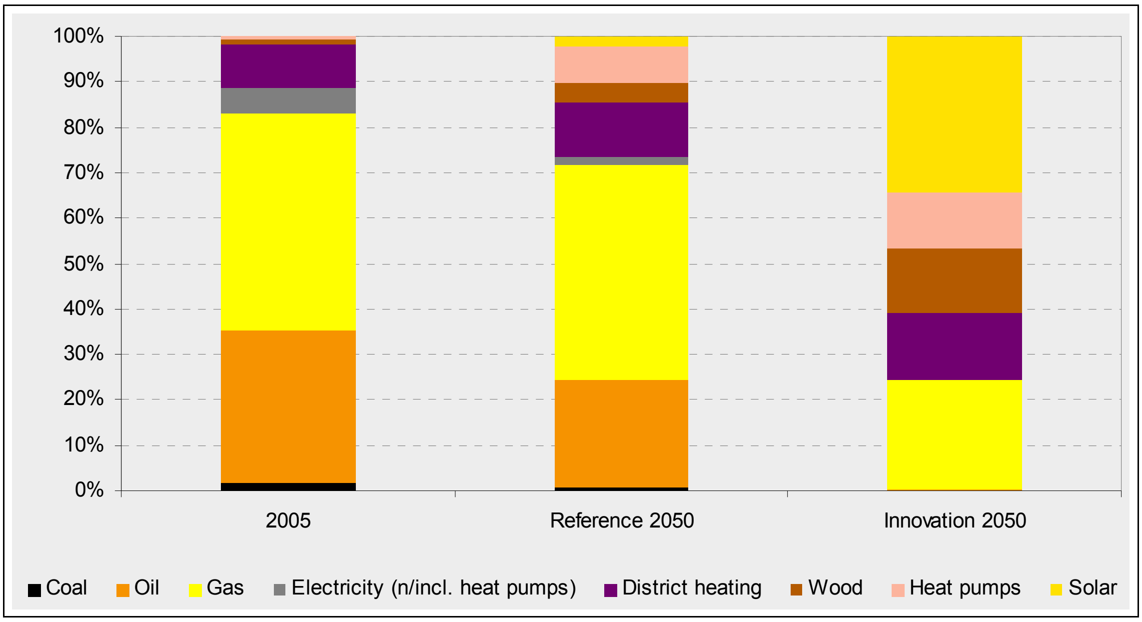
This development is brought about in the innovation scenario by substitution in existing buildings at the time when the heating system is replaced, and in new buildings, primarily by installing heating systems from the outset that are based on renewable energy sources, as well as district heating and local heating. The relative heating structure is shown in Table 6.1-3 and Figure 6.1-1.

Table 6.1-3: Comparison of scenarios: Heating structure of housing stock, by living space, 2005 – 2050, in %

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
District heating	9.5%	10.3%	10.9%	11.5%	12.1%	10.9%	12.3%	13.6%	14.9%
Oil	33.6%	29.0%	26.8%	25.0%	23.5%	23.9%	15.9%	8.0%	0.4%
Gas	47.7%	49.7%	49.3%	48.4%	47.6%	43.0%	36.6%	30.1%	23.9%
Coal	1.9%	1.0%	0.9%	0.9%	0.8%	1.0%	0.7%	0.3%	0.0%
Wood	1.3%	2.1%	2.9%	3.6%	4.3%	4.6%	7.8%	10.9%	14.0%
Electricity (n/incl. heat pumps)	5.4%	4.2%	3.3%	2.5%	1.7%	3.8%	2.5%	1.3%	0.1%
Heat pumps	0.5%	3.3%	5.1%	6.7%	8.1%	4.1%	6.9%	9.7%	12.5%
Solar	0.1%	0.4%	0.9%	1.4%	2.0%	8.6%	17.3%	25.9%	34.3%
All homes	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Prognos 2009

Figure 6.1-1: Comparison of scenarios: Heating structure of housing stock, by living space, 2005 and 2050, in %



Source: Prognos 2009

The energy performance standard of the building shell plays an important role in reducing demand for space heating. Here the innovation scenario assumes that an extremely high standard of quality will be aimed for by 2050 in both new buildings and existing buildings (specific thermal energy demand averaging 5 kWh/m^2/yr) and will even exceed the current passive house standard (15 kWh/m^2/yr). In new buildings, this will be done by gradually tightening standards. In upgrades, the upgrade rate must be increased (depending on building age, the rate will be more than doubled in some cases by 2050), and the energy efficiency of the upgrades must also improve dramatically. After two cycles, buildings from the current inventory must have achieved the standard for new buildings that will prevail by that time. Details on these time tracks can be found in the chapters on the Reference and innovation scenarios. In summary, by 2050 the mean specific thermal energy demand is reduced 50% from the 2005 level even in the reference scenario, and 86% in the innovation scenario.

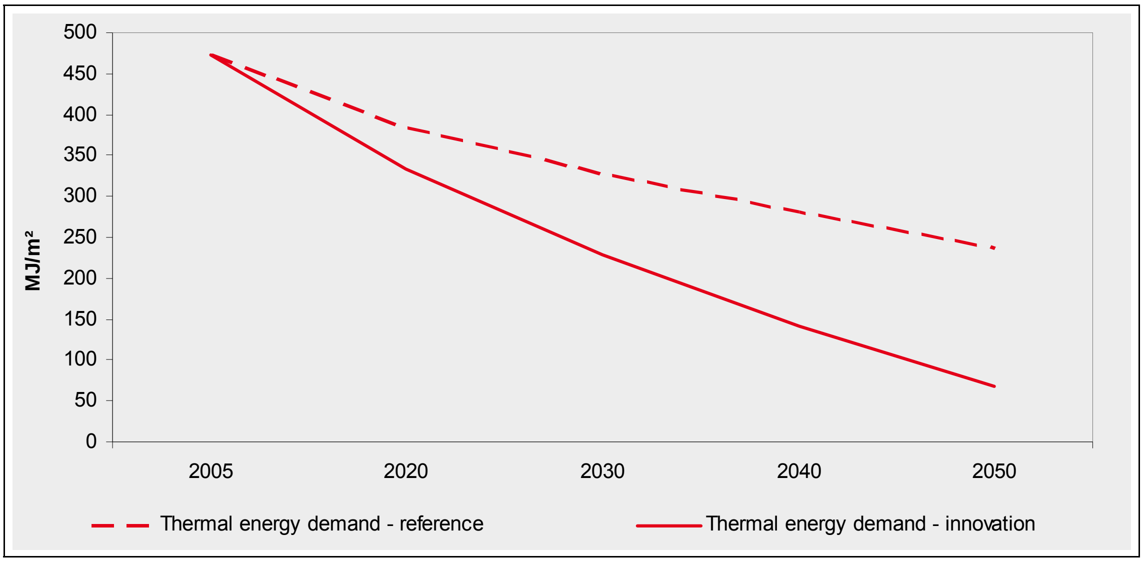
Because of the change in heating structure, with a larger proportion of heat pumps and high-efficiency gas furnaces in the mix, the mean utilisation ratio for heating systems is slightly higher in the innovation scenario than in the reference scenario (see Table 6.1-4, Figure 6.1-2).

Table 6.1-4: Comparison of scenarios: Mean specific thermal energy demand, mean utilisation ratio of heating systems, mean specific final energy consumption of housing stock, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Thermal energy demand (MJ/m^2)	473	385	328	280	236	333	229	141	67
Utilisation ratio (%)	83	92	97	100	102	94	102	107	111
Final energy consumption (MJ/m^2)	573	417	337	280	231	353	224	132	61

Source: Prognos 2009

Figure 6.1-2: Comparison of scenarios: Mean specific thermal energy demand of existing living space, 2005 – 2050, in MJ/m^2



Source: Prognos 2009

The overall result is the final energy demand for space heating in the residential sector as shown in Table 6.1-5 and Figure 6.1-3. Final energy demand in 2050 is 73% lower in the innovation scenario than in the reference scenario; the Innovation figure is 85% below the starting value from 2005 (weather-adjusted).

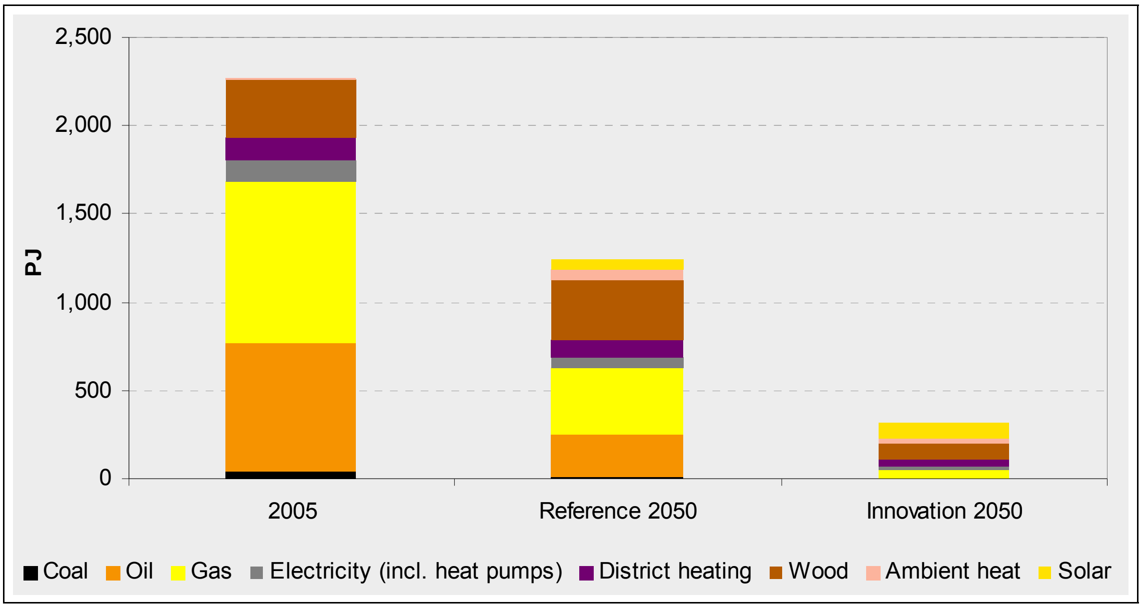
The structure of energy sources changes substantially; 84% of space heating will come from renewable energies, district heating or electricity (for heat pumps) (see Figure 6.1-4).

Table 6.1-5: Comparison of scenarios: Final energy consumption of space heating in the residential sector, by energy source, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**204 0**	**2050**
District heating	137	132	124	112	99	124	101	72	38
Oil	730	519	403	313	241	360	157	47	1
Gas	919	733	589	480	383	567	298	141	49
Coal	38	19	14	12	9	17	8	2	0
Wood	326	333	339	342	342	298	245	171	90
Electricity (incl. heat pumps)	113	97	81	67	54	85	59	36	23
Solar	1	12	38	49	53	87	149	135	83
Ambient heat	4	24	44	54	61	36	54	49	31
Total final energy consumption	2,268	1,86 9	1,632	1,429	1,242	1,573	1,07 0	653	315

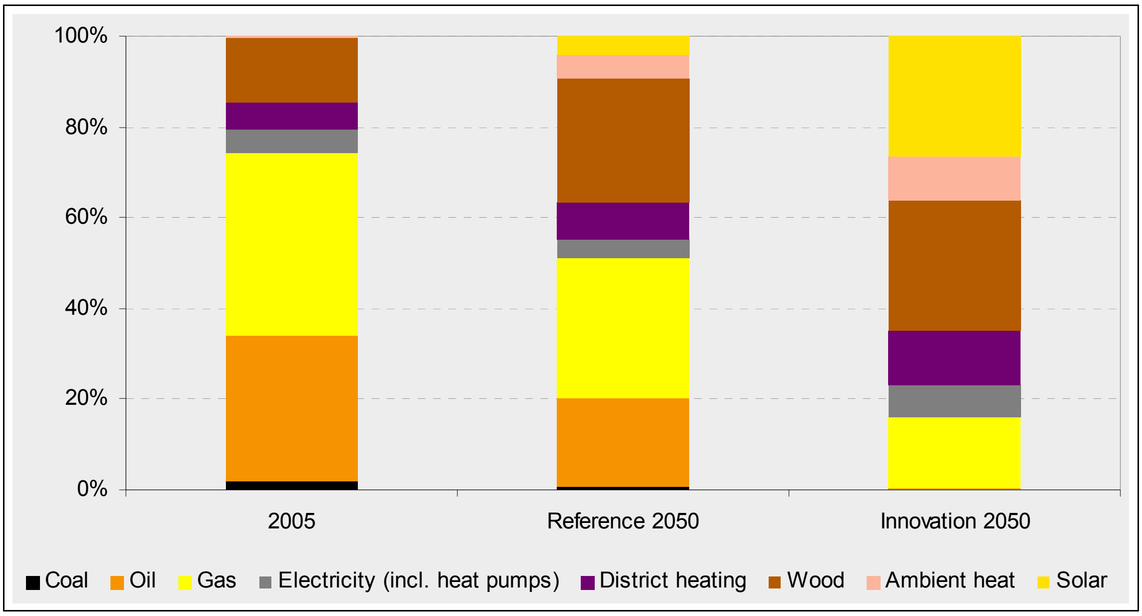
Source: Prognos 2009

Figure 6.1-3: Comparison of scenarios: Final energy consumption of space heating in the residential sector, by energy source, 2005 – 2050, in PJ



ource: Prognos 2009

Figure 6.1-4: Comparison of scenarios: Energy source structure for space heating in the residential sector, in %



Source: Prognos 2009

The structure for supplying the population with hot water under the innovation scenario differs substantially from the reference scenario (see Table 6.1-6):

- Conventional central hot water systems based on district heating, oil, gas, coal and wood, and decentralised oil and gas systems, will disappear almost entirely.
- Solar installations will become the most important heating system. The market share of solar installations will rise from 3% in 2005 to 56% in 2050. It is assumed that this represents the maximum possible market share. The possibilities of using solar heat depend on the orientation of roof surfaces and on the ratio of roof surface area to the floor space to be served.
- Electric hot water systems, including heat pumps, will likewise gain slightly in market share. The market share of electric systems will increase from 27% to 43% during the period.

Because of the larger share of electric heat pumps, the average overall efficiency of hot water systems in 2050 in the innovation scenario, at 106%, is greater than in the reference scenario (Table 6.1-7).

The two scenarios likewise differ in regard to the amount of demand for hot water. The innovation scenario assumes a reduction of per capita hot water consumption to just under 40 litres per day (compared to 51 litres in the reference scenario). This is accomplished with water-saving valves that limit water flow-through without reducing water pressure.

In addition, the innovation scenario includes greater shifts: the hot water needed for washing machines and dishwashers will largely be provided from a central hot water system, not by electric heaters within the appliances themselves. This will shift a portion of the energy consumed by electric appliances towards energy consumption for heating hot water (+7 PJ in 2050).

Thus total final energy consumption of hot water heating in the residential sector by 2050 is 52% less in the innovation scenario than in the reference scenario (Table 6.1-8, Figure 6.1-5).

The structure of energy sources shifts almost entirely towards renewable forms, including the operating power for heat pumps and operating gas for gas-driven heat pumps, or shares in the central use of other high-efficiency gas technologies (e.g., Stirling engines) (Figure 6.1-6).

Table 6.1-6: Comparison of scenarios: Structure of hot water supply for population, 2005 – 2050, in million persons

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Hot water from									
Central systems coupled to heating									
District heating	7.0	6.2	5.9	3.9	3.2	5.0	3.1	0.7	0.0
Oil	16.9	12.6	10.7	10.0	8.0	8.6	3.4	2.2	0.2
Gas	27.7	24.6	22.2	12.8	13.7	17.6	9.3	3.2	0.9
Coal	0.3	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.0
Wood	0.2	0.4	0.5	0.1	0.1	1.2	1.7	0.1	0.1
Central, non-coupled systems									
Solar*	2.6	8.0	13.9	22.3	26.8	10.5	21.6	31.8	40.2
Heat pumps	1.0	3.7	4.7	6.4	6.7	4.8	7.4	9.1	10.0
Decentralised systems									
Electricity	21.2	22.2	20.5	20.3	13.9	29.2	31.9	28.9	20.9
Gas	4.1	1.7	0.0	0.0	0.0	2.3	0.0	0.0	0.0
Total persons served	81.0	79.6	78.5	76.1	72.4	79.5	78.5	76.1	72.4
No own hot water heating	1.4	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0

** Converted to full supply* *Source: Prognos 2009*

Table 6.1-7: Comparison of scenarios: Utilisation ratio of hot water supply by population, 2005 – 2050, in %

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Central systems coupled to heating									
District heating	78	81	83	84	86	81	83	84	86
Oil	63	72	77	81	84	72	77	81	84
Gas	69	81	87	91	95	81	90	98	103
Coal	52	56	58	61	64	56	58	61	64
Wood	57	63	64	66	67	63	64	66	67
Central, non-coupled systems									
Solar*	100	100	100	100	100	100	100	100	100
Heat pumps	206	221	231	241	251	221	231	241	251
Decentralised systems									
Electricity	92	92	92	92	92	92	92	92	92
Gas	73	77	79	79	79	77	79	79	79
Total	74	86	92	97	100	89	97	103	106

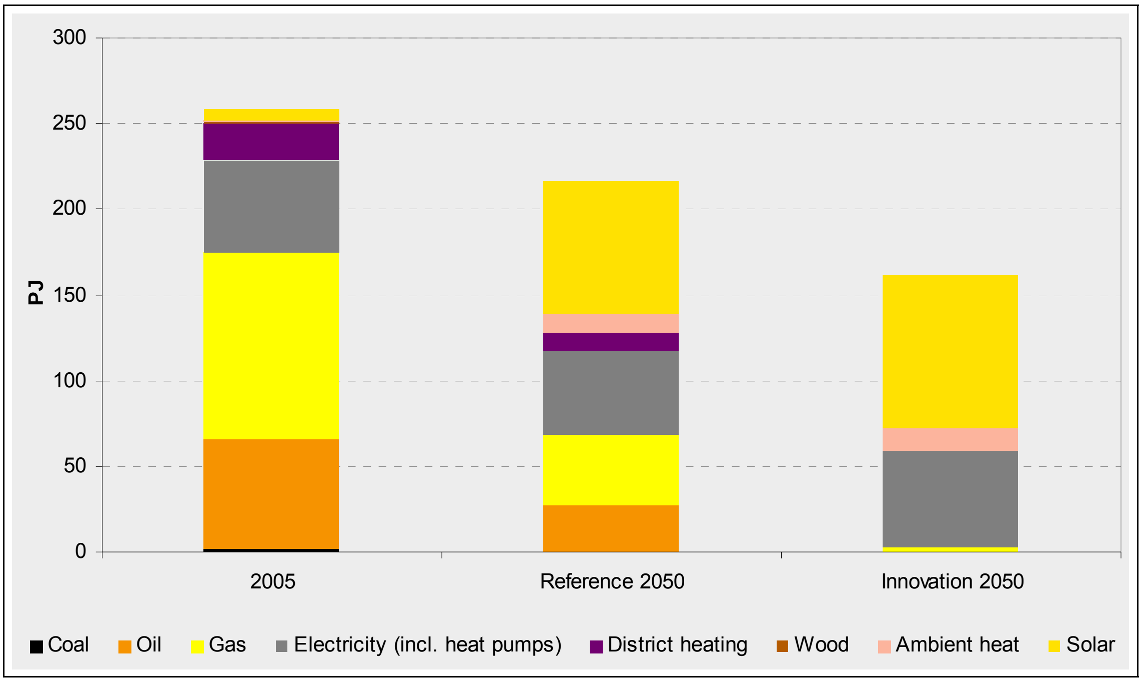
** Converted to full supply* *Source: Prognos 2009*

Table 6.1-8: Comparison of scenarios: Final energy consumption of water heating, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
District heating	21.8	20.1	20.2	13.4	10.7	15.8	9.6	2.1	0.0
Oil	64.8	45.9	39.7	35.4	27.0	30.4	11.5	6.5	0.4
Gas	109.1	85.3	72.6	40.7	41.3	62.5	26.8	7.9	2.0
Coal	1.5	0.8	0.6	1.1	0.2	0.7	0.4	0.4	0.0
Wood	0.9	1.6	2.2	0.4	0.3	5.0	6.7	0.3	0.2
Electricity (incl. heat pumps)	53.0	62.7	61.7	65.6	48.5	82.1	88.5	78.3	56.4
Subtotal	251.0	216.4	197.2	156.7	128.2	196.5	143.4	95.4	59.1
Solar	6.3	20.9	39.5	64.6	76.5	26.6	55.7	76.1	89.4
Ambient heat	1.3	5.3	7.6	10.9	11.5	6.7	10.8	12.8	13.4
Total final energy consumption	258.6	242.5	244.3	232.2	216.2	229.8	209.9	184.3	161.9

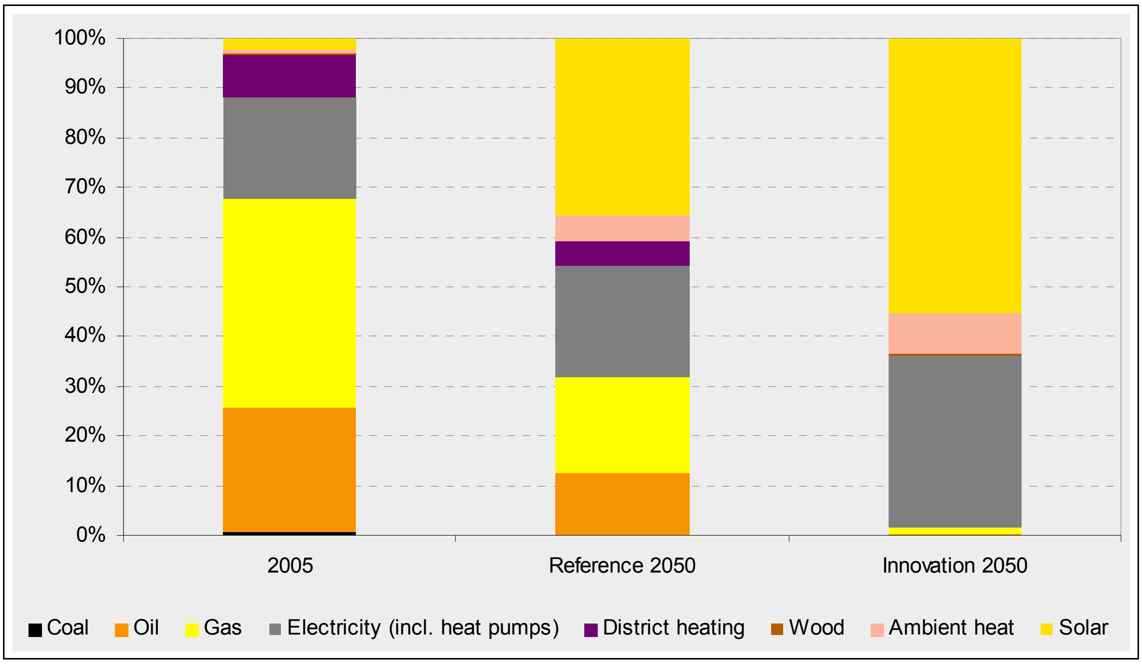
Source: Prognos 2009

Figure 6.1-5: Comparison of scenarios: Final energy consumption of water heating, by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

Figure 6.1-6: Comparison of scenarios: Final energy source structure for water heating, 2005 – 2050, in %



Source: Prognos 2009

6.1.1.3 Cooking and electric applications

For cooking, the scenarios indicate only slight changes over time, due to a somewhat faster market penetration by induction stoves. No serious changes in other conditions are assumed (such as a change in cooking habits against the reference scenario). In 2050, the energy consumption for cooking is the same in both scenarios at the level of resolution discussed here (Table 6.1-9).

Both scenarios assume the same levels of equipment and basic applications for other electric appliances. The only exception here is air conditioning systems. Because of the better energy performance standard of building shells, summer heat gains will also be less. Additionally, more solar cooling systems and high-performance collectors will be used. This means that the increase of power consumption for air conditioning is lower in the innovation scenario than in the reference scenario. For other power uses (entertainment/communication, white goods and brown goods), the potential for increasing technical energy efficiency is utilised somewhat better in the innovation scenario than in the reference scenario, especially in refrigeration and freezing, and in washing and drying. Consequently there is a greater decrease in the associated mean specific appliance consumptions (Table 6.1-10).

Higher equipment efficiency in the innovation scenario is achieved in part because of extensive market penetration by waterless washing machines that need no dryer, and by magnetic refrigerators. The miniaturisation of appliances – such as viewers being used in place of full-size screens (counted under colour TVs) – also has a certain importance.

As a result, in 2050 power consumption for electric appliances is 20% lower in the innovation scenario than in the reference scenario (down 40% from 2005). The most important contributions here come from washing machines (–60%), washer-dryers (–50%), refrigerators (–40%), and air conditioners (–40%) (see Table 5.3-12, Figure 6.1-7).

Table 6.1-9: Comparison of scenarios: Final energy consumption of cooking, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2066	2076	2086	2096
Percent of residential sector with stoves	99.0 %	98.0 %	97.0 %	96.0 %	95.0 %	98.0 %	97.0 %	96.0 %	95.0%
Electric stove	80.2 %	84.6 %	86.4 %	88.0 %	88.6 %	82.9 %	83.9 %	84.4 %	84.2%
Gas stove	18.9 %	15.2 %	13.5 %	12.0 %	11.4 %	14.9 %	13.1 %	11.6 %	10.8%
Wood or coal stove	0.8%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Appliances used (million)									
Electric stove	31.2	33.5	34.1	34.4	32.8	33.5	34.1	34.4	32.8
Gas stove	7.4	6.0	5.3	4.7	4.2	6.0	5.3	4.7	4.2
Wood or coal stove	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Specific consumption in kWh per appliance per year									
Electric stove	383.2	328.7	285.3	251.3	230.7	327.0	283.6	250.4	230.7
Gas stove	576.4	479.8	408.1	352.3	317.1	477.3	405.8	351.2	317.1
Wood or coal stove	622.8	620.2	594.6	550.5	531.4	617.0	591.1	548.7	531.4
Final energy consumption in PJ									
Electric stove	43.0	39.6	35.0	31.1	27.2	39.4	34.8	31.0	27.2
Gas stove	15.3	10.4	7.8	6.0	4.8	10.4	7.8	6.0	4.8
Wood or coal stove	0.7	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Total final energy consumption	59.0	50.1	42.9	37.1	32.1	49.9	42.7	37.0	32.1

Source: Prognos 2009

Table 6.1-10: Comparison of scenarios: Development of equipment component of specific consumption, by electric appliances, 2005 – 2050, in kWh per appliance per year (= mean consumption per existing unit of equipment per year)

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Light	281	125	105	42	33	125	105	42	33
Refrigerator	256	199	145	122	114	191	126	92	70
Refrigerator-freezer	329	237	156	114	95	229	145	102	79
Freezer	299	225	170	141	127	218	152	114	89
Washing machine	223	171	143	128	117	163	113	76	42
Washer-dryer	613	495	422	379	348	480	340	232	147
Dryer	298	235	204	183	166	227	173	129	90
Dishwasher	243	202	184	169	156	200	176	153	133
Colour TV	162	207	150	97	83	207	148	94	79
Radio / sound system	51	48	46	44	42	48	46	44	42
Video / DVD player	40	8	8	8	8	8	8	8	8
Electric iron	25	24	23	22	20	24	23	22	20
Vacuum cleaner	24	23	22	21	20	23	22	21	20
Coffee maker	85	85	68	68	68	85	68	68	68
Toaster	25	24	23	22	20	24	23	22	20
Hair dryer	25	24	23	22	20	24	23	22	20
Extraction hood (cooker)	45	43	41	39	37	43	41	39	37
Microwave	35	33	32	30	29	33	32	30	29
PC (incl. peripherals)	196	84	62	62	62	84	62	62	62
Communal area lighting, etc.	28	21	20	17	17	21	20	17	17

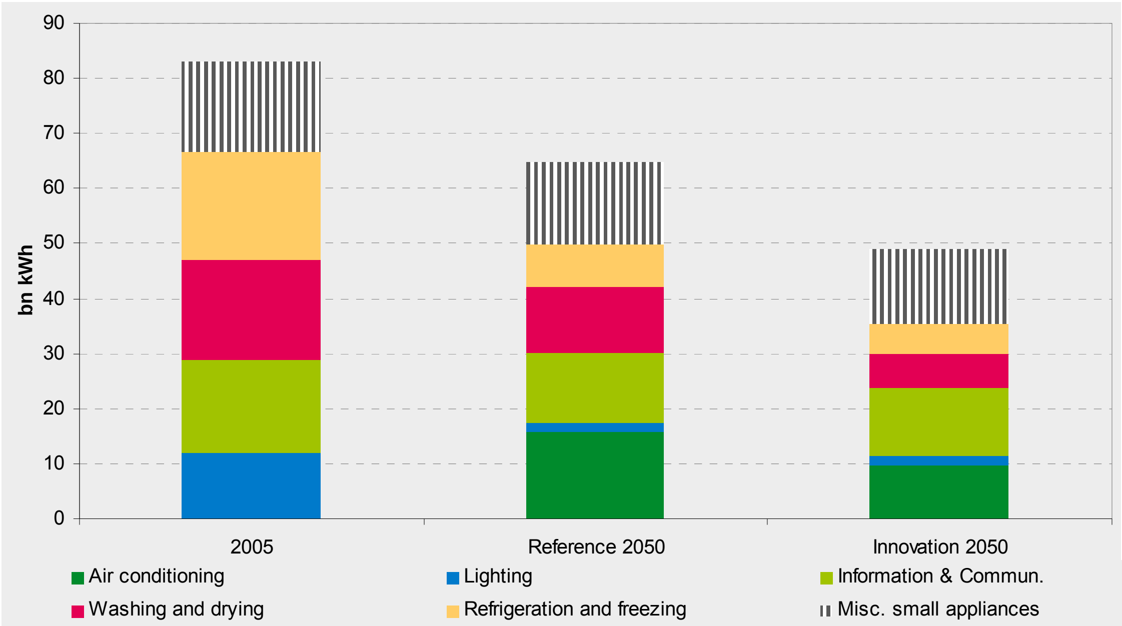
Source: Prognos 2009

Table 6.1-11: Comparison of scenarios: Final energy consumption of electric appliances in the residential sector, 2005 – 2050, in billion kWh

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Light	11.2	5.2	4.4	1.8	1.3	5.2	4.4	1.8	1.3
Refrigerator	7.6	5.3	3.7	2.5	2.0	5.1	3.2	1.9	1.2
Refrigerator-freezer	4.2	3.7	2.6	2.3	2.0	3.6	2.4	2.0	1.6
Freezer	7.9	6.5	5.0	4.3	3.8	6.3	4.5	3.4	2.7
Washing machine	7.1	4.3	2.2	1.4	0.9	4.1	1.7	0.8	0.3
Washer-dryer	1.8	2.9	4.0	6.0	7.0	2.8	3.2	3.7	3.0
Dryer	4.1	3.4	2.8	2.0	1.3	3.3	2.4	1.4	0.7
Dishwasher	5.3	4.7	2.9	2.7	2.5	4.7	2.8	2.4	2.1
TV	7.0	9.8	7.5	5.1	4.4	9.8	7.4	4.9	4.2
Radio / sound system	1.9	1.8	1.7	1.6	1.5	1.8	1.7	1.6	1.5
Video / DVD player	1.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Electric iron	0.9	0.8	0.8	0.7	0.7	0.8	0.8	0.7	0.7
Vacuum cleaner	0.9	0.9	0.8	0.8	0.7	0.9	0.8	0.8	0.7
Coffee maker	3.1	3.2	2.6	2.6	2.4	3.2	2.6	2.6	2.4
Toaster	0.9	0.9	0.8	0.8	0.7	0.9	0.8	0.8	0.7
Hair dryer	0.8	0.8	0.7	0.7	0.7	0.8	0.7	0.7	0.7
Extraction hood (cooker)	1.0	1.1	1.1	1.0	1.0	1.1	1.1	1.0	1.0
Microwave	0.9	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.0
PC (incl. peripherals)	6.8	6.7	5.7	6.3	6.6	6.7	5.7	6.3	6.6
Communal area lighting, etc.	0.6	0.5	0.4	0.4	0.3	0.5	0.4	0.4	0.3
Air conditioning	0.0	2.6	7.1	11.1	15.9	1.9	4.5	6.9	9.7
Other consumption	7.7	9.0	10.0	9.1	7.9	8.9	9.4	7.9	6.4
Total final energy consumption	83.0	75.4	68.4	64.5	64.9	73.5	62.2	53.5	49.1

Source: Prognos 2009

Figure 6.1-7: Comparison of scenarios: Final energy consumption of electric appliances (appliance classes) in the residential sector, 2005 and 2050, in billion kWh



Source: Prognos 2009

6.1.1.4 Total final energy demand in the residential sector

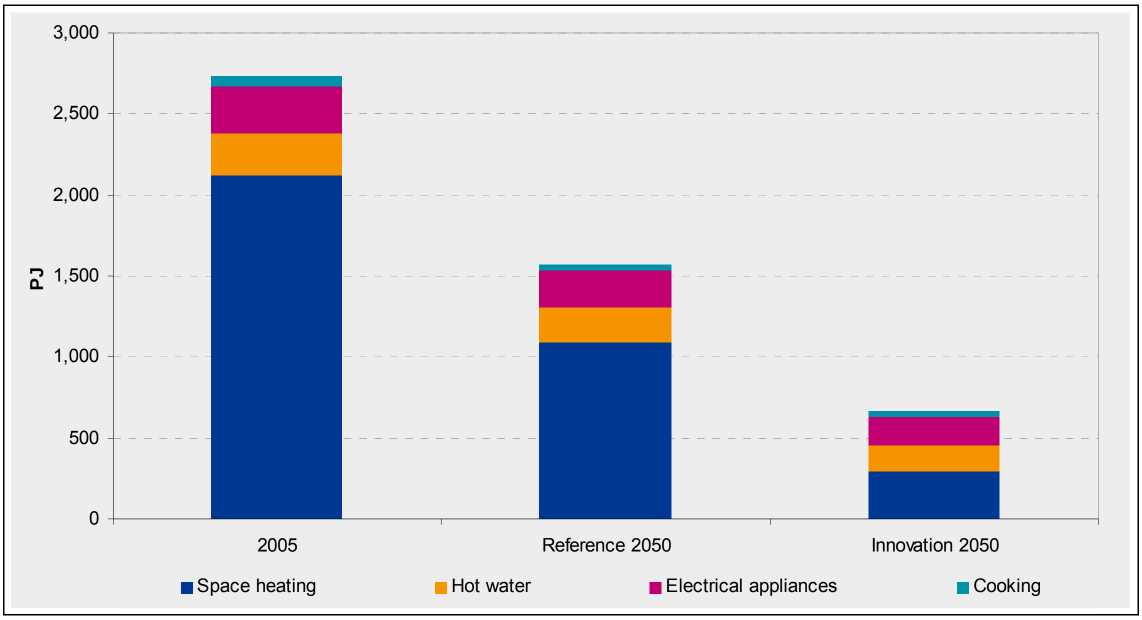
In sum, in the innovation scenario final energy demand in the residential sector in 2050 is 54% less than in the reference scenario and 75% less than the initial value from 2005. Because of the sharp reduction in space heating, the shares of the various types of use in energy demand shift (Table 6.1-12, Figure 6.1-8).

Table 6.1-12: Comparison of scenarios: Final energy consumption in the residential sector, by type of use, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Type of use									
Space heating	2,118	1,718	1,479	1,275	1,087	1,458	989	603	291
Hot water	259	243	244	232	216	230	210	184	162
Cooking	59	50	43	37	32	50	43	37	32
Electrical appliances	299	271	246	232	234	265	224	193	177
Total final energy consumption	2,735	2,282	2,013	1,777	1,569	2,003	1,465	1,017	662
Share in %									
Space heating	77.5 %	75.3 %	73.5 %	71.8 %	69.3 %	72.8 %	67.5 %	59.3 %	44.0%
Hot water	9.5%	10.6 %	12.1 %	13.1 %	13.8 %	11.5 %	14.3 %	18.1 %	24.5%
Cooking	2.2%	2.2%	2.1%	2.1%	2.0%	2.5%	2.9%	3.6%	4.8%
Electrical appliances	10.9 %	11.9 %	12.2 %	13.1 %	14.9 %	13.2 %	15.3 %	18.9 %	26.7%

Source: Prognos 2009

Figure 6.1-8: *Comparison of scenarios: Final energy consumption in the residential sector, by type of use, 2005 and 2050, in PJ*



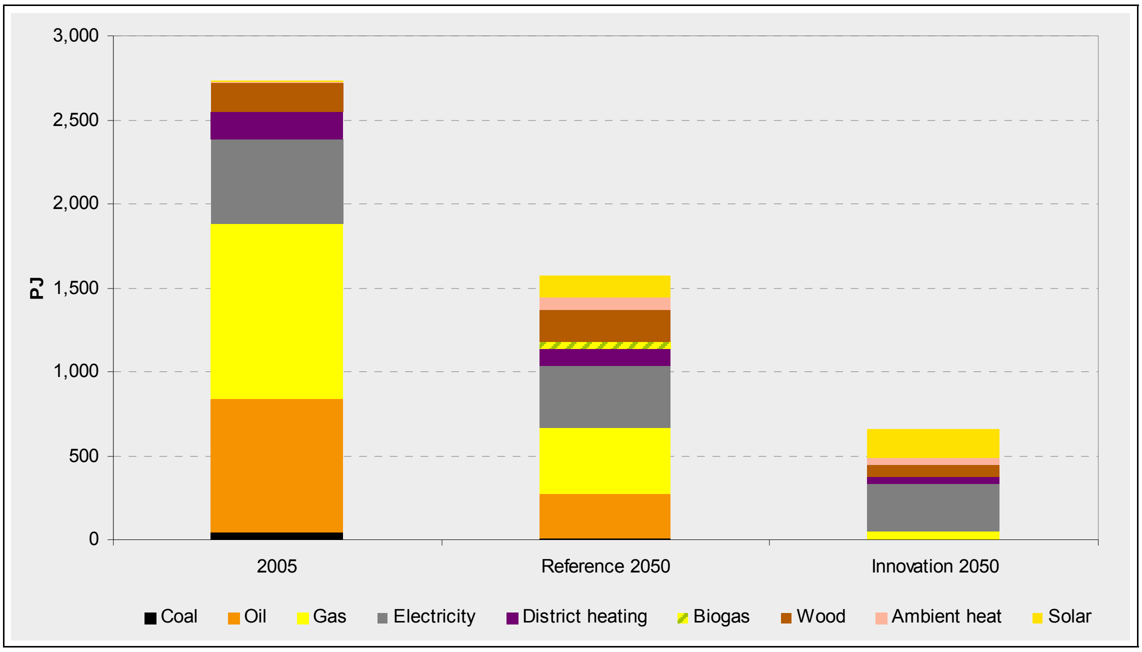
Source: Prognos 2009

Table 6.1-13: *Comparison of scenarios: Final energy consumption in the residential sector, by energy source, 2005 and 2050, in PJ*

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Energy source									
District heating	158	153	144	126	110	140	111	74	38
Oil	795	565	442	348	268	390	168	54	1
Gas	1,043	819	638	489	389	633	316	144	51
Coal	40	19	15	13	9	18	8	3	0
Wood	178	184	188	189	188	189	171	122	66
Electricity	508	470	424	396	364	471	406	338	283
Ambient heat	6	29	52	65	73	42	65	62	44
Solar	7	33	78	114	129	113	205	211	173
Biogas	0	9	32	38	40	7	16	11	5
Total final energy consumption	2,735	2,282	2,013	1,777	1,569	2,003	1,465	1,017	662
Structure in %									
District heating	5.8%	6.7%	7.2%	7.1%	7.0%	7.0%	7.5%	7.2%	5.8%
Oil	29.1 %	24.8 %	22.0 %	19.6 %	17.1 %	19.5 %	11.5 %	5.3%	0.2%
Gas	38.1 %	35.9 %	31.7 %	27.5 %	24.8 %	31.6 %	21.6 %	14.1 %	7.7%
Coal	1.5%	0.9%	0.8%	0.7%	0.6%	0.9%	0.6%	0.3%	0.0%
Wood	6.5%	8.1%	9.4%	10.6 %	12.0 %	9.4%	11.6 %	11.9 %	10.0%
Electricity	18.6 %	20.6 %	21.1 %	22.3 %	23.2 %	23.5 %	27.7 %	33.2 %	42.8%
Ambient heat	0.2%	1.3%	2.6%	3.7%	4.6%	2.1%	4.4%	6.1%	6.7%
Solar	0.3%	1.5%	3.9%	6.4%	8.2%	5.7%	14.0 %	20.7 %	26.1%
Biogas	0.0%	0.4%	1.6%	2.1%	2.5%	0.3%	1.1%	1.1%	0.8%

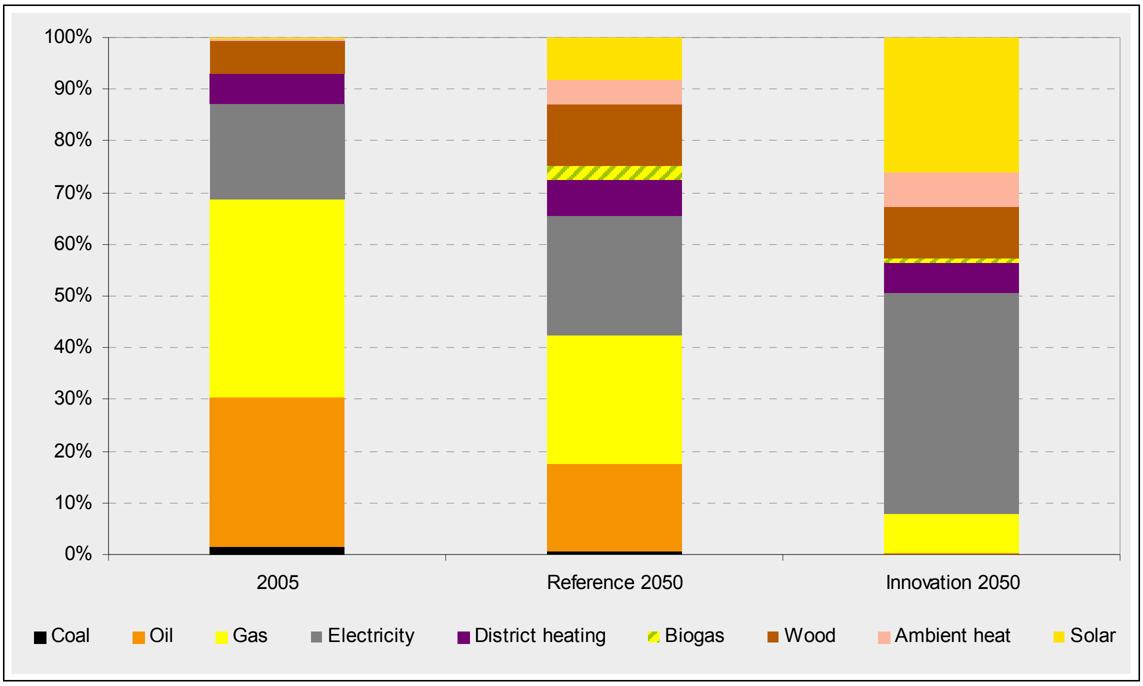
Source: Prognos 2009

Figure 6.1-9: Comparison of scenarios: Final energy consumption in the residential sector, by energy source, 2005 and 2050, in PJ



Source: Prognos 2009

Figure 6.1-10: Comparison of scenarios: Final energy source structure in the residential sector, 2005 and 2050, in PJ



Source: Prognos 2009

6.1.2 Final energy demand in the service sector

6.1.2.1 Framework data

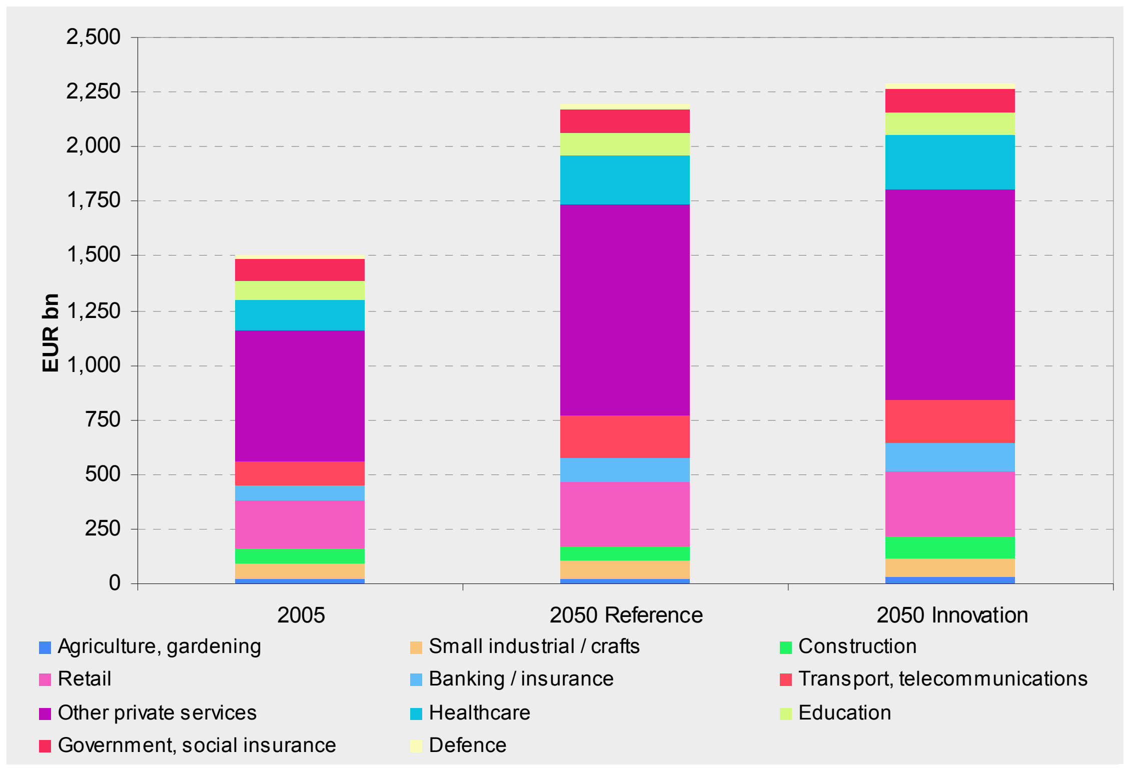
The main differences in the development of segment structure in the service sector are an increase of EUR 36.5 billion (55%) in value added in the construction industry by 2050 in the innovation scenario compared to the reference scenario, and an increase of EUR 20.6 billion (19%) in value added in the banking and insurance industry. These are directly related to heavier building investment to meet improved standards for new buildings and – far more substantially – the complete upgrading of the building inventory to the highest energy standards. In the other sectors, there are slight changes in value added – they work with different (energy-saving) technologies and in some cases the services are different, but they are counted in the same segments. For example, there will be less physical transport, but communication will increase (due to a virtualization of exchange). Both count under transport and communications, and value added remains nearly the same in total. On the whole, the service sector will profit from the ambitious CO_2 reduction path. Value added in 2050 is EUR 92.1 billion (4.2%) higher in the innovation scenario than in the reference scenario (see Table 6.1-14, Figure 6.1-11).

Table 6.1-14: Comparison of scenarios: Persons employed (in 1,000) and gross value added (in EUR billion) in the service sector, by segment, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Pers. employed (in 1,000)									
Agriculture, gardening	853	702	611	533	464	728	649	580	516
Small industrial / crafts	1,673	1,331	1,188	1,061	953	1,347	1,210	1,087	980
Construction	2,185	1,968	1,834	1,686	1,597	2,115	2,063	1,979	1,940
Retail	5,903	5,628	5,345	5,081	4,813	5,646	5,373	5,116	4,852
Banking / insurance	1,239	1,127	1,082	1,037	1,005	1,181	1,164	1,141	1,120
Transport, telecomm.	2,118	2,187	2,179	2,175	2,132	2,187	2,179	2,175	2,132
Other private services	9,675	11,089	10,478	9,834	9,574	11,097	10,490	9,848	9,590
Healthcare	4,036	4,830	4,655	4,504	4,625	4,930	4,806	4,693	4,849
Education	2,281	2,521	2,403	2,298	2,282	2,522	2,404	2,300	2,284
Government, social insur.	2,298	2,059	1,857	1,676	1,534	2,060	1,858	1,677	1,535
Defence	373	350	350	350	350	350	351	351	351
All segments	32,634	33,792	31,982	30,235	29,329	34,163	32,546	30,947	30,150
Gross value added (EUR bn)									
Agriculture, gardening	23	23	23	23	23	25	25	26	27
Small industrial / crafts	68	77	80	82	86	79	82	85	89
Construction	76	71	69	66	65	82	89	94	102
Retail	215	234	252	268	294	236	254	271	297
Banking / insurance	69	85	90	95	107	91	101	111	128
Transport, telecomm.	114	145	159	173	196	145	159	173	196
Other private services	598	704	776	853	963	704	778	855	966
Healthcare	141	178	192	209	233	184	204	225	253
Education	84	91	92	93	97	91	92	93	97
Government, social insur.	99	111	108	107	108	111	108	107	108
Defence	16	19	20	22	25	19	20	22	25
All segments	1,503	1,736	1,861	1,991	2,196	1,766	1,912	2,062	2,288

Source: Prognos 2009

Figure 6.1-11: Comparison of scenarios: Gross value added (in EUR billion) in the service sector, by segment, 2005 and 2050



Source: Prognos 2009

6.1.2.2 Final energy

Specific final energy demand in all segments decreases considerably in the innovation scenario by comparison to the reference scenario (see Table 6.1-15). Here it must be borne in mind that the reference scenario already cut specific energy consumption by more than half across the board. The main contributors here are a systematic reduction in space heating demand, and the great increases in efficiency in lighting that are already possible with the technology currently in use. The large reductions in demand for space heating are primarily because the mean service life of buildings in this sector is relatively short; it is more common for a building to be replaced than extensively and expensively renovated. Consequently a large portion of the building stock in this sector will have turned over by 2050. Likewise, the reference scenario already assumed a large increase in efficiency for all office equipment, and in information and communications network technology (under the “Green IT” concept). This development will advance primarily because the cost of the energy supply and cooling for servers, together with the associated space needs, now make up a considerable item in the budget of many industries (such as banking and insurance) that depend heavily on IT.

Further savings are realised under the innovation scenario due to process changes – for example in the generation of process heat and cold, and by the more efficient use of mechanical energy (more efficient motors and pumps, miniaturised processes), control and automation equipment, and changes in products, materials and services.

Table 6.1-15: Comparison of scenarios: Specific energy consumption in the service sector, 2005 – 2050, in PJ/EUR billion, and indexed to year 2005

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Specific consumption									
Agriculture, gardening	5.48	4.09	3.38	2.92	2.44	3.62	2.69	2.10	1.63
Small industrial / crafts	1.54	1.00	0.80	0.69	0.58	0.88	0.62	0.49	0.38
Construction	1.04	0.83	0.69	0.60	0.53	0.68	0.49	0.38	0.30
Retail	1.39	0.98	0.75	0.67	0.55	0.82	0.51	0.38	0.28
Banking / insurance	0.65	0.43	0.34	0.29	0.24	0.36	0.24	0.19	0.15
Transport, telecommunications	0.49	0.32	0.22	0.17	0.13	0.28	0.17	0.12	0.09
Other private services	0.53	0.39	0.30	0.26	0.22	0.35	0.23	0.18	0.14
Healthcare	1.34	0.89	0.59	0.41	0.33	0.76	0.44	0.29	0.23
Education	1.02	0.70	0.45	0.32	0.25	0.60	0.31	0.20	0.15
Government, social insurance	1.34	0.90	0.67	0.52	0.42	0.78	0.50	0.35	0.27
Defence	1.93	1.46	1.24	1.07	0.91	1.38	1.13	0.94	0.78
Specific consumption, indexed									
Agriculture, gardening	100	75	62	53	45	66	49	38	30
Small industrial / crafts	100	65	52	45	38	57	41	32	25
Construction	100	80	66	57	51	65	47	36	29
Retail	100	71	54	48	39	59	37	28	20
Banking / insurance	100	66	52	45	37	55	37	29	23
Transport, telecommunications	100	66	46	34	26	58	35	25	19
Other private services	100	75	58	49	42	66	44	34	27
Healthcare	100	67	44	31	25	57	33	22	17
Education	100	69	45	31	24	59	31	19	14
Government, social insurance	100	67	50	39	31	58	37	26	20
Defence	100	75	64	55	47	71	58	49	40

Source: Prognos 2009

The integrated final energy demand by segment, energy source and type of use for both scenarios is shown in Table 6.1-16. Even in the reference scenario, the rise of about 46% in gross value added between 2005 and 2050 is more than offset by an above-proportional increase in energy efficiency – final energy consumption in 2050 in the reference scenario is 50% less than in 2005, and in the innovation scenario it is 67% less.

Every segment contributes to the reduction to a different degree, depending on the nature of the limiting factors – process heat and mechanical energy. The further reduction in specific energy consumption varies from about 15% (defence) to nearly 50% (retail), although given the respective changes in value added, this does not result in a substantial structural shift in energy consumption by segment (see Figure 6.1-12).

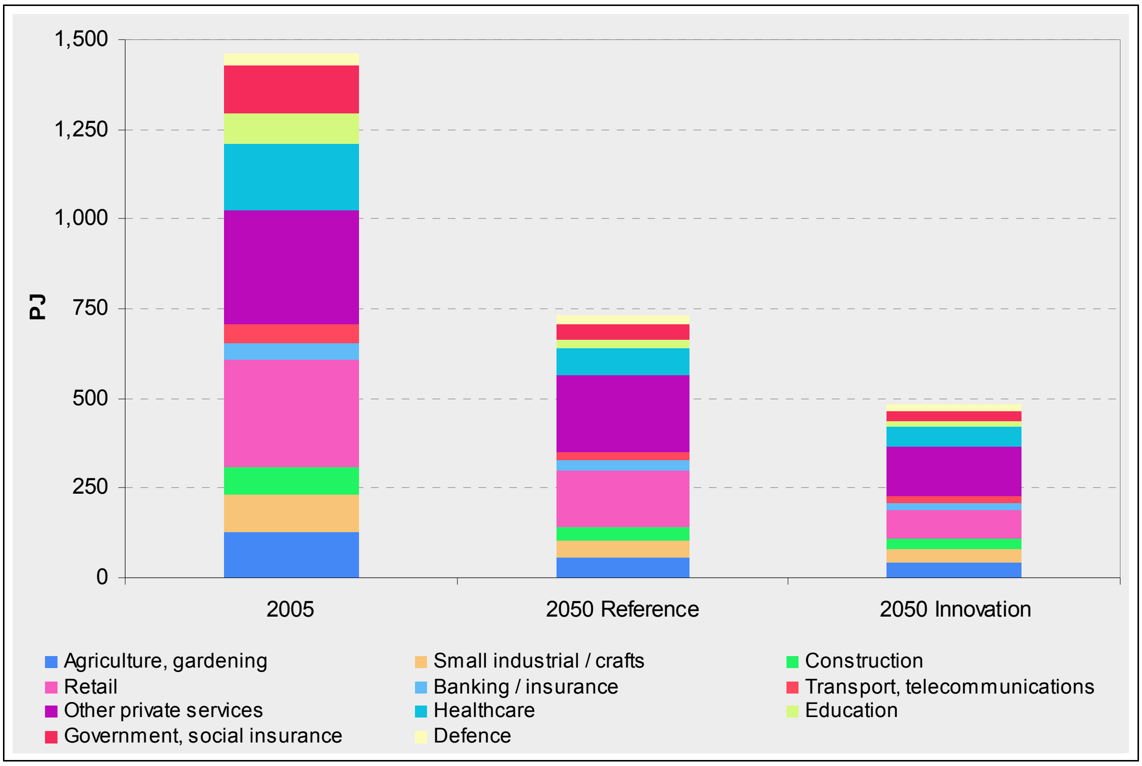
In terms of energy source and type of use, the reduction in the innovation scenario compared to the reference scenario is primarily the result of a massive reduction in the consumption of electricity for lighting, ventilation and cooling.

Table 6.1-16: Comparison of scenarios: Energy consumption in the service sector, 2005 – 2050, by segment, type of use and energy source, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Segment									
Agriculture, gardening	127	95	78	67	57	89	68	55	45
Small industrial / crafts	104	77	63	56	50	69	51	41	34
Construction	79	59	47	39	35	56	43	35	31
Retail	298	230	189	180	160	194	130	104	82
Banking / insurance	45	36	30	28	25	32	25	21	19
Transport, telecommunications	55	47	35	29	25	41	27	21	18
Other private services	315	277	236	222	211	243	181	153	136
Healthcare	189	158	114	86	76	141	89	66	59
Education	85	63	42	30	24	54	29	18	14
Government, social insurance	133	100	73	56	45	86	54	38	29
Defence	32	27	25	24	22	26	23	21	19
All segments	1,462	1,169	933	815	731	1,031	720	574	486
Type of use									
Space heating	664	415	189	53	7	347	108	18	2
Process heat	310	310	301	292	291	300	283	265	256
Cooling and ventilation	65	85	137	213	215	63	79	96	75
Lighting	148	119	97	80	66	95	64	43	30
Office equipment	56	52	45	36	28	46	36	26	18
Mechanical force	220	189	165	142	124	180	151	126	106
All types of use	1,462	1,169	933	815	731	1,031	720	574	486
Energy source									
Coal	5	0	0	0	0	0	0	0	0
Oil	279	159	80	30	20	140	57	19	15
Gas	515	394	256	171	147	350	201	141	130
Electricity	443	415	426	465	439	354	310	282	229
District heating	96	69	43	28	22	61	34	22	19
Renewables (w/o biofuels)	10	34	41	44	35	32	37	39	32
Motor fuels (incl. biofuels)	114	98	87	76	67	94	82	70	60
All energy sources	1,462	1,169	933	815	731	1,031	720	574	486

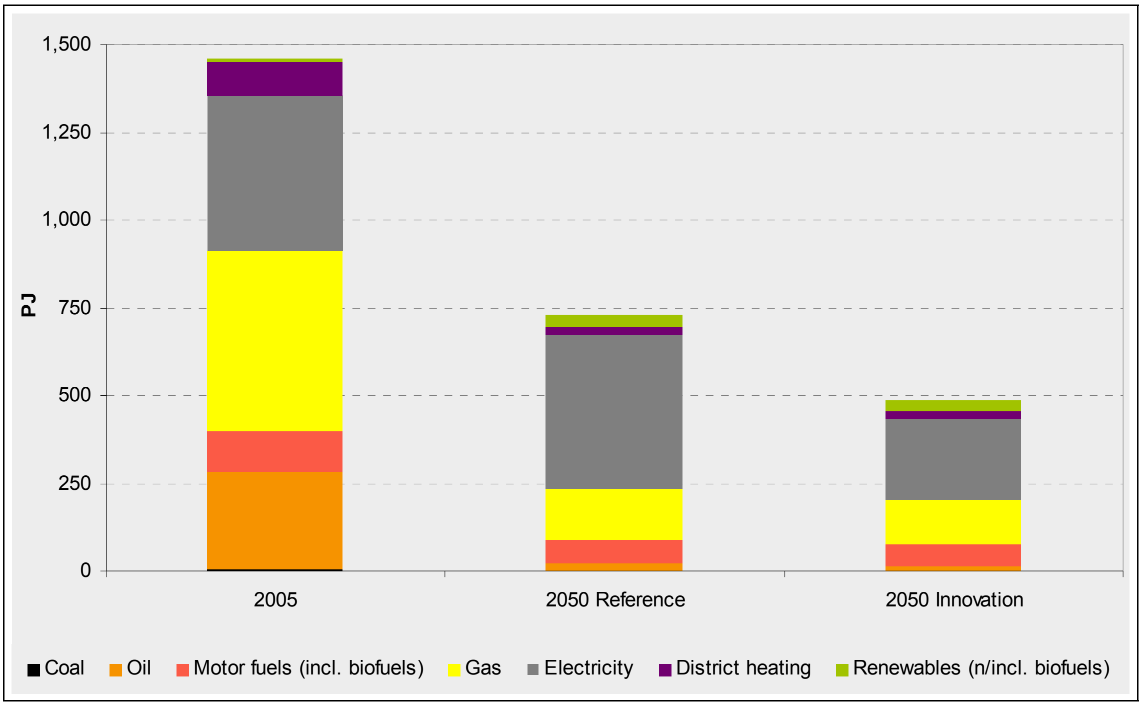
Source: Prognos 2009

Figure 6.1-12: Comparison of scenarios: Energy consumption in the service sector, 2005 and 2050, by segment, in PJ



Source: Prognos 2009

Figure 6.1-13: Comparison of scenarios: Final energy consumption in the service sector, 2005 and 2050, by energy source, in PJ

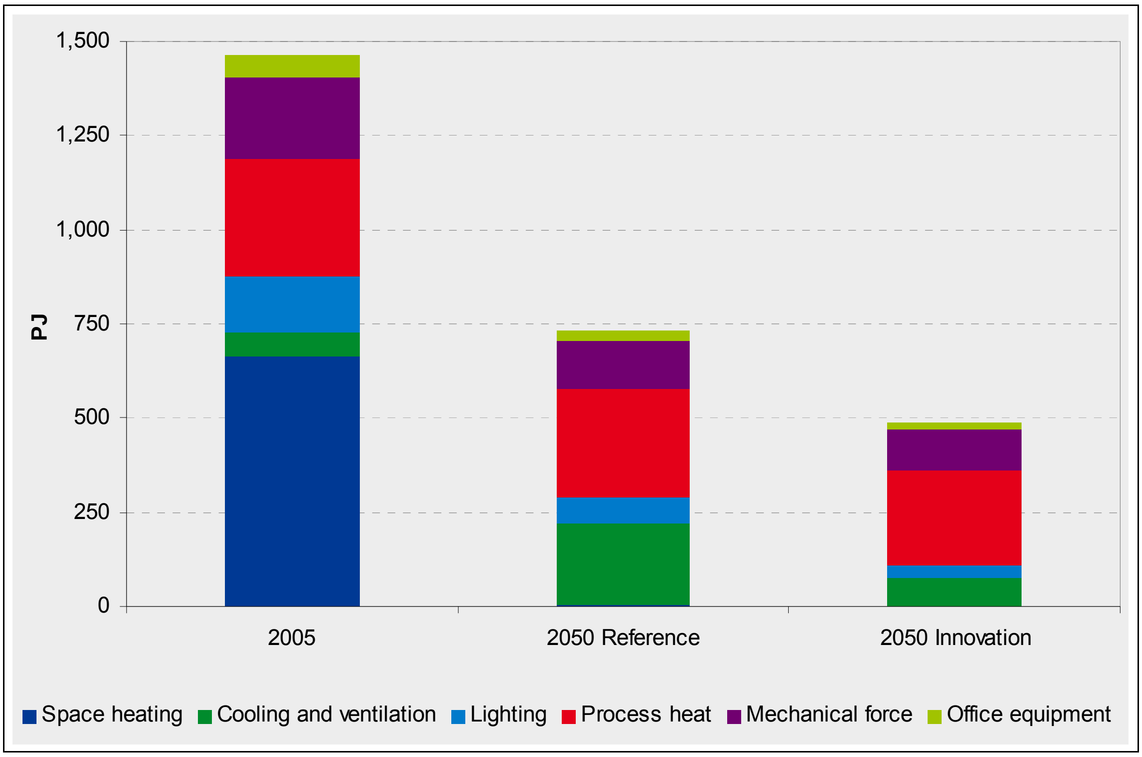


Source: Prognos 2009

The "base" of gas and heating oil is due primarily to their uses for process heat. Because transport is assigned the priority for the use for biofuels, there will not be enough biogas available, though in technical terms it could be used here as well. Only a very low level of changeover to electricity is assumed for process heat (with a simultaneous large increase in efficiency). The renewable sources are primarily solar thermal hot water heating, and solar and ambient heat combined with a use of heat pumps for space heating, hot water heating, and water cooling.

Figure 6.1-14 shows the breakdown of final energy demand by type of use. The reduction of space heating demand to nearly zero is clear in both scenarios. In the reference scenario, global warming leads to the expectation of a substantial rise in demand for room cooling, which will make up a large share of the sector's future energy consumption unless all available potentials for efficiency can be mined in a concerted way. Market penetration by cooling options in 2050 is the same in both scenarios, but in the innovation scenario the useful energy is provided by way of innovative technologies, especially bivalent heat pumps – some of them gas-fuelled – that can provide cooling in summer and heat in winter, as well as by solar cooling. The two items for process heat and mechanical energy cannot be reduced at will through efficiency measures, because there are physical lower limits that can never be achieved in real processes.

Figure 6.1-14: Comparison of scenarios: Final energy consumption in the service sector, by type of use, 2005 and 2050, in PJ



Source: Prognos 2009

6.1.3 Final energy demand in the industry sector

6.1.3.1 Framework data

Table 6.1-17 shows industrial production by segment for both scenarios. The priority on CO_2 reduction and energy efficiency will cause a slight shift in segment structure, and ultimately a small reduction of production in 2050 (0.7%) in the industry sector, with a concomitant increase in value added in the service sector (+4%, see Sec. 6.1.2.1). Within industry, the chemical and plastics segment in particular will benefit, but so too will glass and ceramics, from the development of new materials and especially from demand for high-performance insulation, high-performance windows, etc., as a consequence of high-quality energy upgrades in buildings. Energy-intensive metal production (both ferrous and non-ferrous metals) is the loser from the substitutions in this materials revolution. Customised materials and construction techniques will come onto the market that will supplant metals or use them in composites or entirely new compounds, so that both quantities and value added will decrease in these segments. It is also expected that part of production will be relocated to regions of the world where the appropriate concentrated energy potential is readily available.

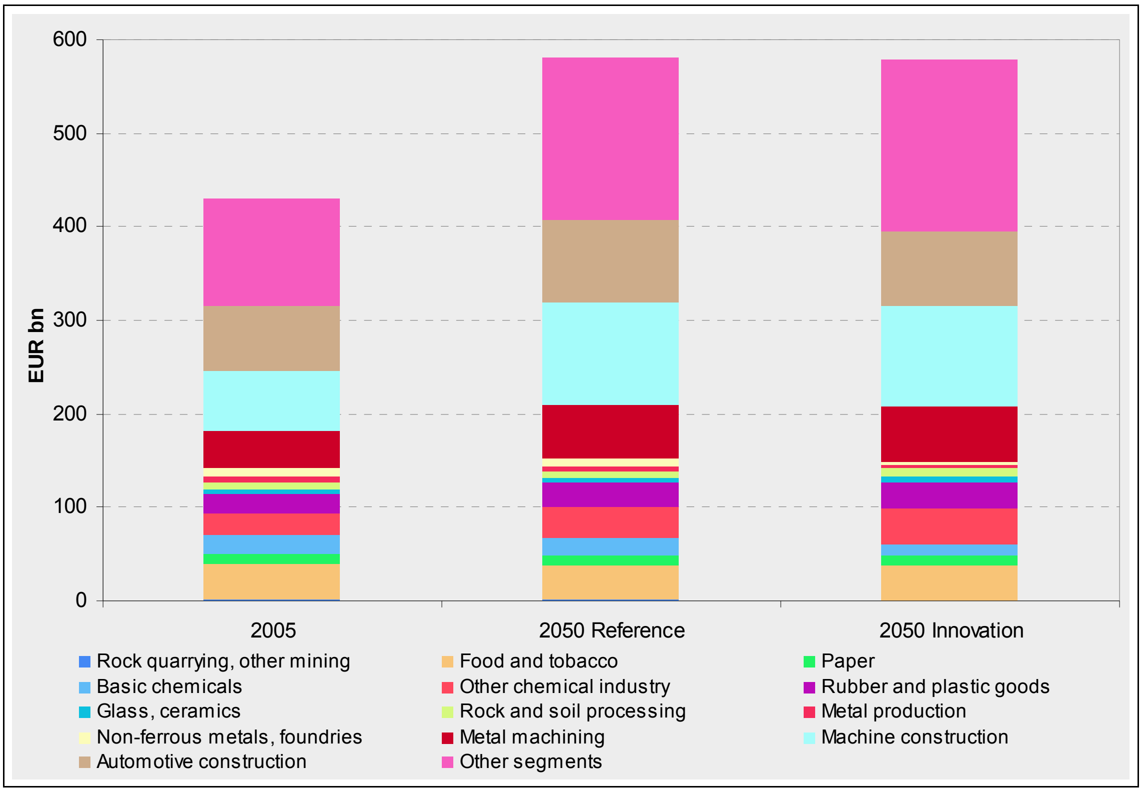
Automotive construction will produce fewer, smaller and lighter-weight vehicles on the whole than in the reference scenario, and will boost the transition to extensive electric mobility. The other branches of business include the energy industry, with its distribution and supplier industries (electronic instrumentation, etc.), whose production will gain substantially by the renovation of the electricity sector. Despite substantial changes in its internal structure (efficiency technologies, other kinds of machines, larger share of control electronics), machine construction will remain the fastest-growing segment. All told, the segment structure will not change dramatically. No “key segment” that the economy depends on heavily will be lost (see also Table 6.1-17, Figure 6.1-15). The different developments of energy-intensive segments and other segments in the two scenarios are shown in Figure 6.1-16.

Table 6.1-17: Comparison of scenarios: Industrial production 2005 – 2050 (categories from energy balance sheet), EUR billion, in 2000 prices

	Reference scenario					Innovation scenario				
	2005	2020	2030	2040	2050	2005	2020	2030	2040	2050
Rock quarrying, other mining	1.9	1.3	1.1	1.0	0.9	1.9	1.2	1.0	0.9	0.8
Food and tobacco	37.3	37.0	36.3	35.7	37.0	37.3	37.0	36.4	35.9	37.2
Paper	10.4	11.1	10.6	10.5	10.7	10.4	11.1	10.7	10.6	10.9
Basic chemicals	20.7	20.1	19.1	19.0	19.8	20.7	17.6	14.9	13.0	12.0
Other chemical industry	23.0	29.0	29.7	30.4	32.0	23.0	30.7	32.7	34.6	37.4
Rubber and plastic goods	20.6	24.0	24.2	24.5	25.5	20.6	25.0	26.0	27.1	28.9
Glass, ceramics	5.2	6.3	5.9	5.7	5.7	5.2	6.6	6.4	6.4	6.7
Rock and soil processing	8.0	7.9	7.8	7.7	8.0	8.0	8.2	8.2	8.4	8.9
Metal production	6.0	5.9	4.9	4.4	4.4	6.0	5.2	3.8	2.8	2.2
Non-ferrous metals, foundries	8.3	8.9	8.8	8.8	8.9	8.3	7.5	6.4	5.4	4.5
Metal machining	41.3	51.5	53.1	54.6	57.3	41.3	51.6	53.4	55.1	57.9
Machine construction	64.0	91.9	97.9	102.4	108.7	64.0	91.9	98.0	102.4	108.8
Automotive construction	68.0	77.8	80.7	84.3	89.3	68.0	74.4	75.0	76.3	78.8
Other segments	115.5	149.6	158.1	164.5	173.2	115.5	152.9	163.7	172.4	183.5
Total industrial production	430.3	522.0	538.1	553.4	581.3	430.3	521.1	536.6	551.2	578.4

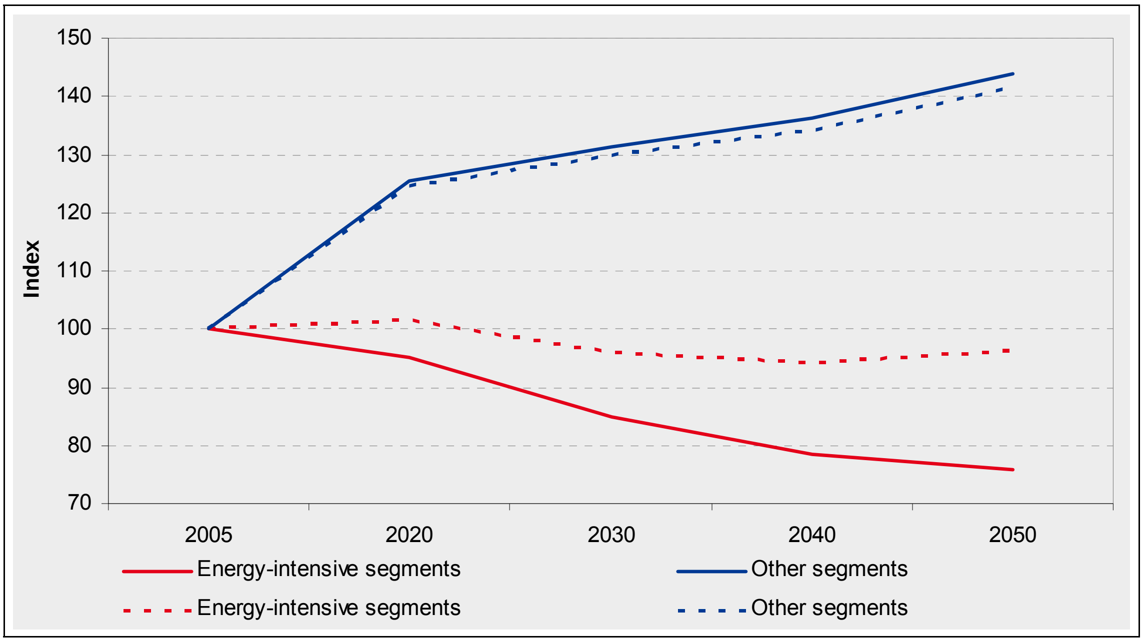
Source: Prognos 2009

Figure 6.1-15: Comparison of scenarios: Industrial production, by segment, 2005 and 2050, EUR billion, in 2000 prices



Source: Prognos 2009

Figure 6.1-16: Comparison of scenarios: Industrial production by energy-intensive segments and other segments, 2005 – 2050, indexed, reference scenario (dotted line), innovation scenario (solid line)



Source: Prognos 2009

6.1.3.2 Final energy demand

The specific energy consumption per unit of production value decreases in all segments under the reference scenario. On average, in 2050 it is 58% below the 2005 value. This means an average annual efficiency increase of about 1.2%. In the innovation scenario, by 2050 the average specific energy consumption decreases to 35% of the 2005 value, equivalent to an average annual efficiency improvement of about 2.3%.

Changes in specific energy consumption vary among the different segments (see Table 6.1-18).

The additional specific savings are less in the more energy-intensive segments than in the less energy-intensive segments. This is in part because there are physical lower bounds for processes that require process heat and mechanical energy, and therefore any further efficiency increases must be primarily brought about in auxiliary processes. Moreover, energy is normally a very noticeable cost factor in the energy-intensive segments, and they have been optimising it for several years already. Savings in a core process will be realised primarily with innovations in processes and materials, further optimisation in controls, and miniaturisation.

Thus the final energy consumption in the industry sector is as shown in Table 6.1-19 and Figure 6.1-17.

In the reference scenario, final energy demand is reduced a total of 21%, while it decreases 53% in the innovation scenario. The energy-intensive segments’ weight in total consumption decreases overall.

Table 6.1-18: Comparison of scenarios: Specific energy consumption in industrial segments, 2005 – 2050, in PJ/EUR billion

	Reference scenario					Innovation scenario				
	2005	**2020**	**2030**	**2040**	**2050**	**2005**	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	10.3	7.5	6.8	6.1	5.5	10.3	5.7	4.5	3.7	3.4
Food and tobacco	5.4	4.8	4.5	4.2	3.9	5.4	3.7	3.0	2.6	2.5
Paper	21.1	20.2	19.4	18.7	18.0	21.1	16.2	14.1	13.1	12.9
Basic chemicals	17.5	14.3	13.6	13.0	12.5	17.5	11.4	9.9	9.1	9.0
Other chemical industry	3.4	3.1	2.8	2.6	2.4	3.4	2.3	1.9	1.7	1.6
Rubber and plastic goods	3.7	3.4	3.2	3.0	2.9	3.7	2.6	2.2	2.0	1.9
Glass, ceramics	17.8	16.7	15.8	15.0	14.2	17.8	13.3	11.3	10.3	10.0
Rock and soil processing	23.1	19.5	17.6	15.8	14.2	23.1	14.9	11.8	10.0	9.4
Metal production	89.0	80.0	76.1	73.3	69.6	89.0	71.7	65.2	61.8	59.4
Non-ferrous metals, foundries	16.8	14.2	13.5	12.8	12.1	16.8	11.4	9.8	8.9	8.7
Metal machining	2.5	2.4	2.2	2.1	2.0	2.5	1.8	1.5	1.3	1.3
Machine construction	1.2	1.1	1.0	0.9	0.9	1.2	0.8	0.7	0.6	0.6
Automotive construction	1.9	1.7	1.6	1.5	1.4	1.9	1.2	1.0	0.9	0.9
Other segments	1.8	1.6	1.5	1.4	1.3	1.8	1.2	1.0	0.9	0.9
Total spec. energy consumption	5.6	4.4	3.9	3.5	3.3	5.6	3.4	2.6	2.2	2.0

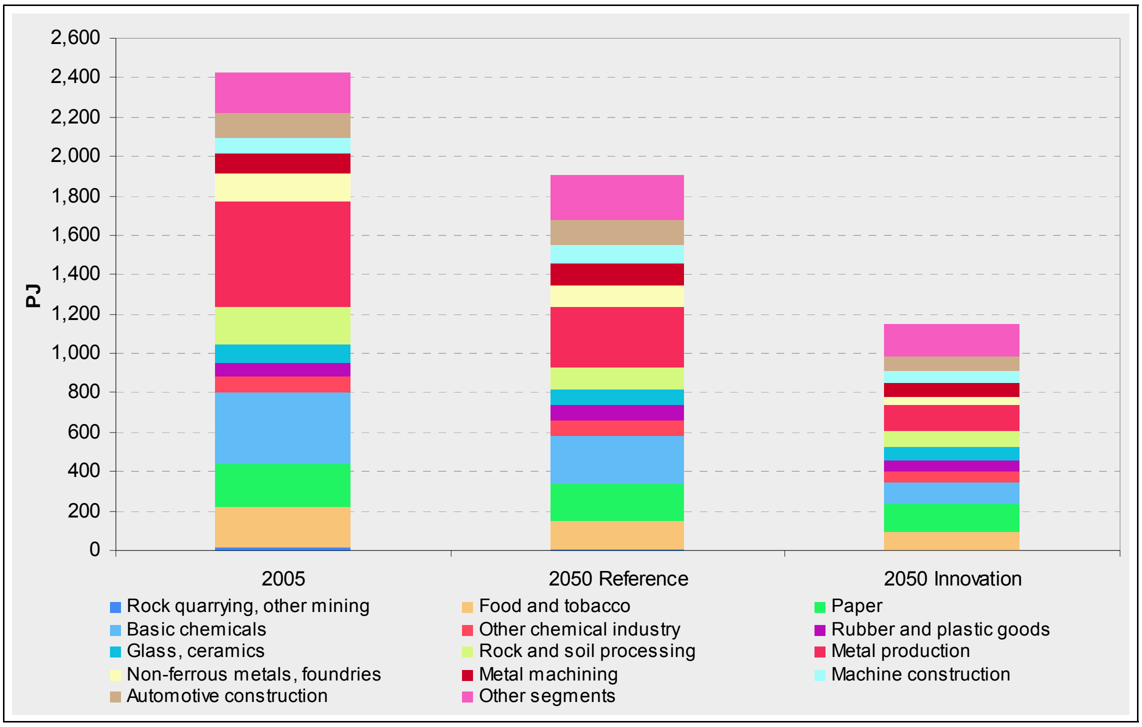
Source: Prognos 2009

Table 6.1-19: Comparison of scenarios: Final energy consumption in the industry sector, by segment, 2005 – 2050, in PJ

	Reference scenario					Innovation scenario				
	2005	**2020**	**2030**	**2040**	**2050**	**2005**	**2020**	**2030**	**2040**	**2050**
Rock quarrying, other mining	19	9	7	6	5	19	7	4	3	3
Food and tobacco	201	179	163	149	143	201	136	109	95	94
Paper	220	223	205	196	193	220	181	151	140	141
Basic chemicals	362	287	260	247	246	362	201	147	119	108
Other chemical industry	77	89	84	80	78	77	71	61	57	59
Rubber and plastic goods	77	81	77	74	73	77	65	56	53	55
Glass, ceramics	92	105	94	85	81	92	87	73	66	67
Rock and soil processing	185	154	136	122	113	185	122	97	84	83
Metal production	537	468	373	325	303	537	373	245	173	130
Non-ferrous metals, foundries	140	127	119	112	108	140	86	63	48	39
Metal machining	104	122	118	114	113	104	93	79	73	75
Machine construction	79	98	98	96	95	79	74	64	59	61
Automotive construction	127	128	125	124	123	127	93	77	70	71
Other segments	203	232	234	232	234	203	182	164	158	165
Total final energy demand	2,424	2,301	2,094	1,961	1,909	2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

Figure 6.1-17: Comparison of scenarios: Final energy consumption in the industry sector, by segment, 2005 and 2050, in PJ



Source: Prognos 2009

Table 6.1-20 and Figure 6.1-18 compare final energy consumption in the industry sector by type of use. Process heat and mechanical energy continue to dominate as types of use; these are needed to convert, process and refine material objects. In the innovation scenario, the relative share of process heat increases from 66% in 2005 to 70% in 2050. This is because the potential for savings is greater in all other segments, especially space heating, lighting and auxiliary energy (motors, pumps, compressed air).

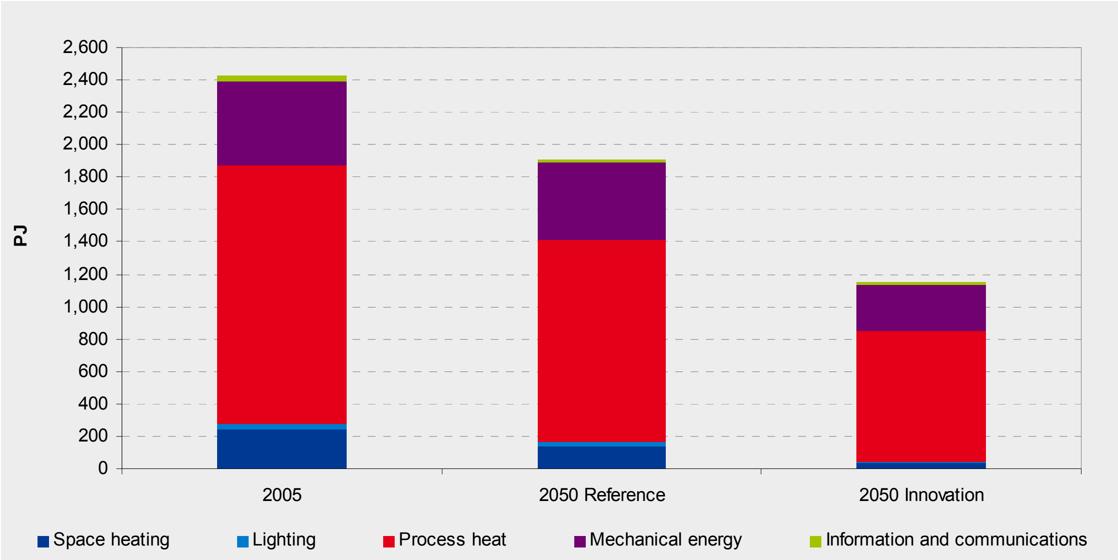
The final energy consumption in the industry sector, broken down by energy source, is shown in Table 6.1-21 and Figure 6.1-19. In metallurgy especially, a share of coal remains in the mix even in the innovation scenario, for use in the direct production of high-temperature process heat and for reduction processes. The primary energy source in process heat production is gas, which is used with high efficiency.

Table 6.1-20: Comparison of scenarios: Final energy consumption in the industry sector, by type of use, 2005 – 2050, in PJ

	Reference scenario					Innovation scenario				
	2005	**2020**	**2030**	**2040**	**2050**	**2005**	**2020**	**2030**	**2040**	**2050**
Space heating	240	182	162	147	138	240	89	53	38	35
Process heat	1,597	1,524	1,376	1,283	1,248	1,597	1,239	983	844	801
Mechanical energy	516	527	496	475	469	516	403	329	295	293
Information and communications	33	31	27	24	23	33	18	12	10	10
Lighting	39	37	34	31	30	39	20	14	11	11
Total final energy demand	2,424	2,301	2,094	1,961	1,909	2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

Figure 6.1-18: Comparison of scenarios: Final energy consumption in the industry sector, by type of use, 2005 and 2050, in PJ



Source: Prognos 2009

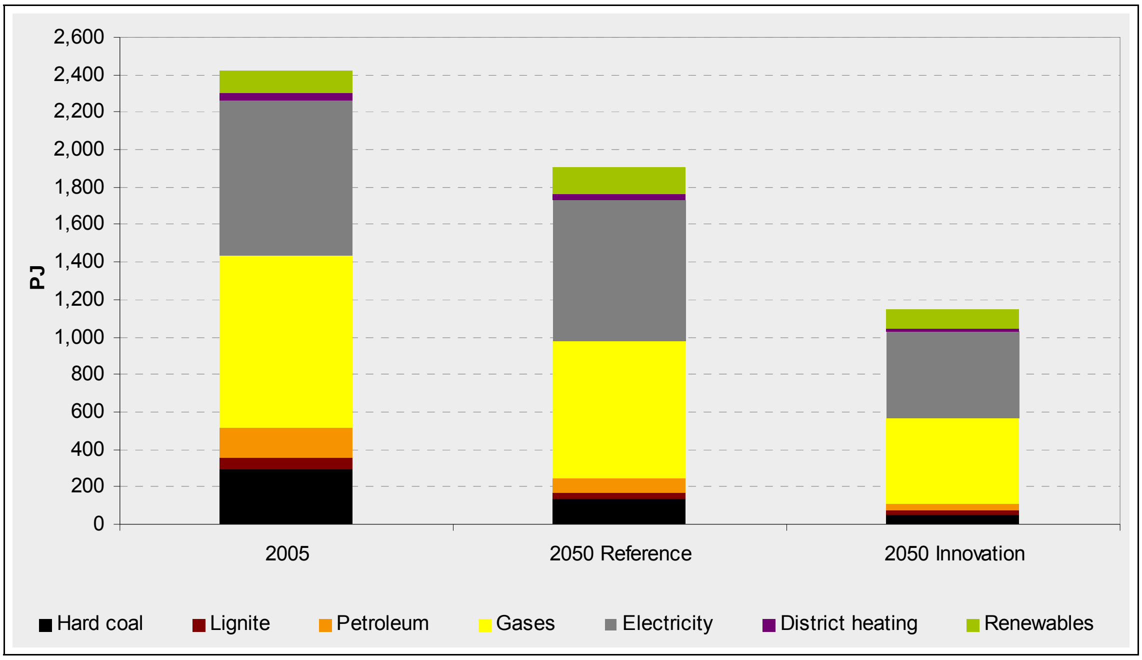
Table 6.1-21: Comparison of scenarios: Final energy consumption in the industry sector, by energy source, 2005 – 2050, in PJ

	Reference scenario					Innovation scenario				
	2005	2020	2030	2040	2050	2005	2020	2030	2040	2050
Hard coal	296	252	193	158	137	296	206	130	83	55
Lignite	59	48	41	35	32	59	38	29	24	22
Petroleum	162	132	107	87	72	162	93	61	43	35
of which: Heating oil, light	77	63	54	45	38	77	44	31	23	20
Heating oil, heavy	67	55	42	33	27	67	39	24	16	11
Other petroleum products	19	14	11	9	7	19	10	7	5	4
Gases	921	883	807	759	742	921	677	536	467	451
of which: Natural gases	800	780	724	687	674	800	597	484	429	422
LPG, refinery gas	11	13	11	9	8	11	9	6	4	3
Coke oven gas	33	27	22	19	18	33	21	14	10	8
Blast furnace gas	77	63	50	44	42	77	49	33	24	18
Renewables	118	129	132	137	144	118	103	96	97	104
Electricity	823	814	773	748	746	823	623	517	467	466
District heating	45	43	40	37	35	45	28	21	17	16
Total final energy demand	2,424	2,301	2,094	1,961	1,909	2,424	1,769	1,391	1,199	1,149

Source: Prognos 2009

The importance of electricity in the overall energy mix increases slightly, from 34% in 2005 to 39% in 2050 in the reference scenario, and to 41% in the innovation scenario. This comparatively moderate increase results from systematic efficiency measures in auxiliary energy sources, and from the reduction of low-temperature heating demand, so that there are hardly any changeovers to electricity.

Figure 6.1-19: Comparison of scenarios: Final energy consumption in the industry sector, by energy source, 2005 and 2050, in PJ



Source: Prognos 2009

Industry has only limited opportunities to use renewable energy sources directly. At most, solar thermal, ambient heat and geothermal energy might be used to generate low-temperature heat, and in exceptional cases where the installation is favourably located, geothermal energy might be used to generate higher heat or in combined heat and power generation. In the innovation scenario particularly, accumulating waste and biogenic residues are intentionally used for energy not in the industry sector, but in the transport sector. For that reason, even though the share of renewables increases from 5% in 2005 to 8% in 2050 under the reference scenario and to 9% in the innovation scenario, it remains limited for technical reasons.

6.1.4 Final energy demand in the transport sector

6.1.4.1 Framework data, transport volume

Transport volume differs only marginally in the two scenarios. Germany remains a country of transit for international trade, and actively participates in international trade because it remains export-oriented. Freight transport volume grows more than 80% in both scenarios between 2005 and 2050.

Passenger transport volume depends primarily on commuting and leisure travel, and develops under the continuing assumption of a situation of saturation with vehicles and time budgets for mobility relative to the adult population. Passenger transport volume decreases about 8% between 2005 and 2050 in the innovation scenario, and only 6% in the reference scenario. Here the innovation scenario assumes slightly less commuter traffic, more aware leisure travel habits, and a changeover to slow transport for short trips.

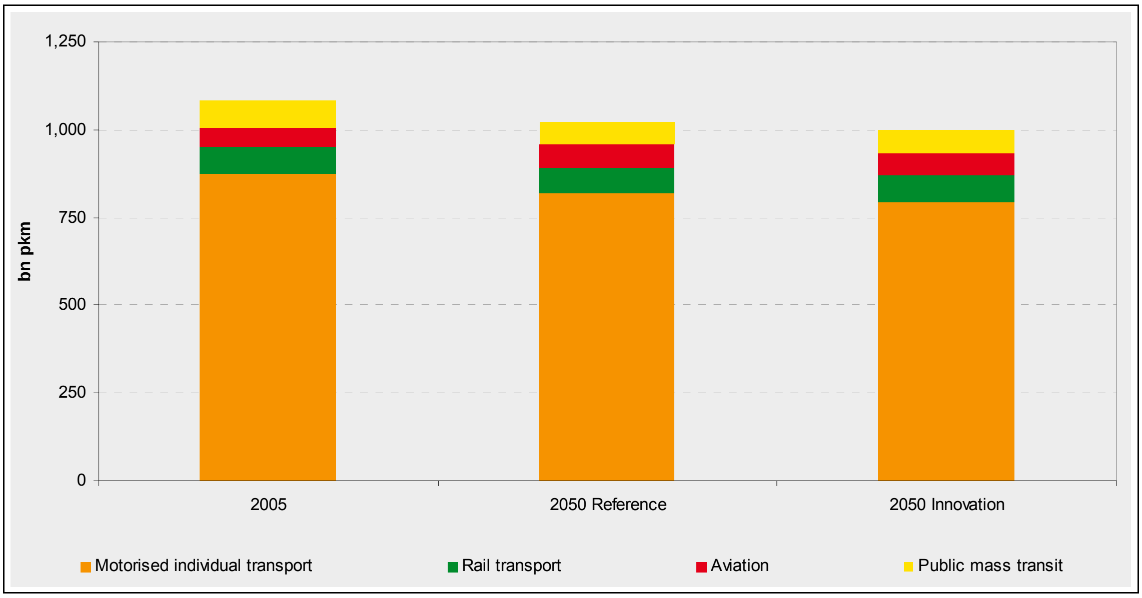
The modal split changes between the scenarios. In passenger transport, professionals in the field consider a shift to rail almost impossible on any significant scale, in part because of demographic changes. By 2050, it is assumed as realistic that roads' share of passenger transport volume will decrease about 0.5% between the two scenarios. Table 6.1-22 shows the comparison of passenger transport volume between the scenarios, and Table 6.1-23 shows the comparison for freight transport volume.

Table 6.1-22: Comparison of scenarios: Passenger transport volume, by mode of transport, in billion passenger kilometres, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Motorised individual transport	**876**	**889**	**884**	**860**	**819**	**880**	**867**	**839**	**793**
Passenger cars	857	871	867	845	805	862	851	824	781
Two-wheeled	19	18	17	16	14	18	16	14	13
Rail transport	**77**	**81**	**81**	**78**	**74**	**81**	**81**	**79**	**76**
Local transport by rail	43	44	43	42	40	44	44	43	41
Long-distance transport by rail	34	37	37	36	34	36	37	36	35
Public mass transit	**79**	**74**	**70**	**68**	**64**	**74**	**70**	**68**	**66**
Trams, urban rapid railways, underground	15	16	15	15	14	16	15	15	14
Buses	63	58	55	53	50	58	55	53	51
Aviation	**53**	**68**	**69**	**68**	**66**	**67**	**68**	**66**	**63**
Total passenger transport volume	**1,084**	**1,111**	**1,104**	**1,075**	**1,023**	**1,101**	**1,087**	**1,052**	**998**
Share in %									
Motorised individual transport	80.8	80.0	80.0	80.0	80.0	79.9	79.8	79.7	79.5
Rail transport	7.1	7.3	7.3	7.3	7.2	7.3	7.5	7.5	7.6
Public mass transit	7.2	6.6	6.4	6.3	6.3	6.7	6.5	6.5	6.6
Aviation	4.9	6.1	6.3	6.4	6.4	6.1	6.2	6.3	6.3

Source: ProgTrans / Prognos 2009

Figure 6.1-20: Comparison of scenarios: Passenger transport volume, by mode of transport, 2005 and 2050, in billion passenger kilometres



Source: ProgTrans / Prognos 2009

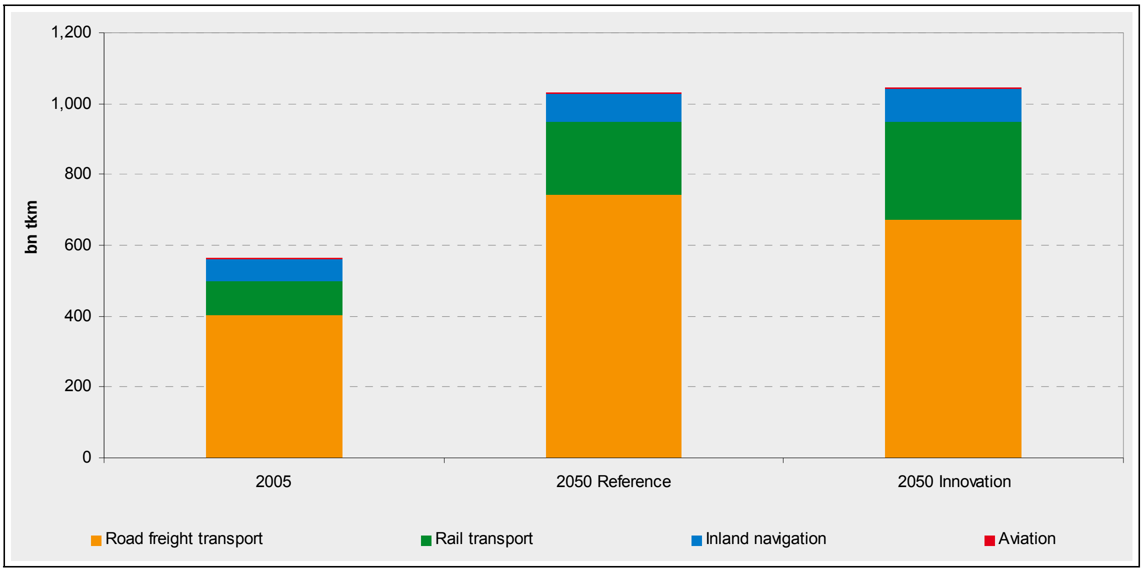
In the innovation scenario, the share of rail in transport volume for freight transport in particular is projected to increase more than a third by 2050 in comparison to the reference scenario. This is done under the assumption that the capacity of the existing network will be utilised significantly better. There is no assumption that the rail infrastructure will be expanded with a "third track." However, the shift to rail also entails new distribution traffic, especially on the road, so that in 2050 freight transport volume is slightly higher (about 1.3%) in the innovation scenario than in the reference scenario. In addition to rail, inland navigation will also benefit from a shift. Where transport volume via water increases about 20% between 2005 and 2050 in the reference scenario, it increases 48% in the innovation scenario.

Table 6.1-23: Comparison of scenarios: Freight transport volume, in billion (metric) ton-kilometres, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Freight transport by road	**403**	**565**	**634**	**684**	**744**	**550**	**604**	**635**	**671**
German heavy goods vehicles/road tractors	272	365	406	441	533	355	387	409	434
Long-distance transport	196	285	326	360	452	275	307	328	353
Local/regional transport	75	80	80	80	81	80	80	80	81
Foreign heavy goods vehicles/road tractors	131	199	228	243	211	195	217	226	237
Rail transport	**95**	**141**	**162**	**182**	**206**	**156**	**192**	**232**	**278**
Inland navigation	**64**	**67**	**72**	**75**	**79**	**71**	**78**	**85**	**95**
Aviation	**1**	**2**	**2**	**3**	**4**	**2**	**2**	**3**	**3**
Total freight transport volume	**563**	**775**	**869**	**944**	**1,033**	**779**	**876**	**953**	**1,047**
Share in %									
Road transport	71.5	72.9	72.9	72.4	72.1	70.6	69.0	66.6	64.1
Rail transport	16.9	18.2	18.6	19.3	19.9	20.1	21.9	24.3	26.5
Inland navigation	11.4	8.7	8.3	8.0	7.6	9.1	8.9	8.9	9.1
Aviation	0.2	0.2	0.2	0.3	0.4	0.2	0.2	0.3	0.3

Source: ProgTrans / Prognos 2009

Figure 6.1-21: Comparison of scenarios: Freight transport volume, by mode of transport, 2005 and 2050, in billion (metric) ton-kilometres



Source: ProgTrans / Prognos 2009

6.1.4.2 Final energy consumption of road transport

The main factors that affect energy consumption in the transport sector are the vehicle fleet, with a technology shift towards electrification in passenger transport, and the gradual replacement of fossil fuels with biofuels, especially in freight transport.

In **passenger transport** in the reference scenario, the conventional vehicle fleet in particular continues to improve moderately, and the replacement of gasoline and diesel cars increases. Gas drives and hybrid (later all-electric) drives will gradually be introduced, but all in all will account for substantially less than 50% of the total vehicle fleet. In the innovation scenario, by contrast, electric cars are introduced, and all-gasoline or all-diesel cars vanish as a matter of strategic energy and transport policy. Thus in 2050, the fleet will still include some diesel vehicles (because of their long service lives) running on biofuels, but they make up less than 20% of the fleet in the reference scenario. The largest share belongs to hybrid drives running on biofuels, all-electric vehicles, and plug-in hybrids. All-hydrogen fuel-cell cars have no significant share of the mix in 2050. It is unlikely that the problems of a hydrogen infrastructure will be solved by then; setting up an electricity infrastructure seems more realistic from today's vantage point. The defining quantities for energy consumption by cars and station wagons are summarised in Table 6.1-24.

Table 6.1-24: Comparison of scenarios: Determining factors for energy consumption by passenger cars and SUVs, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Total vehicles in use (000)	**45,521**	**48,491**	**48,739**	**47,835**	**45,828**	**48,491**	**48,739**	**47,835**	**45,828**
Gasoline, w/o hybrids	36,050	29,078	24,025	16,382	7,915	26,999	14,624	5,253	0
Gasoline hybrids	25	784	4,057	8,197	10,593	4,134	17,033	19,223	16,288
Diesel drives	9,392	17,314	17,560	15,239	10,823	15,840	10,255	5,401	1,739
Natural gas drives	20	493	815	1,091	1,640	507	1,330	2,429	2,805
LPG gas drives	32	457	710	1,064	1,570	510	1,312	2,423	2,800
Electric drives	2	158	624	2,659	6,020	212	1,824	5,456	8,401
Plug-in hybrid drives	0	204	944	3,070	6,113	287	2,358	7,519	12,640
Fuel cell drives	0	2	3	132	1,154	2	3	132	1,154
Annual kilometres travelled (000 vkt/vehicle)	**12.8**	**12.4**	**12.4**	**12.4**	**12.3**	**12.3**	**12.2**	**12.0**	**11.9**
Gasoline, w/o hybrids	10.9	9.4	9.9	10.8	11.6	9.7	11.1	11.5	11.8
Gasoline hybrids	8.1	8.4	9.8	10.8	11.6	8.6	11.0	11.5	11.8
Diesel drives	19.9	17.6	16.5	15.4	14.4	17.5	16.3	14.7	13.2
Natural gas drives	15.7	16.6	16.5	15.4	14.4	16.5	16.3	14.7	13.2
LPG drives	15.7	16.6	16.5	15.4	14.4	16.5	16.3	14.7	13.2
Electric drives	3.2	4.6	7.3	10.2	11.5	4.7	8.2	10.9	11.7
Plug-in hybrid drives	0.0	4.6	7.3	10.2	11.5	4.7	8.2	10.9	11.7
Fuel cell drives	1.5	2.7	3.9	5.3	6.8	2.8	4.3	5.6	7.0
Total kilometres travelled (bn vkt)	**581.7**	**602.0**	**605.5**	**591.3**	**564.7**	**595.0**	**592.5**	**573.8**	**543.4**
Gasoline, w/o hybrids	393.9	272.9	238.3	176.4	91.8	262.4	161.9	60.3	0.0
Gasoline hybrids	0.2	6.5	39.8	88.3	122.8	35.8	186.7	220.7	191.9
Diesel drives	186.7	305.1	290.6	234.6	156.0	277.8	166.8	79.7	22.9
Natural gas drives	0.3	8.2	13.5	16.8	23.6	8.4	21.6	35.8	37.0
LPG drives	0.5	7.6	11.8	16.4	22.6	8.4	21.3	35.7	37.0
Electric drives	0.0	0.7	4.6	27.0	69.4	1.0	14.9	59.2	98.5
Plug-in hybrid drives	0.0	0.9	6.9	31.2	70.5	1.4	19.2	81.6	148.1
Fuel cell drives	0.0	0.0	0.0	0.7	7.9	0.0	0.0	0.7	8.0
Specific consumption									
Cars (gas., diesel, hybrid; L/100 km)	7.8	6.0	5.2	4.9	4.6	5.8	4.6	4.1	3.9
Gasoline, w/o hybrids (L/100 km)	8.3	6.7	5.8	5.4	5.0	6.4	5.2	4.7	4.2
Gasoline hybrids (L/100 km)	6.2	5.0	4.4	4.0	3.8	4.8	3.9	3.5	3.2
Diesel drives (L/100 km)	6.8	5.4	4.9	4.7	4.5	5.4	4.8	4.4	4.3
Natural gas drives (kg/100 km)	5.6	4.5	3.9	3.7	3.4	4.3	3.5	3.2	2.9
LPG drives (kg/100 km)	6.1	4.9	4.3	4.0	3.7	4.7	3.8	3.4	3.1
Electric drives (kWh/100 km)	20.6	17.0	15.0	14.2	14.0	16.5	14.5	14.0	13.9
Plug-in hybrid drives (kWh/100 km)		24.5	21.5	20.1	19.2	23.5	20.0	18.6	17.7
Fuel cells (kg H2/100 km)	1.8	1.4	1.2	1.2	1.1	1.4	1.2	1.2	1.1
Occupancy (pkm/vkt)	**1.5**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**

Source: ProgTrans / Prognos 2009

Annual kilometres travelled are slightly less in the innovation scenario than in the reference scenario (by about half a percent), because of reduced individual passenger transport. The result is that total kilometres travelled are also slightly lower.

Specific consumption is substantially less in the innovation scenario than in the reference scenario – as a consequence of more rigorous strategies in transport policy in the case of internal combustion-engine vehicles, and as a consequence of market developments and economies of scale in the case of partially-electric or all-electric vehicles. Here it should be borne in mind that these figures are the aggregate average consumption by the given fleets, not just consumption by new cars. On average for the entire fleet, energy consumption per vehicle kilometre travelled (vkt) decreases 51% in the reference scenario and 65% in the innovation scenario. Converted to the measurement of CO_2 emissions per kilometer, which is currently set as the efficiency standard for cars in the EU, mean emissions decrease from 190 g/vkt in 2005 to 82 g/vkt in 2050 for the reference scenario, and 48 g/vkt in the innovation scenario. Here biofuels are assigned the same CO_2 factor as fossil fuels.

Table 6.1-25: Comparison of scenarios: Energy consumption by passenger cars and SUVs, by type of drive, in PJ, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids	1,062	598	456	322	174	546	276	92	0
Gasoline hybrids	0	11	57	116	150	56	245	278	242
Diesel drives	457	590	507	398	253	538	286	126	35
Natural gas drives	1	19	27	31	40	18	38	57	53
Liquefied petroleum gas drives	1	17	23	30	38	18	38	56	53
Electric drives	0	1	5	25	60	1	15	59	101
Fuel cell drives	0	0	0	1	10	0	0	1	10
Total final energy consumption	1,521	1,235	1,074	923	726	1,177	898	669	495
Change in % p.a.		**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline, n/incl. hybrids		-3.4	-2.6	-3.4	-6.0	-4.5	-7.7	-10.4	-100.0
Gasoline hybrids		25.9	15.5	7.5	2.6	52.6	9.7	1.3	-1.4
Diesel drives		-0.3	-1.6	-2.4	-4.4	-2.1	-6.8	-7.9	-11.9
Natural gas drives		10.1	1.8	1.5	2.7	9.8	7.2	4.0	-0.6
Liquefied petroleum gas drives		4.4	2.1	2.6	2.5	5.9	7.1	4.1	-0.6
Electric drives		-	16.3	17.3	9.1	-	26.4	14.8	5.6
Fuel cell drives		-	-	-	26.5	-	5.0	48.9	25.9
Total final energy consumption		-1.6	-1.2	-1.5	-2.4	-2.2	-2.7	-2.9	-3.0

Source: ProgTrans / Prognos 2009

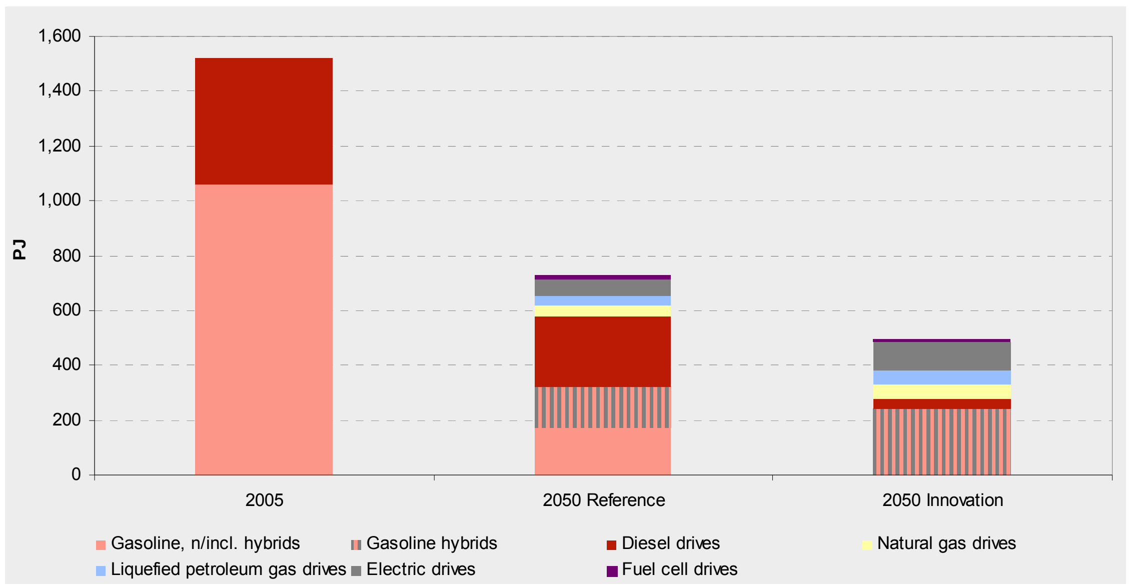
The resulting final energy consumption of the car and station wagon fleet, broken down by type of drive, is shown in Table 6.1-25 and Figure 6.1-22. Here one can see that “hybridisation,” partial electrification and full electrification result in an overall reduction of 31% in energy consumption in 2050 in the innovation scenario compared to the reference scenario, even though kilometres travelled decrease substantially less (only 3%).

In **freight transport,** total kilometres travelled are 5% less in 2050 under the innovation scenario than under the reference scenario, while the vehicle fleet is 8% smaller. Specific consumption for all vehicle and drive classes in 2050 averages 7% less in the innovation scenario than in the reference scenario (Table 6.1-26).

Consequently in 2050 the final energy consumption of freight transport by road is 11% lower in the innovation scenario than in the reference scenario. This is primarily the effect of more efficient drives; there is very little change in the various drives’ share of the vehicle fleet (Table 6.1-27).

In road transport as a whole, consumption is 21% lower in the innovation scenario than in the reference scenario. The main contributors here are the strategic change in the passenger car fleet and the additional efficiency enhancements. At the fuel level, about 25% of gasoline and diesel are replaced with biofuels by 2050 in the reference scenario, compared to complete replacement in the innovation scenario (Table 6.1-28).

Figure 6.1-22: Comparison of scenarios: Energy consumption of passenger cars and SUVs, by type of drive, 2005 and 2050, in PJ



Source: ProgTrans / Prognos 2009

Table 6.1-26: Comparison of scenarios: Determining factors for energy consumption by freight vehicles, 2005 – 2050

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Total vehicles in use (000)	**4,424**	**4,872**	**5,108**	**5,272**	**5,496**	**4,742**	**4,873**	**4,936**	**5,053**
Gasoline drives	308	144	105	79	53	139	100	74	50
Diesel drives	4,107	4,648	4,880	5,026	5,228	4,499	4,603	4,652	4,753
Natural gas drives	6	62	93	125	160	86	141	171	201
LPG drives	2	12	19	26	33	11	17	24	30
Electric drives	2	7	12	16	21	7	11	15	20
Annual kilometres travelled (000 vkt/vehicle)	**19.3**	**20.2**	**20.0**	**19.9**	**19.8**	**20.4**	**20.5**	**20.5**	**20.5**
Gasoline drives	10.4	10.3	9.9	8.8	6.8	10.6	10.4	9.4	7.3
Diesel drives	20.0	20.6	20.5	20.4	20.3	20.9	21.0	21.1	21.1
Natural gas drives	10.9	11.7	11.6	11.4	11.3	12.0	12.1	12.1	12.2
LPG gas drives	9.5	11.1	11.1	11.1	11.0	11.4	11.7	11.9	12.0
Electric drives	8.6	8.8	8.8	8.7	8.6	9.0	9.2	9.2	9.2
Total kilometres travelled (bn vkt)	**85.5**	**98.2**	**102.3**	**105.2**	**109.0**	**96.8**	**99.9**	**101.4**	**103.7**
Gasoline drives	3.2	1.5	1.0	0.7	0.4	1.5	1.0	0.7	0.4
Diesel drives	82.2	95.8	99.8	102.6	106.3	94.1	96.9	98.2	100.4
Natural gas drives	0.1	0.7	1.1	1.4	1.8	1.0	1.7	2.1	2.5
LPG drives	0.0	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4
Electric drives	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2
Specific consumption (PJ/bn km)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Gasoline drives (L/100 km)	13.7	11.7	10.7	10.6	11.0	11.4	10.0	9.4	9.5
Diesel drives (L/100 km)	23.5	20.4	19.4	18.4	18.0	20.1	18.6	17.5	16.8
Natural gas drives (kg/100 km)	15.8	14.2	13.3	12.9	12.8	13.8	12.4	11.5	11.1
LPG drives (kg/100 km)	16.6	15.4	14.5	14.1	14.0	14.9	13.5	12.5	12.2
Electric drives (kWh/100 km)	56.0	50.4	47.5	44.3	42.8		46.1	43.0	41.2
Mean load factor (tkm/vkt)	**4.3**	**5.1**	**5.5**	**5.9**	**7.0**	**5.0**	**5.4**	**5.7**	**6.0**

Source: ProgTrans / Prognos 2009

Table 6.1-27: Comparison of scenarios: Final energy consumption of freight transport by road, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline drives	13.8	5.4	3.5	2.4	1.3	5.2	3.3	2.1	1.1
Diesel drives	660.6	667.7	674.6	673.4	687.2	646.2	629.0	610.5	606.4
Natural gas drives	0.5	4.7	6.6	8.5	10.6	6.5	9.7	10.9	12.5
Liquefied petroleum gas drives	0.1	1.0	1.5	2.0	2.6	1.0	1.4	1.8	2.2
Electric drives	0.0	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.3
Fuel cell drives	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total energy consumption	675.0	678.9	686.4	686.6	702.0	659.0	643.6	625.5	622.5
Change in % p.a.		**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline drives		-6.0	-3.3	-3.8	-6.0	-6.3	-3.6	-4.3	-6.1
Diesel drives		0.2	-0.2	0.0	0.2	0.0	-0.5	-0.3	-0.1
Natural gas drives		5.5	2.9	2.6	2.3	7.9	3.1	1.1	1.4
Liquefied petroleum gas drives		7.0	3.6	3.0	2.5	6.4	3.2	2.4	2.2
Electric drives		-	3.2	2.6	2.3	-	3.3	2.5	2.2
Fuel cell drives		-	-	-	-	-	-	-	-
Total energy consumption		0.2	-0.2	0.0	0.2	0.0	-0.5	-0.3	0.0

Source: ProgTrans / Prognos 2009

Table 6.1-28: Comparison of scenarios: Final energy consumption of all road transport, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline drives	1,025	614	513	435	316	609	524	368	236
Diesel drives	1,124	1,281	1,204	1,094	962	1,207	937	757	661
Natural gas drives	2	24	34	41	52	26	50	69	68
Liquefied petroleum gas drives	2	18	25	32	41	19	39	59	56
Electric drives	0	1	5	25	60	1	15	59	101
Fuel cell drives	0	0	0	1	10	0	0	1	10
Total final energy consumption	2,152	1,939	1,782	1,628	1,442	1,862	1,565	1,313	1,133
For information only: Biofuel	69	181	251	300	317	255	494	617	732
Change in % p.a.		**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Gasoline drives		-3.2	-1.3	-1.6	-3.1	-2.8	-1.7	-3.5	-4.3
Diesel drives		0.0	-0.8	-1.0	-1.3	-1.0	-2.7	-2.1	-1.3
Natural gas drives		8.7	2.0	1.7	2.6	9.0	6.1	3.4	-0.2
Liquefied petroleum gas drives		-	1.8	2.6	2.7	-	6.7	2.1	-1.4
Electric drives		-	14.7	16.2	6.6	-	25.2	10.5	4.0
Fuel cell drives		-	5.8	62.2	16.4	-	5.6	62.0	15.8
Total final energy consumption		-1.0	-0.8	-0.9	-1.2	-1.5	-1.8	-1.7	-1.4

Source: ProgTrans / Prognos 2009

6.1.4.3 Final energy consumption of all transport

Final energy consumption of all transport by 2050 is dominated by road transport in both scenarios. For that reason, rail, inland navigation and freight transport are lumped together for the comparison of the scenarios.

Final energy consumption, broken down by mode of transport and energy source, is shown in Table 6.1-29.

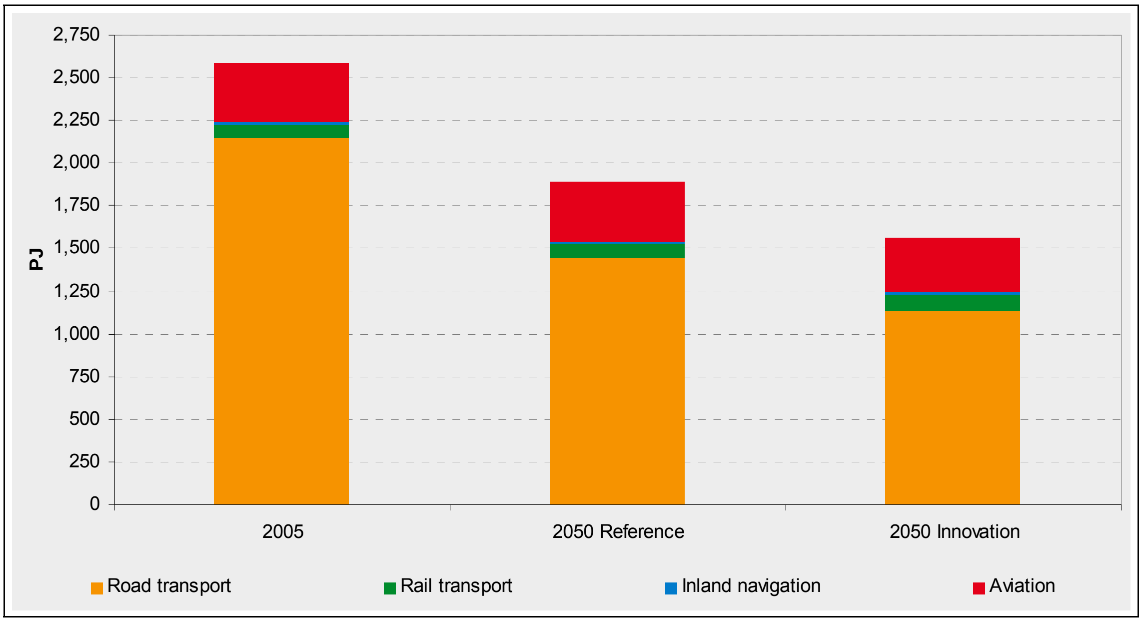
Table 6.1-29: Comparison of scenarios: Final energy consumption of the entire transport sector, 2005 – 2050, by mode of transport and energy source, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Road transport									
Gasoline	1,025	614	513	435	316	609	524	368	236
Gasoline substitutes from biomass	9	46	64	76	71	87	228	257	236
Gasoline from petroleum	1,015	568	449	359	245	521	296	112	0
Diesel	1,124	1,281	1,204	1,094	962	1,207	937	757	661
Diesel substitutes from biomass	60	135	187	224	245	209	430	540	661
Diesel from petroleum	1,064	1,147	1,017	869	717	998	507	217	0
Natural gas	2	24	34	41	52	26	50	69	68
Liquefied petroleum gas	2	18	25	32	41	19	39	59	56
Hydrogen	0	0	0	1	10	0	0	1	10
Electricity	0	1	5	25	60	1	15	59	101
Motor oil	1	0	0	0	0	0	0	0	0
All road transport	2,152	1,940	1,782	1,628	1,443	1,862	1,565	1,314	1,133
Rail transport									
Electricity	58	64	67	69	71	67	72	78	86
Diesel (incl. biofuel)	19	14	14	13	13	14	13	12	11
Coal	0	0	0	0	0	0	0	0	0
All rail transport	77	78	80	82	83	81	85	90	97
Inland navigation									
Diesel (incl. biofuel)	13	14	14	15	15	15	15	16	18
Aviation									
Aviation fuels	345	394	374	365	350	383	354	336	312
All transport	**2,587**	**2,426**	**2,251**	**2,090**	**1,891**	**2,341**	**2,019**	**1,756**	**1,560**
Gasoline (incl. biofuel)	1,025	614	513	435	316	609	524	368	236
Gasoline substitutes from biomass	9	46	64	76	71	87	228	257	236
Gasoline from petroleum	1,015	568	449	359	245	521	296	112	0
Diesel (incl. biofuel)	1,155	1,310	1,232	1,122	990	1,236	965	786	691
Diesel substitutes from biomass	62	138	191	230	252	214	443	561	691
Diesel from petroleum	1,093	1,172	1,041	892	738	1,021	522	225	0
Aviation fuels	345	394	374	365	350	383	354	336	312
Natural gas	2	24	34	41	52	26	50	69	68
Liquefied petroleum gas	2	18	25	32	41	19	39	59	56
Hydrogen	0	0	0	1	10	0	0	1	10
Electricity	58	65	72	94	131	68	87	137	187
Motor oil	1	0	0	0	0	0	0	0	0

Source: ProgTrans / Prognos 2009

Figure 6.1-23 shows final energy consumption of the entire transport sector by mode of transport. Here it is impressively evident that despite the sharp rise in freight transport, total energy consumption in 2050 is 27% lower in the innovation scenario than in the reference scenario due to the combined effects of the modal split, efficient vehicle technology, and the shift in energy sources ("electrification" of individual passenger transport).

Figure 6.1-23: Comparison of scenarios: Final energy demand for the transport sector, by mode of transport, 2005 and 2050, in PJ



Source: ProgTrans / Prognos 2009

Energy consumption for rail transport overall in 2050 exceeds the reference scenario by 8% in the innovation scenario. Its share of final energy consumption in 2050 is 6.2% in the innovation scenario and 4.4% in the reference scenario.

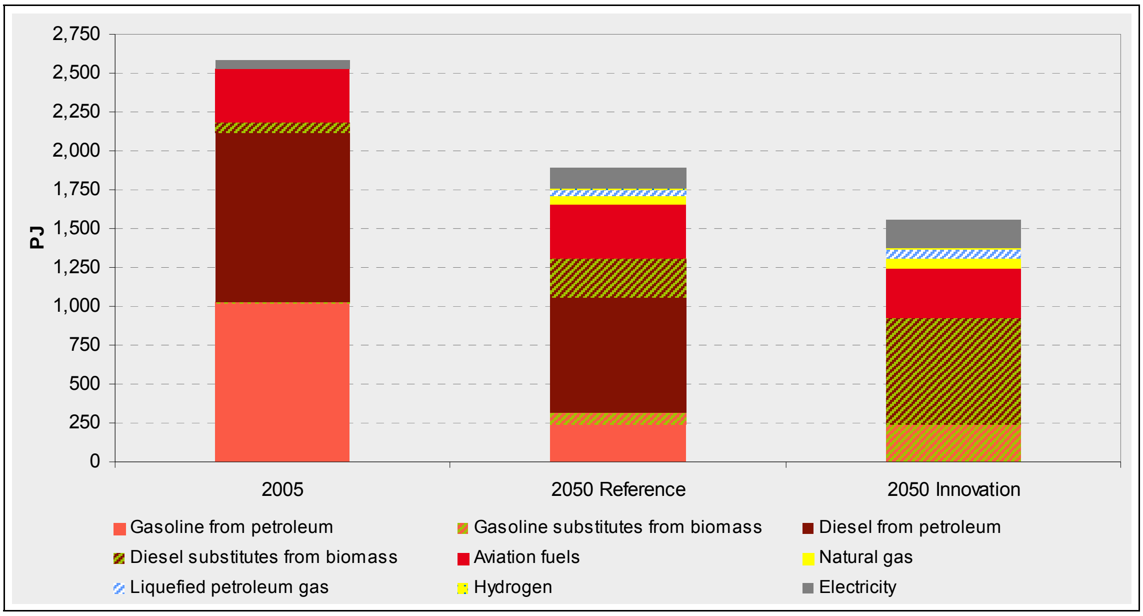
Energy consumption for aviation is 11% less in the innovation scenario than in the reference scenario, primarily because of efficiency measures in airplanes. This is of little significance for the energy consumption of all transport combined.

The following energy source structure appears in the final energy account for the entire transport sector (Figure 6.1-24):

Because of their ongoing dominance, liquid biogenic motor fuels still represent the lion's share of energy sources in the innovation scenario, with nearly 60%. Because of the limitations of biogenic energy sources and the international nature of aviation, we assume that fossil fuels will still be used there (about 350 PJ in 2050 under the reference scenario and 312 PJ in the innovation scenario).

Because of the electrification of individual passenger transport and the shift of a large share of freight to rail, electricity's share of total energy demand will rise from less than 8% to 13%.

Figure 6.1-24: Comparison of scenarios: Final energy demand for the entire transport sector, by energy source, 2005 and 2050, in PJ



Source: ProgTrans / Prognos 2009

The main reasons for this change, which also means a 71% reduction in direct CO_2 emissions attributable to this sector (not including power generation) are summarised below:

- The substantial shift in the modal split for freight transport towards rail,
- The replacement of fossil fuels with biogenic fuels (except in aviation),
- The systematic change of the passenger car fleet towards hybrid and all-electric vehicles, and
- The systematic improvement of the efficiency of the entire vehicle fleet.

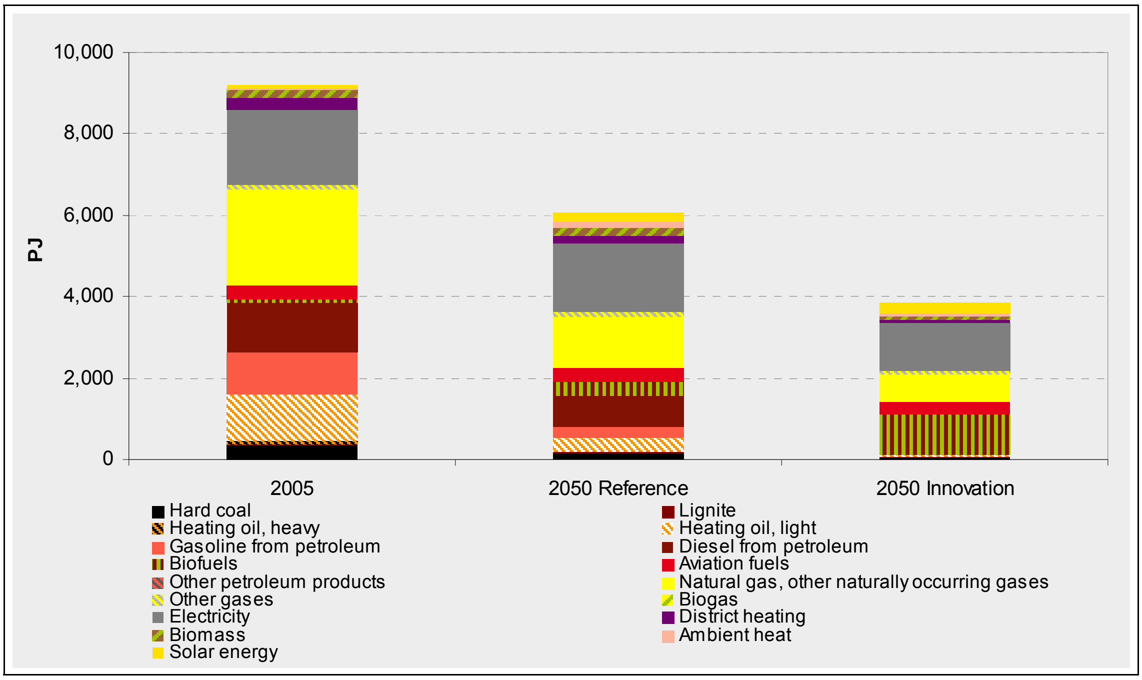
These changes need a systematic policy strategy, with early implementation of new forms of energy efficiency in all areas of mobility, and especially support for the development of electric mobility and for the development of the associated infrastructure.

6.1.5 Total final energy demand

The final energy demand for all sectors decreases by 33.8% between 2005 and 2050 in the reference scenario, and by 58.1% in the innovation scenario. Thus the 2050 value in the innovation scenario is nearly 37% lower than in the reference scenario. Table 6.1-30 summarises the final energy demand for all demand sectors and energy sources.

Figure 6.1-25 shows demand by energy source; Figure 6.1-26 shows it by energy source group. Fossil energy sources are all reduced in the innovation scenario compared to the reference scenario, sometimes sharply. Coal, petroleum products and gases are used practically only in those applications where they are indispensable – to generate process heat in the industry sector (gas is also used in combined heat and power generation). Fossil fuels are used only in aviation; biofuels are used for motorized freight transport and for small shares of passenger transport. There is less use of some renewable energy sources – solid biomass, thermal solar energy and ambient heat – than in the reference scenario. They are used primarily to cover demand for space heating, which is much lower in the innovation scenario because of greater efficiency and better insulation.

Figure 6.1-25: Comparison of scenarios: Total final energy demand, by energy source, 2005 and 2050, in PJ



Source: ProgTrans / Prognos 2009

It is noteworthy that demand for electricity in 2050 is 30% lower in the innovation scenario than in the reference scenario, in spite of the significant shift in energy sources towards electricity in the transport sector (freight on rail, electric cars). The reason is greater efficiency in every sector, and in every type of use, especially in lighting, ventilation/cooling, ICT, and auxiliary energy for processes (motors, pumps, compressed air, etc.), due to intelligent control and automation equipment, process changes and miniaturisation.

Table 6.1-30: Comparison of scenarios: Final energy demand, by energy source and consuming sector, 2005 – 2050, in PJ

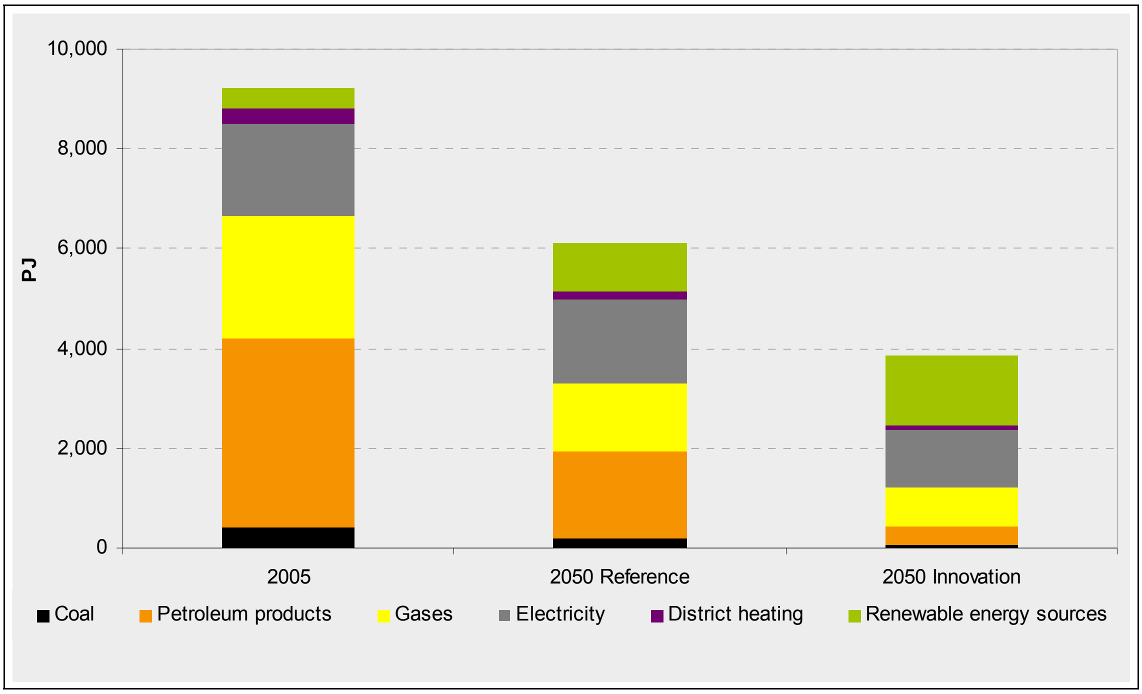
		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
By energy source									
Coal	**400**	**319**	**249**	**206**	**179**	**262**	**168**	**110**	**77**
Hard coal	341	272	208	170	146	224	138	86	55
Lignite	59	48	41	35	32	38	29	24	22
Petroleum products	**3,798**	**3,079**	**2,568**	**2,143**	**1,743**	**2,627**	**1,504**	**809**	**363**
Heating oil, light	1,151	787	576	423	325	574	256	96	36
Heating oil, heavy	67	55	42	33	27	39	24	16	11
Gasoline from petroleum	1,033	583	461	369	254	534	303	115	0
Diesel from petroleum	1,202	1,260	1,114	952	787	1,097	566	246	4
Aviation fuels	345	394	374	365	350	383	354	336	312
Other petroleum products	1	0	0	0	0	0	0	0	0
Gases	**2,482**	**2,139**	**1,760**	**1,493**	**1,382**	**1,705**	**1,142**	**880**	**766**
Natural gas, other naturally occurring gases	2,359	2,018	1,652	1,387	1,263	1,606	1,050	783	671
Other gases	123	121	108	106	119	99	92	97	95
incl.: Furnace gas	77	63	50	44	42	49	33	24	18
Renewable energy sources	**396**	**612**	**791**	**908**	**949**	**804**	**1,297**	**1,409**	**1,412**
Biomass	178	184	188	189	188	189	171	122	66
Ambient heat	68	104	130	147	155	104	124	122	106
Solar energy	73	122	173	213	226	187	279	287	247
Biofuels	77	193	268	321	340	318	708	867	987
Biogas	0	9	32	38	40	7	16	11	5
Electricity	**1,832**	**1,764**	**1,695**	**1,704**	**1,680**	**1,517**	**1,320**	**1,224**	**1,165**
District heating	**300**	**265**	**227**	**190**	**167**	**229**	**165**	**113**	**74**
Total final energy consumption	9,208	8,178	7,291	6,644	6,099	7,144	5,596	4,546	3,857
By consumer sector									
Residential	2,735	2,282	2,013	1,777	1,569	2,003	1,465	1,017	662
Services	1,462	1,169	933	815	731	1,031	720	574	486
Industry	2,424	2,301	2,094	1,961	1,909	1,769	1,391	1,199	1,149
Transport	2,587	2,426	2,251	2,090	1,891	2,341	2,019	1,756	1,560

Source: ProgTrans / Prognos 2009

The energy source groups' shares of final energy consumption in Figure 6.1-27 clearly show that in spite of the "electrification" of systems, electricity's share of total final energy consumption is almost constant in the innovation scenario, compared to the reference scenario. This is primarily because of the structural and efficiency effects described above. In addition, it is clear that a substantial portion of fossil energy sources is replaced with renewables.

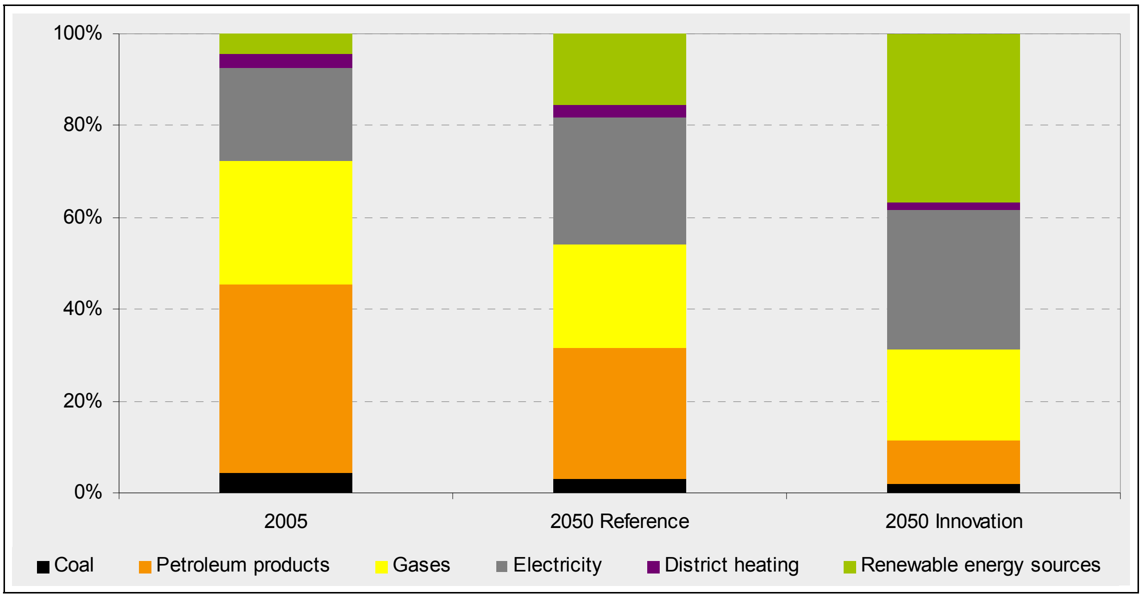
The breakdown by sectors shows that all sectors contribute considerably to the savings in the innovation scenario compared to the reference scenario (Figure 6.1-28), but to different degrees. In the residential sector, 2050 consumption is 60% less in the innovation scenario than in the reference scenario.

Figure 6.1-26: *Comparison of scenarios: Total final energy demand, by energy source group, 2005 and 2050, in PJ*



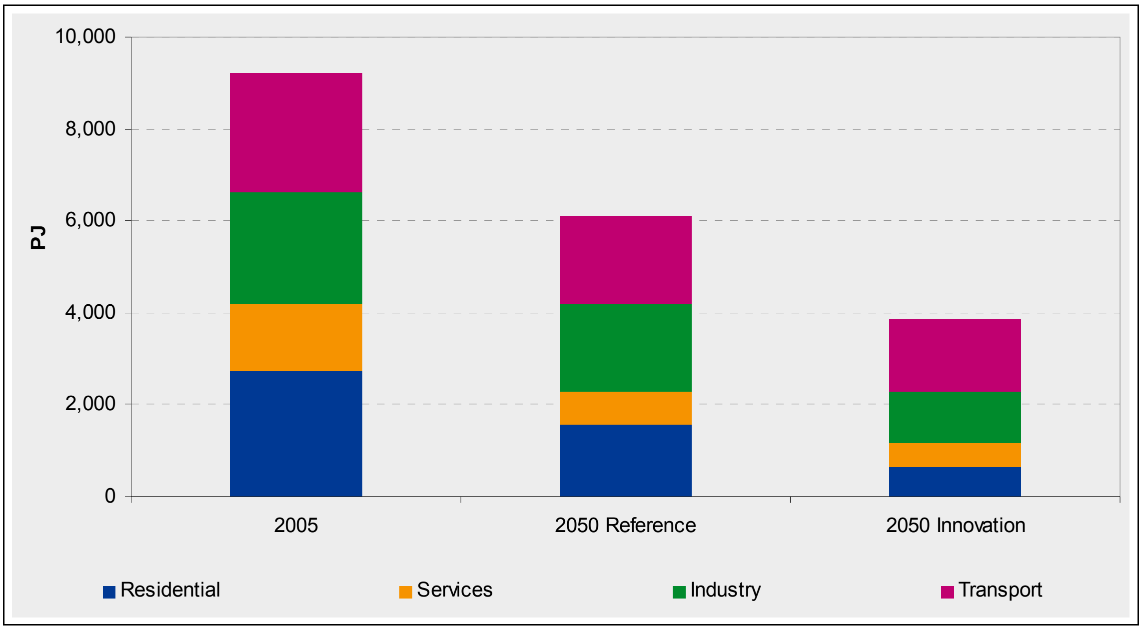
Source: ProgTrans / Prognos 2009

Figure 6.1-27: *Comparison of scenarios: Total final energy demand, by energy source group, 2005 and 2050, share in %*



Source: ProgTrans / Prognos 2009

Figure 6.1-28: Comparison of scenarios: Final energy demand, by sector, 2005 and 2050, in PJ



Source: ProgTrans / Prognos 2009

This is due in part to the radical reduction in demand for space heating, and in part to massive increases in efficiency in lighting and air conditioning.

In the service sector, 2050 consumption is 33% less in the innovation scenario than in the reference scenario. In the industry sector it is 40% less. These savings are due to both the effects of structural change (less energy-intensive industrial production, more services), and the effects of technological efficiency, analogously to the household sector. However, demand for process heat and force cannot be reduced at will for a given production, either in core processes or auxiliary processes; there are physical lower limits here.

In the transport sector the innovation scenario uses "only" 17% less energy in 2050 than the reference scenario does. This reduction is primarily the result of the change in the modal split in freight transport, lower specific consumption by electric vehicles, and the generally more rigorous development of efficiency in the vehicle fleets. There is a substantial change in energy-source structure, which also makes a large contribution towards reducing CO_2 emissions.

The sectors' relative shares of total energy consumption shift slightly because of these structural changes. The substantial reduction in demand for space heating and overall consumption in the household sector reduces that sector's share of total demand in 2050 from 25.7% in the reference scenario to 17.2% in the innovation scenario.

The other sectors "pick up" shares as a consequence. In particular, the transport sector's share grows from 31.0% in the reference scenario to 40.4% in the innovation scenario.

6.2 Power generation

6.2.1 Options without CCS

6.2.1.1 Demand and net generation of electricity

Demand is one of the main drivers for the use of power plants and the construction of new plants. Despite the aggressive introduction of electric mobility, a consistent strategy of efficiency on the demand side in the innovation scenario leads to a decrease in the demand for electricity by 2050 of 30% compared to the reference scenario and 36% compared to 2005 levels. The heavy reliance on renewable and in many cases stochastic sources for generating electricity in the innovation scenario requires temporary storage for a considerable portion of the energy produced. This in turn yields a further need for stored electricity (capacity and energy). The storage needs in 2050 in the innovation scenario without CCS are higher than in the reference scenario by a factor of 3.6. Net electrical generation is 22% under that of the reference scenario (Table 6.2-1).

The peak load in the innovation scenario is 54 GW, 28% under the reference figure. Despite a high installed capacity renewable energies cover less than half of this peak load, i.e. 27 GW — 81% more than in the reference. The rest is supplied by the remaining natural gas power plants and storage (Table 6.2-2).

Table 6.2-1: Comparison of scenarios: Options without CCS, net power consumption and generation, 2005 – 2050, in TWh

		Reference w/o CCS				Innovation w/o CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Final energy consumption – Electricity	517	492	474	478	472	423	370	345	330
Consumption for conversion	16	14	13	10	8	14	13	10	8
Line losses	29	26	25	25	25	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	22	24	25	21	35	56	90
Net power consumption	573	554	534	536	530	485	443	436	453
Net imports*	-9	0	5	8	10	0	15	33	48
Net power generation	583	554	530	529	520	485	428	403	405

**Imported electricity is from renewable sources from 2021 onwards* *Source: Prognos 2009*

Table 6.2-2: Comparison of scenarios: Options without CCS, peak load and secured capacity, 2005 – 2050, in GW

		Reference w/o CCS				Innovation w/o CCS			
	2005	202 0	203 0	2040	2050	202 0	2030	2040	2050
Peak load	84	76	74	75	74	68	60	56	54
Secured capacity	96	80	79	79	78	80	69	69	61
Renewables (incl. imports)	6	13	14	14	15	13	17	22	27
Conventional and stored	89	67	65	64	64	67	52	47	34

Source: Prognos 2009

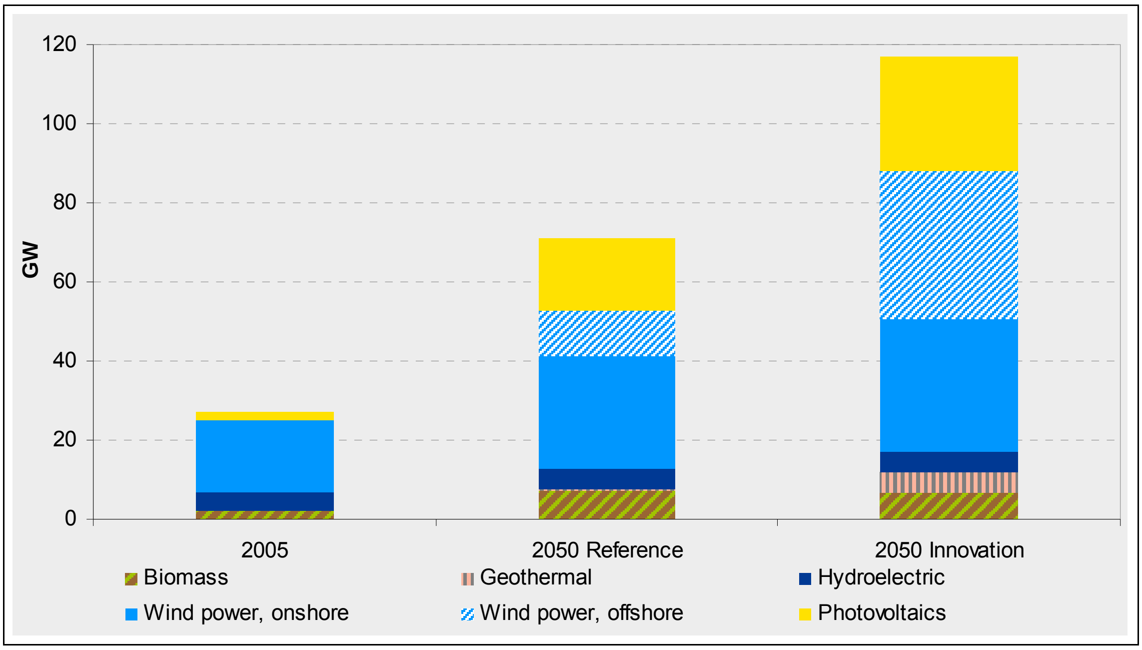
6.2.1.2 Power generation

The innovation scenario depends heavily on the path of expansion outlined for renewable energies. The “gap” in input and output between this path of expansion, the aging conventional power generation network and the demand is, according to the logic of marginal costs, closed by the “allowed” conventional power plants. By definition, the options without CCS cited here assume that CCS is not an available option. In the innovation scenario, the path of (new) renewable energies yields approx. 70% more installed capacity in 2050 compared to the reference (Figure 6.2-1) and about 52% more input (Figure 6.2-2).

In the reference scenario, aging coal-fired power plants are replaced by new plants and additional plants are built at the current CO_2 price but without the CCS option according to the logic of marginal costs. A total of some 38.5 GW of coal power plant capacity is added by 2050 beyond what is already under construction, including 20.4 GW from lignite power plants.

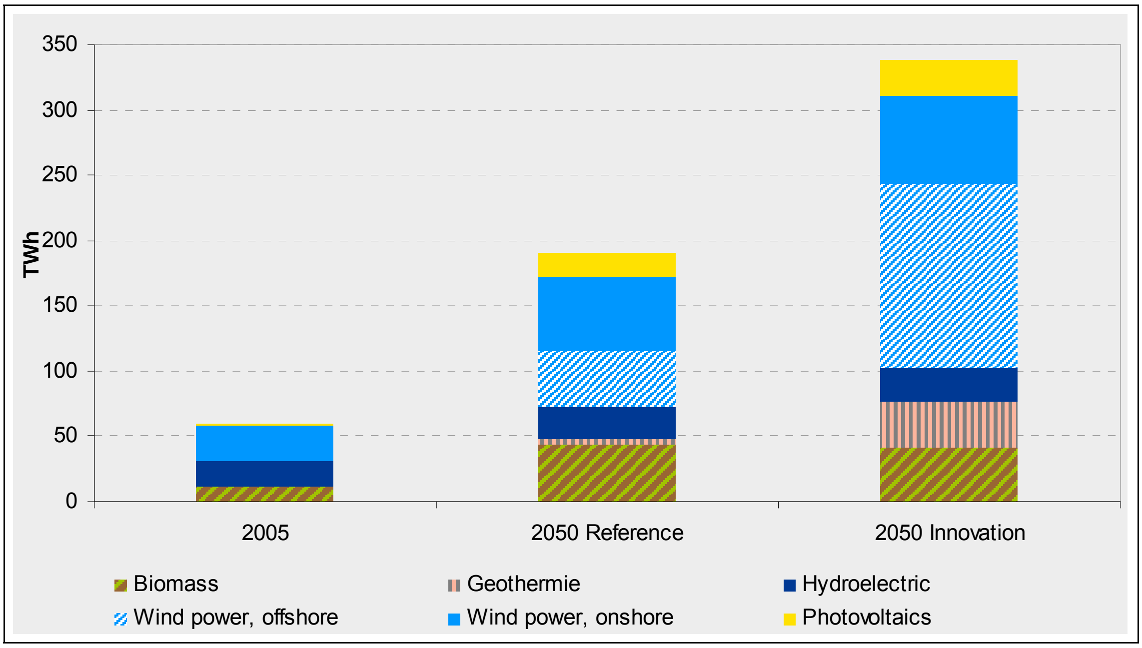
In the innovation scenario, primarily gas power plants are being built. Those coal plants currently under construction start generating electricity, and another 4.3 GW from lignite power plants (according to the logic of marginal costs) are being built. In 2045, the last lignite power plant is taken off-grid (Figure 6.2-3, Figure 6.2-4, Table 6.2-3), since the production of renewable energies and the use of storage capacities gradually reduce the hours at peak capacity so much that operation is no longer sensible. All conventional power plants are already amortised at this time. (The model assumes an amortisation period of 15 years.) The last power plants to go online are still quite “young,” however.

Figure 6.2-1: Comparison of scenarios: Options without CCS, installed capacity of renewable energy sources for power generation, 2005 and 2050, in GW



Source: Prognos 2009

Figure 6.2-2: Comparison of scenarios: Options without CCS, net production on basis of renewable power generated, 2005 and 2050, in TWh



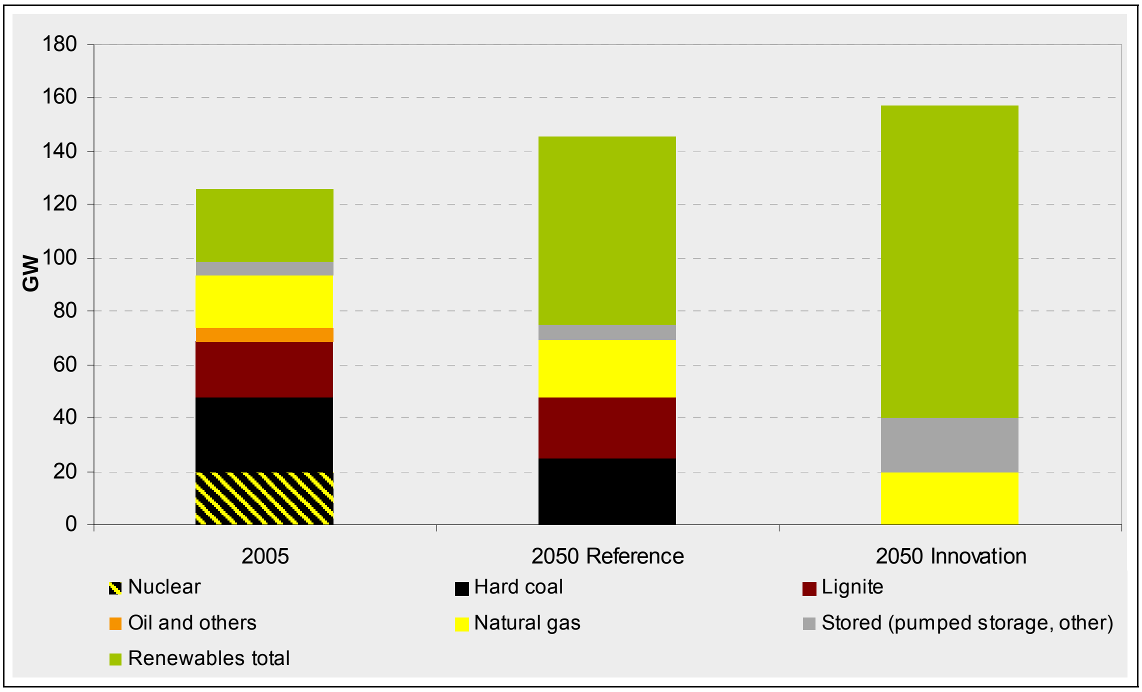
Source: Prognos 2009

Table 6.2-3: *Comparison of scenarios: Options without CCS, net capacity, net power generated and annual capacity factors, by input energy sources, 2005 – 2050*

		Reference w/o CCS				Innovation w/o CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Net capacity in GW									
Nuclear	19.9	4.1	0.0	0.0	0.0	4.1	0.0	0.0	0.0
Hard coal	27.9	28.1	21.4	22.8	24.8	28.1	14.7	7.5	0.0
Hard coal w/ CCS		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lignite	20.8	16.8	25.0	24.3	23.2	16.8	11.4	9.7	0.0
Lignite w/ CCS		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas	19.6	22.6	23.9	23.0	21.3	22.6	23.9	23.0	19.8
Oil and others	5.2	1.7	0.7	0.0	0.0	1.7	0.7	0.0	0.0
Stored (pumped storage, other)	5.4	5.4	5.4	5.4	5.4	5.4	10.4	15.4	20.4
Hydroelectric	4.6	5.1	5.1	5.1	5.1	5.1	5.2	5.2	5.2
Wind power, total	18.4	38.1	38.8	39.4	39.7	38.1	52.8	65.3	71.0
Wind power, onshore	18.4	28.1	28.1	28.2	28.3	28.1	28.9	31.9	33.5
Wind power, offshore		10.0	10.7	11.2	11.4	10.0	23.2	33.5	37.6
Photovoltaics	1.9	17.9	18.2	18.4	18.5	17.9	24.0	27.1	29.0
Biomass	2.2	7.1	7.2	7.2	7.2	7.1	6.9	6.7	6.7
Geothermal		0.3	0.3	0.4	0.5	0.3	0.9	2.1	5.1
Total net capacity	125.9	147.2	146.0	146.1	145.8	147.2	150.3	162.1	157.3
Net power generation in TWh									
Nuclear	151.0	30.2	0.0	0.0	0.0	30.2	0.0	0.0	0.0
Hard coal	128.0	169.6	120.9	136.7	109.1	128.6	68.1	22.0	0.0
Hard coal w/ CCS		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lignite	152.0	101.8	158.6	152.4	166.0	85.9	49.6	23.0	0.0
Lignite w/ CCS		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas	67.0	61.5	49.1	35.8	36.3	49.3	46.9	28.2	11.5
Oil and others	18.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stored (pumped storage, other)	7.1	15.8	16.6	17.4	18.3	15.8	24.4	36.9	54.7
Hydroelectric	19.6	24.3	24.3	24.4	24.4	24.3	24.6	24.8	24.8
Wind power, total	27.2	87.2	95.0	97.6	99.8	87.2	142.2	186.7	209.3
Wind power, onshore	27.2	53.5	56.4	56.5	56.6	53.5	58.1	63.7	66.9
Wind power, offshore		33.7	38.6	41.1	43.1	33.7	84.1	123.0	142.4
Photovoltaics	1.2	15.5	16.6	17.1	17.6	15.5	21.9	25.3	27.7
Biomass	12.0	46.2	46.5	44.7	44.7	46.2	44.7	41.3	41.3
Geothermal		1.8	2.1	2.6	3.6	1.8	6.0	14.7	35.7
Total net power generation	583.2	554.0	529.7	528.7	520.0	484.9	428.4	402.9	405.1
Annual capacity factors in hrs/yr									
Nuclear	7,588	7,435	-	-	-	7,428	-	-	-
Hard coal	4,588	6,024	5,653	5,982	4,400	4,572	4,626	2,923	-
Hard coal w/ CCS	-	-	-	-	-	-	-	-	-
Lignite	7,308	6,067	6,342	6,271	7,168	5,116	4,370	2,373	-
Lignite w/ CCS	-	-	-	-	-	-	-	-	-
Natural gas	3,418	2,722	2,056	1,553	1,701	2,183	1,962	1,222	581
Oil and others	3,481	8	3	-	-	3	3	-	-
Stored (pumped storage, other)	1,315	2,912	3,061	3,217	3,382	2,912	2,338	2,392	2,679
Hydroelectric	4,261	4,758	4,737	4,769	4,769	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,452	2,475	2,514	2,293	2,694	2,859	2,948
Wind power, onshore	1,478	1,909	2,009	2,000	2,000	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000	6,575	6,687	7,000	7,000
Average	4,632	3,763	3,628	3,619	3,568	3,294	2,851	2,486	2,576

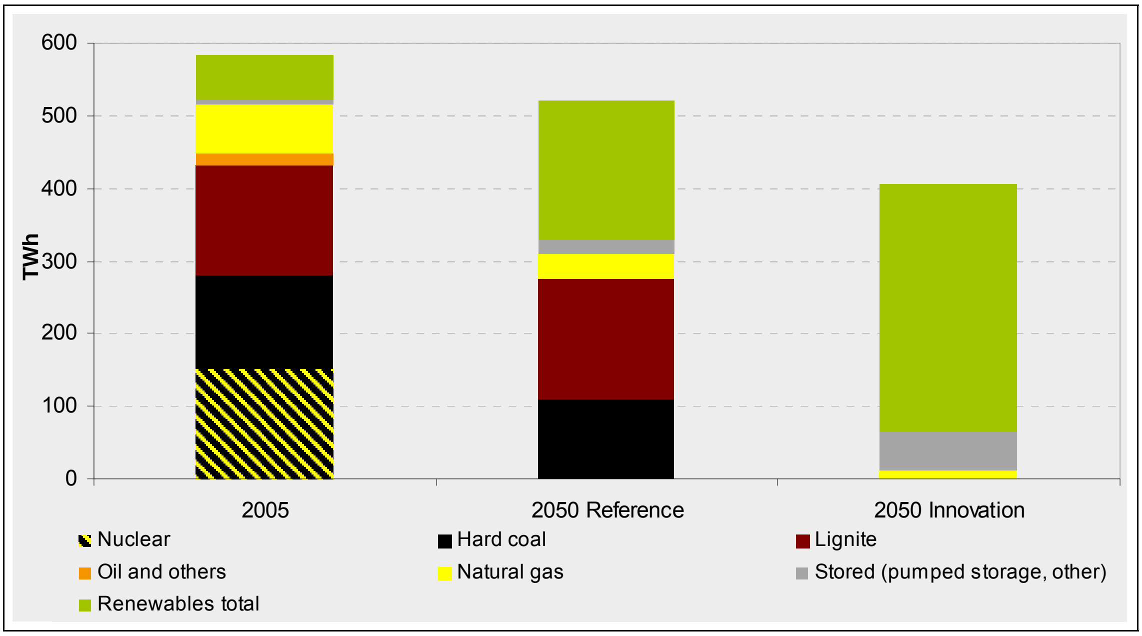
Source: Prognos 2009

Figure 6.2-3: Comparison of scenarios: Options without CCS, installed capacity of the power plant fleet in 2005 and 2050, in GW



Source: Prognos 2009

Figure 6.2-4: Comparison of scenarios: Options without CCS, power generated by energy source in 2005 and 2050, in TWh



Source: Prognos 2009

6.2.1.3 CO_2 emissions

The CO_2 emissions of electricity generation in the reference scenario fall to about 66% of the 2005 figure and in the innovation scenario to 2% (Table 6.2-4).

If the “youngest” lignite power plants (built in 2016 or later) still remain online with modifications (leading to modifications in renewables capacity with reduced feed-in), the result would be an additional emission base of 8–11 million metric tons of CO_2.

Table 6.2-4: Comparison of scenarios: Options without CCS, fuel input, CO_2 factors and CO_2 emissions for power generation, 2005 – 2050, in million metric tons

		Reference w/o CCS				Innovation w/o CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Fuel input in PJ									
Hard coal	1,182	1,461	971	1,004	840	1,128	615	219	-
Hard coal w/ CCS	0	0	0	0	0	0	0	0	0
Lignite	1,537	932	1,189	1,130	1,162	776	409	205	-
Lignite w/ CCS	0	0	0	0	0	0	0	0	0
Natural gas	571	473	371	271	281	380	356	221	95
Oil and others	314	0	0	0	0	0	0	0	0
Biomass	136	486	468	432	415	486	444	394	379
CO2 emission factors in kg/GJ									
Hard coal	94	94	94	94	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9	9	9	9	9
Lignite	112	112	112	112	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11	11	11	11	11
Natural gas	56	56	56	56	56	56	56	56	56
Oil and others	80	80	80	80	80	80	80	80	80
Biomass	23	23	23	23	23	23	23	23	23
CO2 emissions in million metric tons									
Hard coal	111	137	91	94	79	106	58	21	-
Hard coal w/ CCS	0	0	0	0	0	0	0	0	0
Lignite	172	104	133	127	130	87	46	23	-
Lignite w/ CCS	0	0	0	0	0	0	0	0	0
Natural gas	32	27	21	15	16	21	20	12	5
Oil and others	25	0	0	0	0	0	0	0	0
Biomass	3	11	11	10	9	11	10	9	9
Total CO2 emissions	344	279	256	246	234	225	134	65	14

**Emissions excluding component from flue gas desulfurization* *Source: Prognos 2009*

6.2.1.4 Costs

The average annual prime costs and the overall annual costs of electrical generation are calculated from investments (capital costs), fuel costs, fixed and variable operating costs (maintenance, etc.), CO_2 costs and storage costs. For the latter, the costs of a gas turbine power plant are defined as the upper cost limit (opportunity consideration).

What we see is that in the innovation scenario, the prime costs for the years 2020 to 2040 are slightly higher than in the reference scenario. The reason for this lies primarily in the relative proportions of new buildings: The gas power plants result in higher costs than the coal power plants. The coal plants, however, become more expensive in the innovation scenario towards the end of their life cycle due to the lower number of hours at peak capacity under usage requirements (priority for renewables). In 2050, the prime costs of the innovation scenario are slightly below those of the reference scenario. The full production costs in the innovation scenario are always lower than in the reference due to lower demand and the resulting decline in increases of total capacity. In 2050, this difference is around 23% (Table 6.2-5).

Table 6.2-5: Comparison of scenarios: Options without CCS, production cost and full cost of generation, 2005 – 2050

		Reference w/o CCS				Innovation w/o CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Specific production cost of net power generation in euro cents/kWh (real, 2007)									
Average – Conventional generation	4.3	7.8	8.2	8.8	10.0	8.1	10.3	14.8	29.8
Nuclear	4.0	4.1	-	-	-	4.1	-	-	-
Hard coal	4.6	7.4	8.1	8.8	11.3	8.0	9.3	12.9	-
Hard coal w/ CCS						-	-	-	-
Lignite	3.3	6.6	6.1	6.5	6.4	6.8	7.2	10.2	-
Lignite w/ CCS						-	-	-	-
Natural gas	8.0	12.6	14.9	18.4	22.1	13.1	15.1	20.0	29.8
Oil and others						-	-	-	-
Stored (pumped storage, other)	10.3	11.2	10.9	10.9	11.5	11.5	11.9	11.1	9.4
Power imports	0.0	9.5	8.4	7.5	7.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	9.0	8.5	8.4	10.3	8.7	8.0	7.7
Hydroelectric	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	7.1	6.9	8.6	7.3	6.9	6.7
Onshore	11.1	8.0	7.4	7.3	7.3	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1	9.8	8.5	7.5	7.1
Average – Total	5.2	8.7	8.5	8.7	9.4	9.0	9.5	9.4	8.4
Full cost of power generation in EUR bn (real, 2007)									
Conventional generation – Total	22.3	28.2	26.8	28.5	31.0	23.8	17.0	10.8	3.4
Nuclear	6.0	1.2	0.0	0.0	0.0	1.2	0.0	0.0	0.0
Hard coal	5.9	12.6	9.9	12.0	12.3	10.3	6.3	2.8	-
Hard coal w/ CCS	-	-	-	-	-	-	-	-	-
Lignite	5.0	6.7	9.6	9.9	10.7	5.9	3.6	2.4	-
Lignite w/ CCS	-	-	-	-	-	-	-	-	-
Natural gas	5.3	7.7	7.3	6.6	8.0	6.5	7.1	5.6	3.4
Oil and others	-	-	-	-	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.8	1.8	1.9	2.1	1.8	2.9	4.1	5.1
Power imports	-	0.0	0.5	0.6	0.7	0.0	1.3	2.5	3.4
Average – Renewable generation	7.5	18.0	16.7	15.9	16.0	18.0	20.8	23.4	26.1
Hydroelectric	2.2	2.4	2.4	2.4	2.4	2.4	2.5	2.5	2.5
Wind power, total	3.0	7.5	7.0	6.9	6.9	7.5	10.4	13.0	14.1
Onshore	3.0	4.3	4.2	4.1	4.1	4.3	4.3	4.7	4.9
Offshore	-	3.2	2.8	2.8	2.8	3.2	6.1	8.3	9.3
Photovoltaics	0.7	2.3	1.8	1.7	1.7	2.3	2.4	2.5	2.6
Biomass	1.6	5.6	5.3	4.7	4.7	5.6	5.1	4.3	4.3
Geothermal	0.0	0.2	0.2	0.2	0.3	0.2	0.5	1.1	2.5
Total full cost of power generation	30.5	48.0	45.7	47.0	49.8	43.7	42.0	40.8	38.0

Source: Prognos 2009

6.2.2 Options with CCS

6.2.2.1 Demand and net generation of electricity

The demand and drivers for the use of power plants in the options with CCS are similar to those without CCS. The end energy demand for electricity in the options of the reference scenario s is the same: In the innovation scenario in 2050, it is 30% lower than in the reference scenario and 36% lower than in 2005. The heavy reliance on renewable and in many cases stochastic sources for generating electricity in the innovation scenario requires temporary storage for a considerable portion of the energy produced. This in turn yields a further need for stored electricity (input and output). The storage needs in the innovation scenario with CCS are higher than in the reference scenario by a factor of 2.6. Compared to the option without CCS, less storage capacity is needed, since a large share of the load is provided by conventional power plants. Net electricity generation in 2050 is 29% under that of the reference scenario (Table 6.2-6).

The peak load in the innovation scenario falls by 28% to 54 GW by 2050 compared to the reference scenario. Renewable energies are expanded to a total installed capacity of 88 GW. They only contribute 23 GW of secured capacity to cover peak loads, however. Compared to the reference, the secured capacity of renewables in the innovation scenario in 2050 is 53% higher. The rest is supplied by the remaining natural gas power plants and storage (Table 6.2-7).

Table 6.2-6: Comparison of scenarios: Options with CCS, net power consumption and generation, 2005 – 2050, in TWh

		Reference w/ CCS				Innovation w/ CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Final energy consumption – Electricity	517	492	474	478	472	423	370	345	330
Consumption for conversion	16	14	13	10	8	14	13	10	8
Line losses	29	26	25	25	25	26	25	25	25
Stored power consumption (pumped, etc.)	11	21	22	24	25	21	29	40	57
Net power consumption	573	554	534	536	530	485	436	420	420
Net imports*	-9	0	6	8	10	0	14	35	51
Net power generation	583	554	528	528	520	485	423	384	369

** Imported electricity is renewably generated from 2021 onwards*

Source: Prognos 2009

Table 6.2-7: Comparison of scenarios: Options with CCS, peak load and secured capacity, 2005 – 2050, in GW

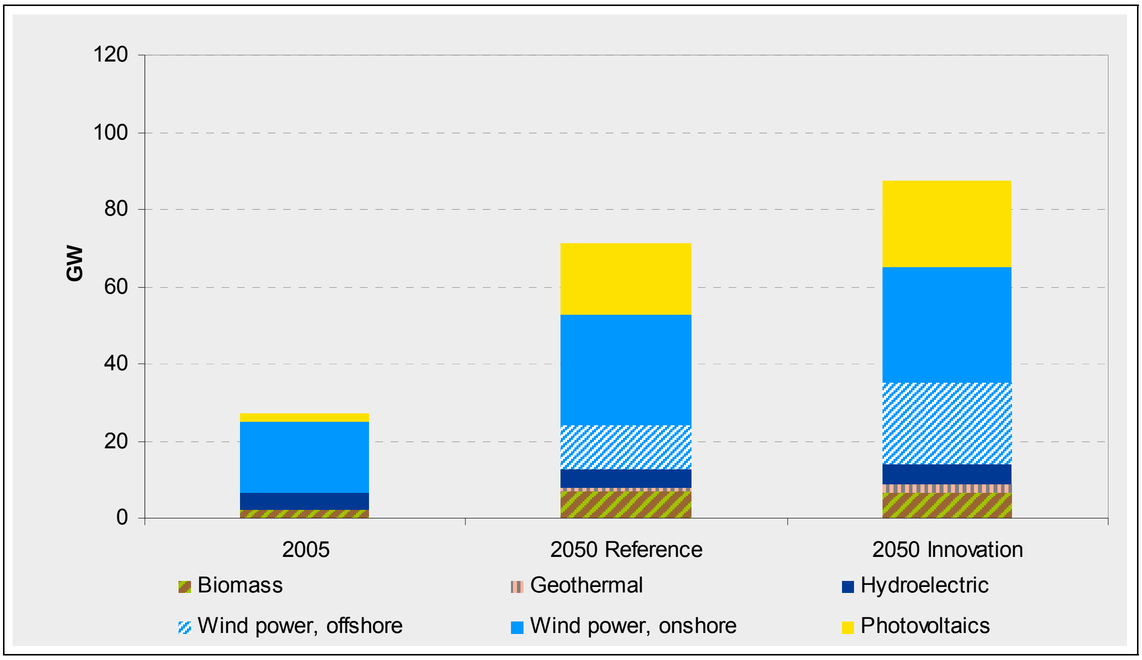
		Reference w/ CCS				Innovation w/ CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Peak load	84	76	74	75	74	68	60	56	54
Secured capacity	96	81	80	82	79	80	67	69	59
Renewables (incl. imports)	6	13	14	14	15	13	16	19	23
Conventional and stored	89	67	66	67	64	67	51	50	36

Source: Prognos 2009

6.2.2.2 Power generation

By definition, this option assumes that CCS is available as an option starting in 2025. Our estimates of CCS costs see a use for CCS power plants in accordance with the merit order. In the innovation scenario, the path of (new) renewable energies yields approx. 25% more installed capacity in 2050 compared to the reference (Figure 6.2-1) and about 1% more input (Figure 6.2-6).

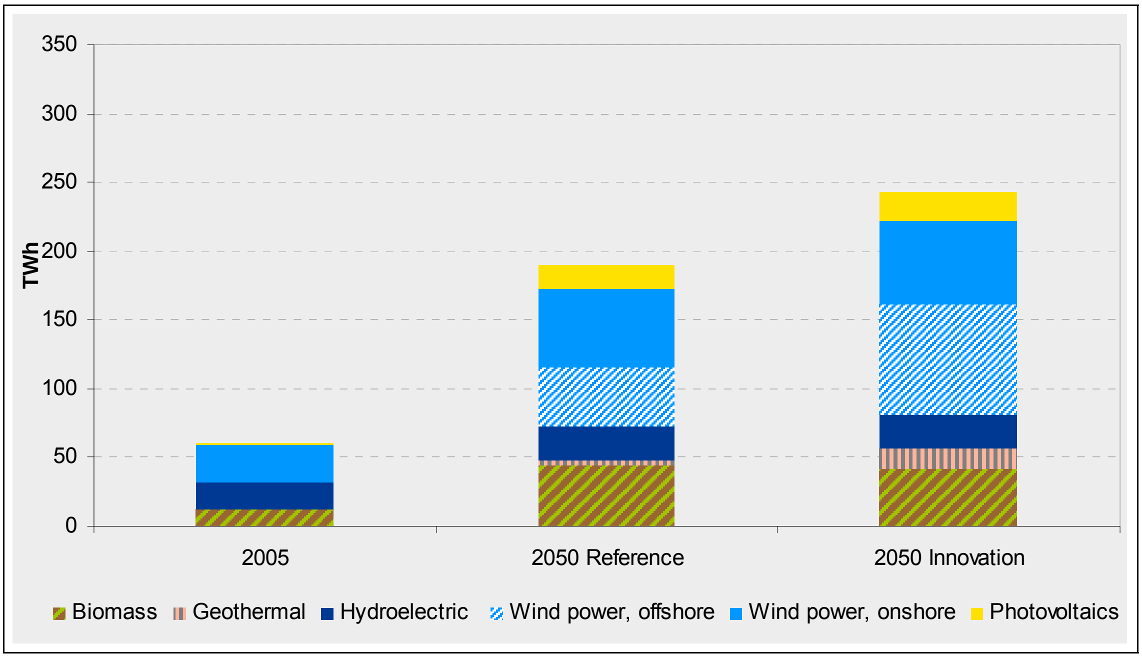
Figure 6.2-5: Comparison of scenarios: Options with CCS, installed capacity of renewable energy sources for power generation, 2005 and 2050, in GW



Source: Prognos 2009

In the reference, aging coal power plants are replaced by new plants and additional plants are built with the CCS alternative at the given CO_2 price according to the logic of marginal costs. A need for new conventional power plants already exists before 2020, and they are built without CCS. In the reference scenario, nearly 24 GW of new power plant capacity without CCS (13.4 GW lignite, 10.6 GW hard coal) comes online beyond those plants already planned. In the innovation scenario, 2.8 GW of lignite comes online. The last lignite power plant without CCS goes offline in 2043 and the last hard coal power plant without CCS in 2046 (Figure 6.2-3). This allocation of usage results from the fact that, for cost-benefit reasons, the power plants without CCS are used less and less at full capacity until their operation finally ceases to be viable. Since they have been in operation for 32 years (with construction dates before 2025), they are fully amortized and do not result in any direct losses. The technical lifespan for some of these plants is not yet reached, however. To avoid unwise investments, therefore, clear conditions would need to be established early on. If the modified power plants built from 2012 to 2016 remain online, the result would be an expanded emission base of about 13 million metric tons of CO_2.

Figure 6.2-6: *Comparison of scenarios: Options with CCS, net production of renewable power generation, 2005 and 2050, in TWh*



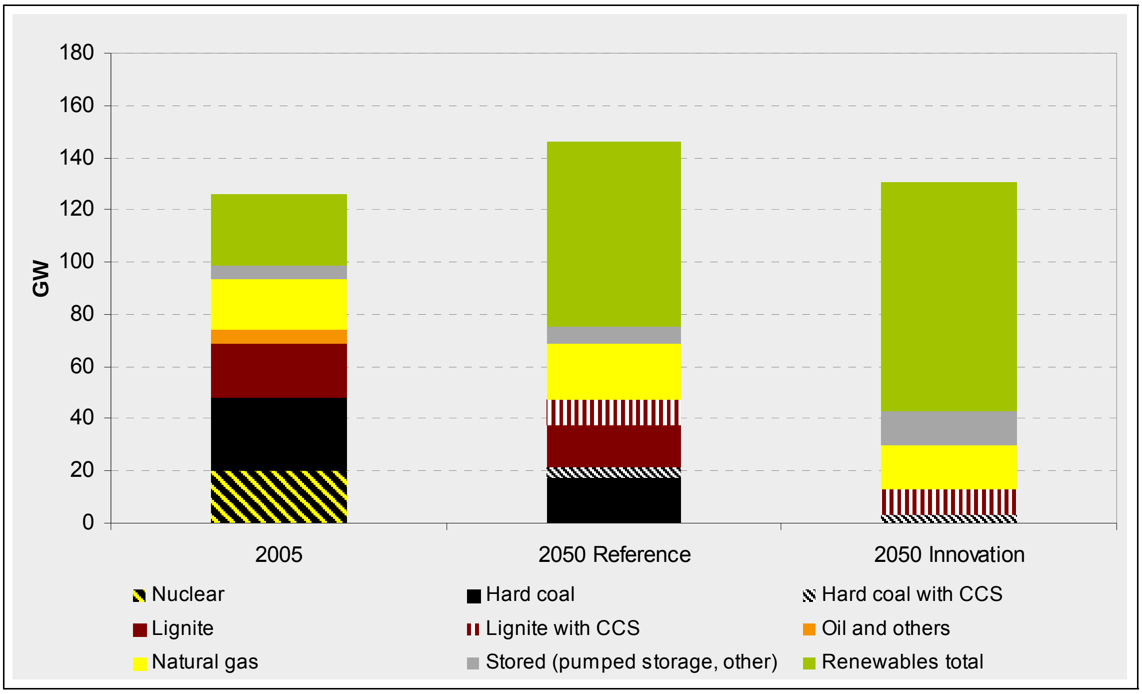
Source: Prognos 2009

Table 6.2-8: Comparison of scenarios: Options with CCS, net capacity, net power generated and annual capacity factors, by input energy source, 2005 – 2050

		Reference w/ CCS				Innovation w/ CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Net capacity in GW									
Nuclear	19.9	4.1	0.0	0.0	0.0	4	0	0	0
Hard coal	27.9	28.1	20.3	18.1	17.3	28	15	8	0
Hard coal w/ CCS		0.0	0.0	2.2	4.2	0	0	3	3
Lignite	20.8	16.8	23.4	22.7	16.5	17	11	10	0
Lignite w/ CCS		0.0	3.0	7.0	9.5	0	4	8	10
Natural gas	19.6	22.6	23.9	23.0	21.3	23	21	20	17
Oil and others	5.2	1.7	0.7	0.0	0.0	2	1	0	0
Stored (pumped storage, other)	5.4	5.7	5.9	6.2	6.4	5	8	10	13
Hydroelectric	4.6	5.1	5.1	5.1	5.1	5	5	5	5
Wind power, total	18.4	38.1	38.8	39.4	39.7	38	44	49	51
Wind power, onshore	18.4	28.1	28.1	28.2	28.3	28	28	30	30
Wind power, offshore		10.0	10.7	11.2	11.4	10	15	19	21
Photovoltaics	1.9	17.9	18.2	18.4	18.5	18	20	22	22
Biomass	2.2	7.1	7.2	7.2	7.2	7	7	7	7
Geothermal		0.3	0.3	0.4	0.5	0	1	1	2
Total net capacity	125.9	147.5	146.8	149.6	146.2	147.2	136.2	142.1	130.4
Net power generation in TWh									
Nuclear	151.0	30.2	0.0	0.0	0.0	30	0	0	0
Hard coal	128.0	169.6	112.3	95.2	64.5	129	76	13	0
Hard coal w/ CCS		0.0	0.0	15.3	28.2	0	0	18	16
Lignite	152.0	101.8	144.0	131.8	110.7	86	47	27	0
Lignite w/ CCS		0.0	22.3	51.9	72.1	0	28	52	57
Natural gas	67.0	61.5	48.4	29.8	36.5	49	48	24	16
Oil and others	18.1	0.0	0.0	0.0	0.0	0	0	0	0
Stored (pumped storage, other)	7.1	15.8	16.6	17.4	18.3	16	20	27	37
Hydroelectric	19.6	24.3	24.3	24.4	24.4	24	24	25	25
Wind power, total	27.2	87.2	95.0	97.6	99.8	87	112	130	140
Wind power, onshore	27.2	53.5	56.4	56.5	56.6	54	57	59	60
Wind power, offshore		33.7	38.6	41.1	43.1	34	55	71	80
Photovoltaics	1.2	15.5	16.6	17.1	17.6	16	19	20	21
Biomass	12.0	46.2	46.5	44.7	44.7	46	45	41	41
Geothermal		1.8	2.1	2.6	3.6	2	4	7	15
Total net power generation	583.2	554.0	528.0	527.9	520.4	484.9	422.5	384.5	368.8
Annual capacity factors in hrs/yr									
Nuclear	7,588	7,435	-	-	-	7,428	-	-	-
Hard coal	4,588	6,024	5,522	5,261	3,725	4,572	5,145	1,704	-
Hard coal w/ CCS	-	-	-	7,020	6,762	-	-	5,843	5,418
Lignite	7,308	6,067	6,156	5,810	6,712	5,116	4,134	2,770	-
Lignite w/ CCS	-	-	7,431	7,415	7,631	-	6,959	6,521	5,710
Natural gas	3,418	2,722	2,025	1,294	1,708	2,183	2,295	1,216	956
Oil and others	3,481	8	3	-	-	3	18	-	-
Stored (pumped storage, other)	1,315	2,786	2,808	2,834	2,866	2,912	2,585	2,607	2,827
Hydroelectric	4,261	4,758	4,737	4,769	4,769	4,758	4,737	4,769	4,769
Wind power, total	1,478	2,293	2,452	2,475	2,514	2,293	2,573	2,664	2,735
Wind power, onshore	1,478	1,909	2,009	2,000	2,000	1,909	2,009	2,000	2,000
Wind power, offshore	-	3,370	3,620	3,677	3,792	3,370	3,620	3,677	3,792
Photovoltaics	632	867	913	934	955	867	913	934	955
Biomass	5,455	6,465	6,470	6,184	6,184	6,465	6,470	6,184	6,184
Geothermal	-	6,575	6,687	7,000	7,000	6,575	6,687	7,000	7,000
Average	4,632	3,757	3,597	3,527	3,560	3,294	3,102	2,706	2,829

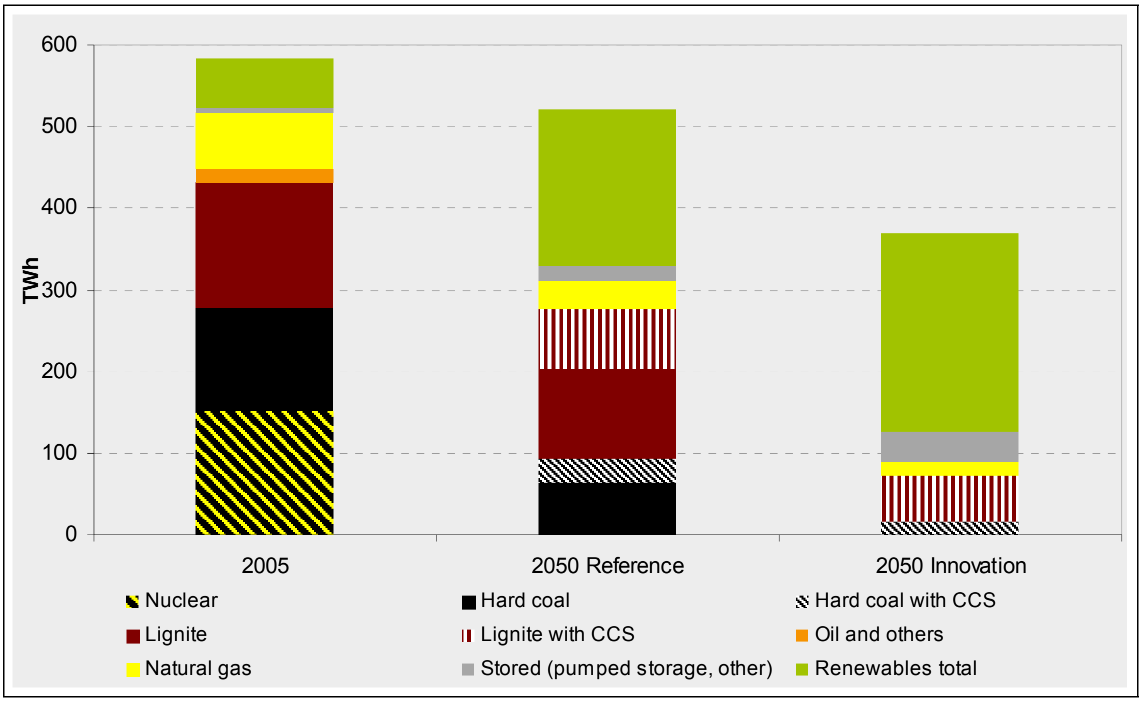
Source: Prognos 2009

Figure 6.2-7: Comparison of scenarios: Options with CCS, installed capacity of the power plant fleet in 2005 and 2050, in GW



Source: Prognos 2009

Figure 6.2-8: Comparison of scenarios: Options with CCS, power generated, by energy source, in 2005 and 2050, in TWh



Source: Prognos 2009

6.2.2.3 CO_2 emissions

The CO_2 emissions of electrical generation in the reference fall to about 48% of the 2005 figure and in the innovation scenario to 4% (Table 6.2-9).

Table 6.2-9: Comparison of scenarios: Options with CCS, fuel input, CO_2 factors and CO_2 emissions for power generated, 2005 – 2050, in million metric tons

		Reference w/ CCS				Innovation w/ CCS			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Fuel input in PJ									
Hard coal	1,182	1,461	909	738	537	1,128	642	137	-
Hard coal w/ CCS	0	0	0	121	220	-	-	150	142
Lignite	1,537	932	1,086	983	812	776	390	249	-
Lignite w/ CCS	0	0	193	426	562	-	238	443	507
Natural gas	571	473	366	228	282	380	365	192	129
Oil and others	314	0	0	0	0	0	0	-	-
Biomass	136	486	468	432	415	486	444	394	379
CO2 emission factors in kg/GJ									
Hard coal	94	94	94	94	94	94	94	94	94
Hard coal w/ CCS	9	9	9	9	9	9	9	9	9
Lignite	112	112	112	112	112	112	112	112	112
Lignite w/ CCS	11	11	11	11	11	11	11	11	11
Natural gas	56	56	56	56	56	56	56	56	56
Oil and others	80	80	80	80	80	80	80	80	80
Biomass	23	23	23	23	23	23	23	23	23
CO2 emissions in million metric tons									
Hard coal	111	137	85	69	50	106	60	13	-
Hard coal w/ CCS	0	0	0	1	2	-	-	1	1
Lignite	172	104	122	110	91	87	44	28	-
Lignite w/ CCS	0	0	2	5	6	-	3	5	6
Natural gas	32	27	21	13	16	21	20	11	7
Oil and others	25	0	0	0	0	0	0	-	-
Biomass	3	11	11	10	9	11	10	9	9
Total CO2 emissions	344	279	241	208	175	225	137	67	23

**Emissions excluding component from flue gas desulfurisation* *Source: Prognos 2009*

6.2.2.4 Costs

The average annual prime costs and the overall annual costs of electrical generation are calculated from investments (capital costs), fuel costs, fixed and variable operating costs (maintenance, etc.), CO_2 costs and storage costs. For the latter, the costs of a gas turbine power plant are defined as the upper cost limit.

What we see is that in the innovation scenario— as in the option without CCS—the prime costs for the years 2020 to 2040 are slightly higher than in the reference scenario. This is due primarily to the relative proportions of new buildings: The gas power plants result in higher costs than the coal power plants. The coal plants, however, are more expensive in the innovation scenario towards the end of their life cycle due to the lower number of hours at peak capacity under usage requirements (priority for renewables). In 2050, the prime costs of the innovation scenario are slightly (5%) below those of the reference scenario, however. The full production costs in the innovation scenario are always lower than in the reference due to lower demand and the resulting lower additions to total capacity. In 2050, this difference is around 25% (Table 6.2-10). Overall, both prime costs and total costs are consistently somewhat lower than the options without CCS. The prime costs converge towards the end of the period of study.

Table 6.2-10: Comparison of scenarios: Options with CCS, production cost and full cost of generation, 2005 – 2050

		Reference w/ CCS				Innovation w/ CCS			
	2005	2020	2030	2040	2050	2020	2030	2040	2050
Specific production cost of net power generation in euro cents/kWh (real, 2007)									
Average – Conventional generation	4.3	5.3	6.9	8.3	9.3	7.9	9.4	10.0	10.5
Nuclear	4.0	4.1	-	-	-	4.1	-	-	-
Hard coal	4.6	4.6	5.3	6.1	8.4	5.2	5.5	11.3	-
Hard coal w/ CCS		0.0	0.0	28.1	18.0	-	-	8.7	10.5
Lignite	3.3	3.2	3.0	3.1	2.9	7.7	8.9	7.5	-
Lignite w/ CCS		0.0	26.0	14.2	10.8	-	5.3	5.2	5.8
Natural gas	8.0	11.1	13.5	18.2	20.8	17.6	16.6	23.2	25.3
Oil and others		0.0	0.0	0.0	0.0	-	-	-	-
Stored (pumped storage, other)	10.3	9.5	10.2	10.9	11.4	11.4	11.5	10.6	9.7
Power imports	0.0	9.5	8.4	7.5	7.0	9.5	8.4	7.5	7.0
Average – Renewable generation	12.0	10.3	9.0	8.5	8.4	10.3	8.9	8.3	8.0
Hydroelectric	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Wind power, total	11.1	8.6	7.3	7.1	6.9	8.6	7.3	7.0	6.8
Onshore	11.1	8.0	7.4	7.3	7.3	8.0	7.4	7.3	7.3
Offshore	0.0	9.5	7.3	6.8	6.5	9.5	7.3	6.8	6.5
Photovoltaics	54.8	14.6	10.9	9.9	9.4	14.6	10.9	9.9	9.4
Biomass	13.2	12.2	11.4	10.5	10.5	12.2	11.4	10.5	10.5
Geothermal	45.8	9.8	8.5	7.5	7.1	9.8	8.5	7.5	7.1
Average – Total	5.2	7.0	7.7	8.5	9.0	8.9	9.2	8.9	8.5
Full cost of power generation in EUR bn (real, 2007)									
Conventional generation – Total	22.3	19.2	22.5	26.9	29.1	23.2	18.6	13.4	9.4
Nuclear	6.0	1.2	0.0	0.0	0.0	1.2	0.0	0.0	0.0
Hard coal	5.9	7.9	5.9	5.8	5.4	6.7	4.2	1.4	0.0
Hard coal w/ CCS	-	-	-	4.3	5.1	-	-	1.5	1.7
Lignite	5.0	3.3	4.3	4.1	3.2	6.6	4.2	2.0	0.0
Lignite w/ CCS	-	-	5.8	7.4	7.8	-	1.5	2.7	3.3
Natural gas	5.3	6.8	6.5	5.4	7.6	8.7	8.0	5.7	4.1
Oil and others	-	-	-	-	-	-	-	-	-
Stored (pumped storage, other)	0.7	1.5	1.7	1.9	2.1	1.8	2.4	2.9	3.5
Power imports	-	0.0	0.5	0.6	0.7	0.0	1.2	2.6	3.6
Average – Renewable generation	7.5	18.0	16.7	15.9	16.0	18.0	18.1	18.5	19.5
Hydroelectric	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.5
Wind power, total	3.0	7.5	7.0	6.9	6.9	7.5	8.2	9.1	9.6
Onshore	3.0	4.3	4.2	4.1	4.1	4.3	4.2	4.3	4.4
Offshore	-	3.2	2.8	2.8	2.8	3.2	4.0	4.8	5.2
Photovoltaics	0.7	2.3	1.8	1.7	1.7	2.3	2.0	2.0	2.0
Biomass	1.6	5.6	5.3	4.7	4.7	5.6	5.1	4.3	4.3
Geothermal	0.0	0.2	0.2	0.2	0.3	0.2	0.3	0.5	1.1
Total full cost of power generation	30.5	38.8	41.4	45.4	47.9	43.1	39.5	37.4	35.7

Source: Prognos 2009

6.3 Primary energy

6.3.1 Options without CCS

In 2050, primary energy input (not including non-energy input) is 31% less in the innovation scenario than in the reference scenario, as a consequence of two contrary effects. Thanks to strategic substitutions and savings on electricity, fossil energy sources are reduced in the innovation scenario compared to the reference scenario, which itself already includes systematic efficiency measures. Renewables are the “substitution winners” in mobility and power generation.

In detail, coal disappears almost entirely from the mix in the innovation scenario. The quantity of hard coal used in 2050 is 96% less in the innovation scenario than in the reference scenario. The quantity of lignite is 98% less. Of the remaining 82 PJ, 77 PJ is used in metal production. The remaining 5 PJ represent conversion losses. The difference for petroleum products is 79%. Here the “classic” motor fuels – gasoline and diesel – are almost entirely eliminated (100% decrease). Diesel, at 4 PJ, is used only in niche applications. Aviation fuels are not replaced, and are reduced by only 11% compared to the reference scenario; they remain in the mix in 2050, at 312 PJ. Because of the limited biomass potential available, biogenic combustibles and motor fuels are also assumed to be without alternatives in the innovation scenario. Heating oil products are used 79% less (light heating oil) and 75% less (heavy heating oil) in 2050 under the innovation scenario than under the reference scenario. They are used in residual amounts for process heat production in industry and in the service sector. Gases are used 51% less in 2050 in the innovation scenario than in the reference scenario. Here two contrary effects are at work. Efficiency increases on the demand side, the reduction of demand for electricity, and lower inputs in power generation all have a reducing effect. Substitution effects for process heat generation in the industry and service sectors, the use of gas in the transport sector, and the greater need for balancing power in power generation all tend to increase usage.

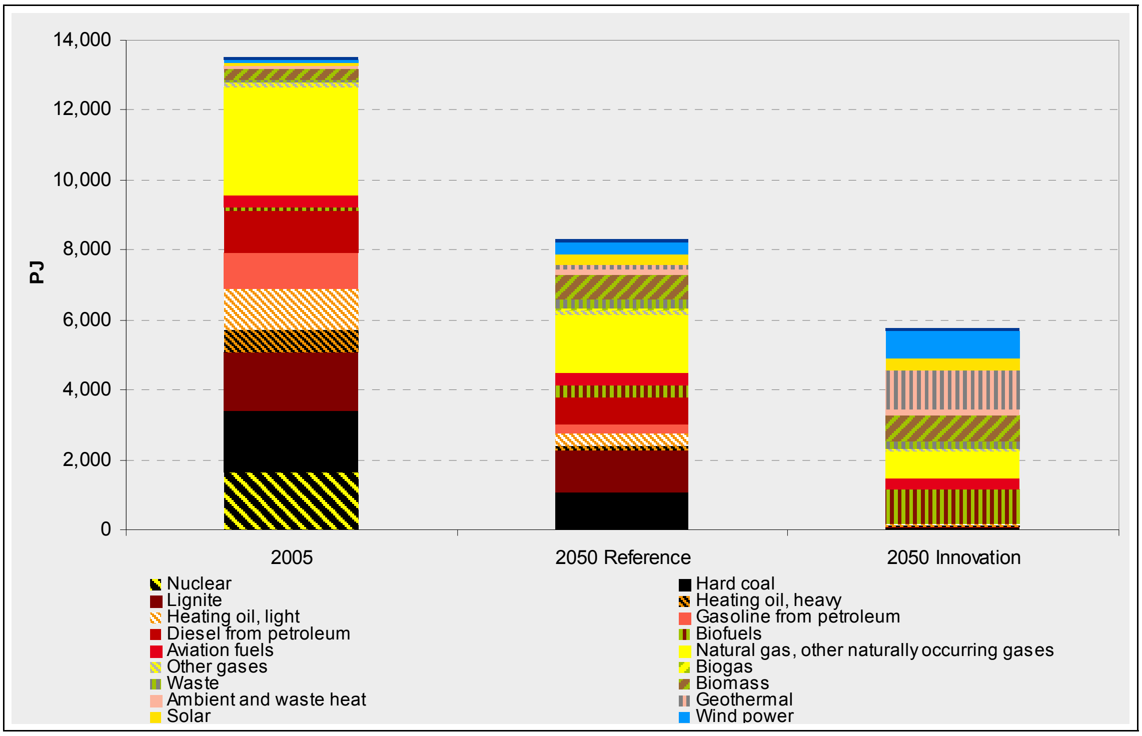
Table 6.3-1: Comparison of scenarios: Option without CCS, primary energy consumption (excluding non-energy consumption), by energy source and sector, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
By energy source, without CCS									
Nuclear	**1,658**	**332**	**0**	**0**	**0**	**331**	**0**	**0**	**0**
Coal	**3,412**	**2,888**	**2,529**	**2,458**	**2,284**	**2,308**	**1,261**	**564**	**82**
Hard coal	1,749	1,888	1,274	1,268	1,066	1,476	814	330	59
Lignite	1,662	1,000	1,255	1,190	1,218	832	447	234	23
Petroleum products	**4,407**	**3,299**	**2,753**	**2,293**	**1,865**	**2,813**	**1,610**	**866**	**389**
Heating oil, light	1,151	787	576	423	325	574	256	96	36
Heating oil, heavy	675	275	227	183	149	225	130	72	37
Gasoline from petroleum	1,033	583	461	369	254	534	303	115	0
Diesel from petroleum	1,202	1,260	1,114	952	787	1,097	566	246	4
Aviation fuels	345	394	374	365	350	383	354	336	312
Other petroleum products	1	0	0	0	0	0	0	0	0
Gases	**3,222**	**2,818**	**2,318**	**1,933**	**1,792**	**2,269**	**1,611**	**1,150**	**875**
Natural gas, other naturally occurring gases	3,099	2,697	2,210	1,827	1,673	2,170	1,519	1,053	780
Other gases	123	121	108	106	119	99	92	97	95
Waste	**87**	**283**	**272**	**251**	**241**	**283**	**258**	**229**	**221**
Renewable energy sources	**741**	**1,678**	**1,937**	**2,090**	**2,148**	**1,932**	**2,939**	**3,484**	**4,200**
Biomass	337	698	724	711	689	765	874	791	726
Ambient and waste heat	69	112	150	187	200	112	149	164	144
Solar	77	180	237	280	292	246	362	388	371
Hydroelectric	82	93	92	93	93	93	94	94	94
Wind power	98	314	342	351	359	314	512	672	753
Biofuels	77	193	268	321	340	318	708	867	987
Biogas	0	17	50	60	60	14	26	17	7
Geothermal	0	71	74	87	114	71	215	490	1,118
Total primary energy consumption	13,526	11,298	9,808	9,024	8,330	9,936	7,680	6,294	5,766
By sector, without CCS									
Residential	2,069	1,660	1,445	1,255	1,096	1,391	949	605	341
Services	923	685	464	322	270	617	376	269	237
Industry	1,556	1,444	1,281	1,176	1,127	1,118	853	714	667
Transport	2,529	2,361	2,180	1,996	1,760	2,272	1,933	1,620	1,373
District heat generation	306	271	255	248	211	253	188	123	79
Power generation	5,583	4,217	3,568	3,429	3,327	3,634	2,723	2,387	2,539
Other energy conversion	561	661	616	598	540	651	658	575	530
Total primary energy consumption	13,526	11,298	9,808	9,024	8,330	9,936	7,680	6,294	5,766

Source: Prognos 2009

The input of renewable energies in the innovation scenario is consistently higher than in the reference scenario, with the efficiency-based exceptions of biogas and waste heat/ambient heat. In total the renewables nearly double. The largest absolute and relative upward change is in geothermal energy (power generation). Here the difference, an increase of 1,004 PJ, is almost ten times the value of the reference scenario. Biofuels nearly triple, because of the substitution of energy sources in road transport. The increase for biomass is only 5%. This is because in the reference scenario, biomass is used “unselectively” for both conventional heat production and combined heat and power generation. In the innovation scenario, these amounts are used primarily to produce biofuels.

Figure 6.3-1: *Comparison of scenarios: Options without CCS, primary energy consumption (excluding non-energy consumption), by energy source, 2005 – 2050, in PJ*



Source: Prognos 2009

For the same reason, biogas is used 88% less in 2050 in the innovation scenario than in the reference scenario. The largest share of biomass, much of which is used to produce biogas for heat production and combined heat and power generation in the reference scenario, is used to produce biofuels in the innovation scenario.

Ambient and waste heat is used 28% less in the innovation scenario than in the reference scenario because of the reduction in demand for space heating. Solar energy is used 27% more in the innovation scenario than in the reference scenario – a result of the contrary effects of the reduction of demand for low-temperature heat, and greater electric power generation. Wind energy expands more than twice as much in the innovation scenario than in the reference scenario.

6.3.2 Options with CCS

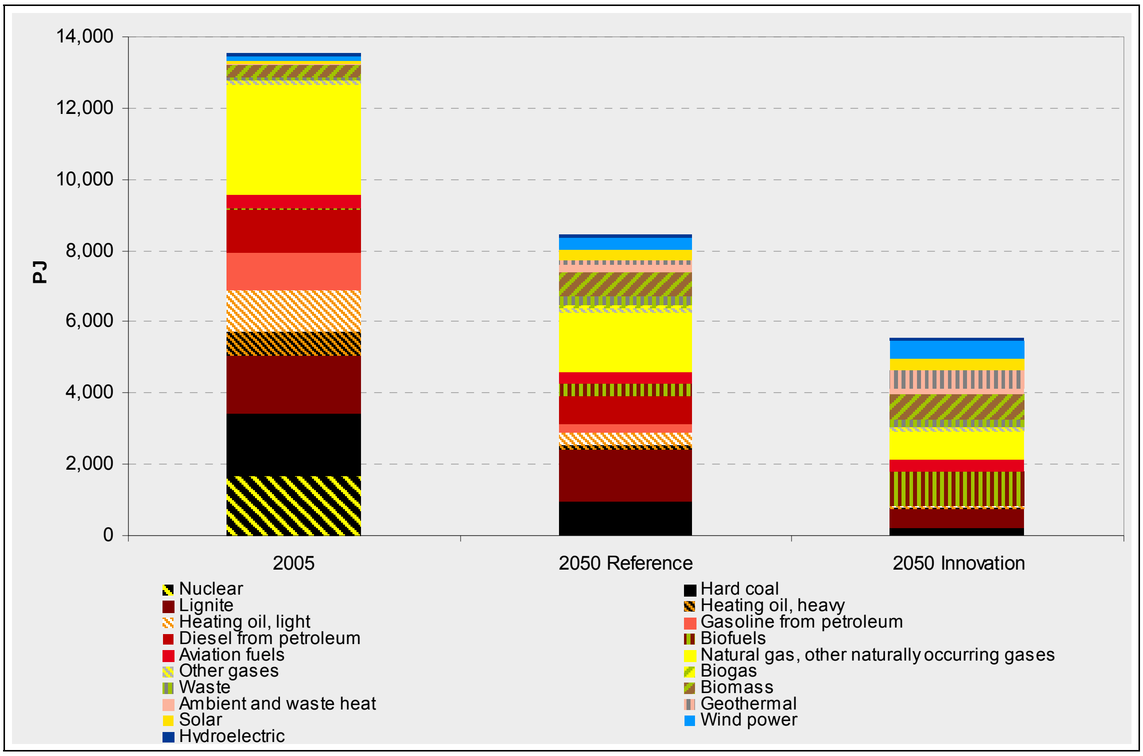
The difference in the options with CCS from those without CCS is essentially the use of coal and renewable energy sources in power generation (Table 6.3-2, Figure 6.3-2).

For coal, consumption in 2050 is 69% less in the innovation scenario than in the reference scenario. It is 78% less for hard coal and 62% less for lignite. This reflects the fact that 10 GW of lignite-fired power plant capacity and 3 GW of hard coal-fired capacity remain in the mix, all with CCS technology.

Accordingly the increase in renewable energy sources in power generation, at 53%, is less than in the options without CCS. The use of geothermal energy in 2050 is only four times as high in the innovation scenario as in the reference scenario. Wind energy is 40% higher and solar energy 19% higher.

Power generation in 2050 is 33% less in the innovation scenario than in the reference scenario. This apparently paradoxical result, compared to the option without CCS, is the result of two mutually complementary effects. First the "starting value" in the reference scenario is higher in the option with CCS than in the option without CCS, because of the lower efficiency of CCS power plants. Second, because of the base load and intermediate load generated by thermal power plants, and the generally lower fluctuating generation from renewable sources, the additional storage demand, with its losses of about 30%, is lower, thus saving a total of 1,141 PJ.

Figure 6.3-2: Comparison of scenarios: Options with CCS, primary energy consumption (excluding non-energy consumption), by energy source, 2005 – 2050, in PJ



Source: Prognos 2009

Table 6.3-2: Comparison of scenarios: Options with CCS, primary energy consumption (excluding non-energy consumption), by energy source and sector, 2005 – 2050, in PJ

		Reference scenario				Innovation scenario			
	2005	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
By energy source, with CCS									
Nuclear	1,658	332	0	0	0	331	0	0	0
Coal	3,412	2,888	2,554	2,585	2,409	2,308	1,514	1,135	753
Hard coal	1,749	1,888	1,207	1,112	975	1,476	843	404	212
Lignite	1,662	1,000	1,347	1,474	1,434	832	671	731	540
Petroleum products	4,407	3,299	2,753	2,293	1,865	2,813	1,611	866	389
Heating oil, light	1,151	787	576	423	325	574	256	96	36
Heating oil, heavy	675	275	227	183	149	225	131	72	37
Gasoline from petroleum	1,033	583	461	369	254	534	303	115	0
Diesel from petroleum	1,202	1,260	1,114	952	787	1,097	566	246	4
Aviation fuels	345	394	374	365	350	383	354	336	312
Other petroleum products	1	0	0	0	0	0	0	0	0
Gases	3,222	2,818	2,313	1,890	1,794	2,269	1,620	1,121	908
Natural gas, other naturally occurring gases	3,099	2,697	2,205	1,784	1,675	2,170	1,528	1,024	813
Other gases	123	121	108	106	119	99	92	97	95
Waste	87	283	272	251	241	283	258	229	221
Renewable energy sources	741	1,678	1,937	2,090	2,148	1,932	2,730	3,007	3,294
Biomass	337	698	724	711	689	765	874	791	726
Ambient and waste heat	69	112	150	187	200	112	149	164	144
Solar	77	180	237	280	292	246	350	369	348
Hydroelectric	82	93	92	93	93	93	93	93	93
Wind power	98	314	342	351	359	314	405	469	504
Biofuels	77	193	268	321	340	318	708	867	987
Biogas	0	17	50	60	60	14	26	17	7
Geothermal	0	71	74	87	114	71	126	235	484
Total primary energy consumption	13,526	11,298	9,828	9,109	8,457	9,936	7,733	6,358	5,564
By sector, with CCS									
Residential	2,069	1,660	1,445	1,255	1,096	1,391	949	605	341
Services	923	685	464	322	270	617	376	269	237
Industry	1,556	1,444	1,281	1,176	1,127	1,118	853	714	667
Transport	2,529	2,361	2,180	1,996	1,760	2,272	1,933	1,620	1,373
District heat generation	306	271	255	248	211	253	188	123	79
Power generation	5,583	4,217	3,591	3,520	3,457	3,634	2,769	2,437	2,315
Other energy conversion	561	661	613	591	538	651	664	590	552
Total primary energy consumption	13,526	11,298	9,828	9,109	8,457	9,936	7,733	6,358	5,564

Source: Prognos 2009

6.4 Total greenhouse gas emissions

In the comparison of scenarios for greenhouse gas emissions, the options with and without CCS differ only slightly. For that reason, they will be described here in parallel, as they are in Chapters 4 and 5.

Generally, the development of greenhouse gas emissions over time is mainly dominated by energy-related emissions, especially energy-related CO2 emissions (from combustion processes).

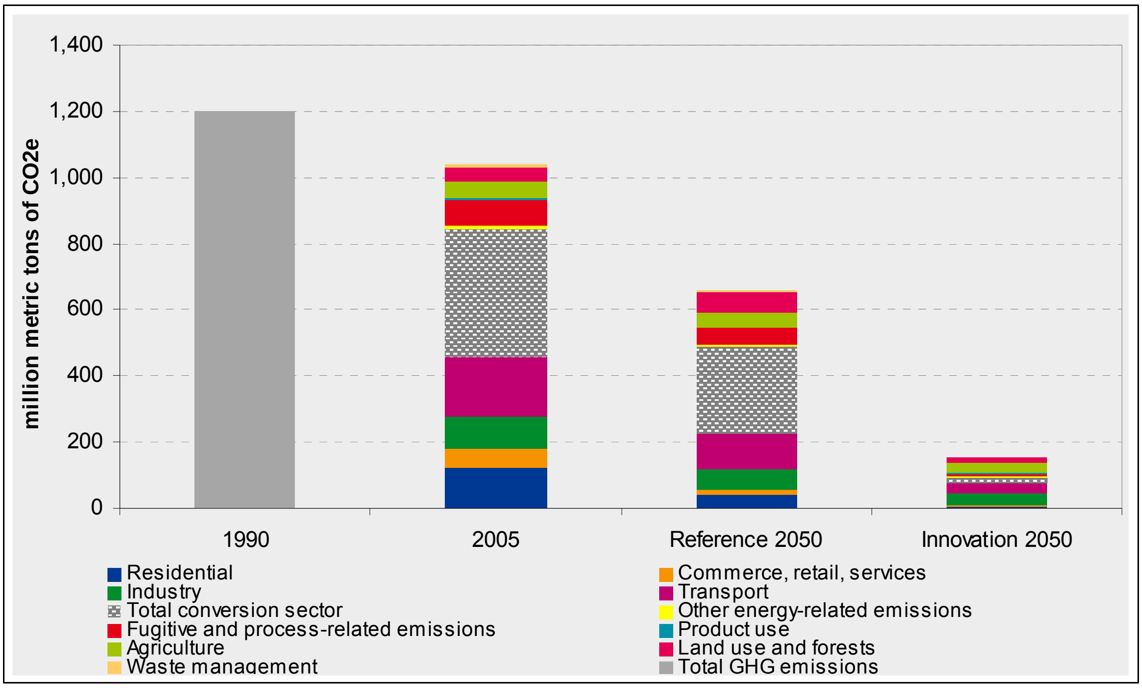
Table 6.4-1: Comparison of scenarios: Total greenhouse gas emissions, by sector, 1990 – 2050, in million metric tons of CO_2 equivalent

	Historical data		Reference scenario				Innovation scenario			
Million metric tons of CO_2 equivalent	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
By sectors										
Fuel combustion without CCS	1,018	843	715	615	550	493	589	353	199	97
of this power generation without CCS		*323*	*280*	*257*	*247*	*235*	*226*	*134*	*65*	*14*
of this industry		*101*	*91*	*78*	*69*	*65*	*70*	*51*	*41*	*36*
of this transport		*179*	*159*	*140*	*123*	*103*	*144*	*91*	*57*	*30*
Fuel combustion with CCS	1,018	843	715	599	511	433	589	357	201	106
of this power generation with CCS		*323*	*280*	*242*	*209*	*176*	*226*	*138*	*67*	*23*
Fugitive and industrial process emissions, product use	107	84	60	57	56	54	54	37	23	10
Agriculture	62	53	48	48	48	48	39	36	33	30
Land use, land use change and forestry	-28	39	60	60	60	60	21	18	18	18
Waste sector	40	13	6	5	4	4	6	4	3	3
By gases										
Variant without CCS										
CO_2	1,019	913	803	703	638	581	634	387	227	117
CH_4	98	46	30	27	25	24	26	21	17	13
N_2O	70	56	42	41	40	40	35	30	27	25
Variant with CCS										
CO_2	1,019	913	803	688	600	521	634	391	229	126
CH_4	98	46	30	27	25	24	26	21	17	13
N_2O	70	56	42	41	40	39	35	30	27	25
HFC	4	10	10	10	10	10	10	7	4	1
PFC	3	1	0	0	0	0	0	0	0	0
SF_6	5	5	3	3	3	3	3	2	1	0
Total without CCS	**1,199**	**1,031**	**888**	**785**	**717**	**658**	**709**	**447**	**276**	**157**
Total with CCS	**1,199**	**1,031**	**888**	**769**	**679**	**598**	**709**	**451**	**278**	**166**
Total without CCS										
Change from 1990	-	-14.0%	-25.9%	-34.5%	-40.2%	-45.1%	-40.8%	-62.7%	-77.0%	-86.9%
Change from 2005	16.3%	-	-13.8%	-23.9%	-30.5%	-36.2%	-31.2%	-56.6%	-73.3%	-84.8%
Total with CCS										
Change from 1990	-	-14.0%	-25.9%	-35.8%	-43.4%	-50.1%	-40.8%	-62.4%	-76.8%	-86.2%
Change from 2005	16.3%	-	-13.8%	-25.4%	-34.2%	-42.0%	-31.2%	-56.3%	-73.1%	-83.9%
Note: Emissions data for 2005 is inventory data; energy-related emissions include CO_2 from flue gas desulfurization										

Source: Prognos /Öko-Institut 2009

In the innovation scenario for 2050, these are 80% lower in the option without CCS and 76% lower in the option with CCS than in the parallel options of the reference scenario. The difference results entirely from differences in the development of power generation. In the option without CCS, the associated CO_2 emissions for 2050 in the innovation scenario are 94% lower than the reference scenario figure (reaching 14 million metric tons); they are 87% lower in the option with CCS (equivalent to 23 million metric tons of CO_2).

Figure 6.4-1: Comparison of scenarios: Options without CCS, total greenhouse gas emissions, by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



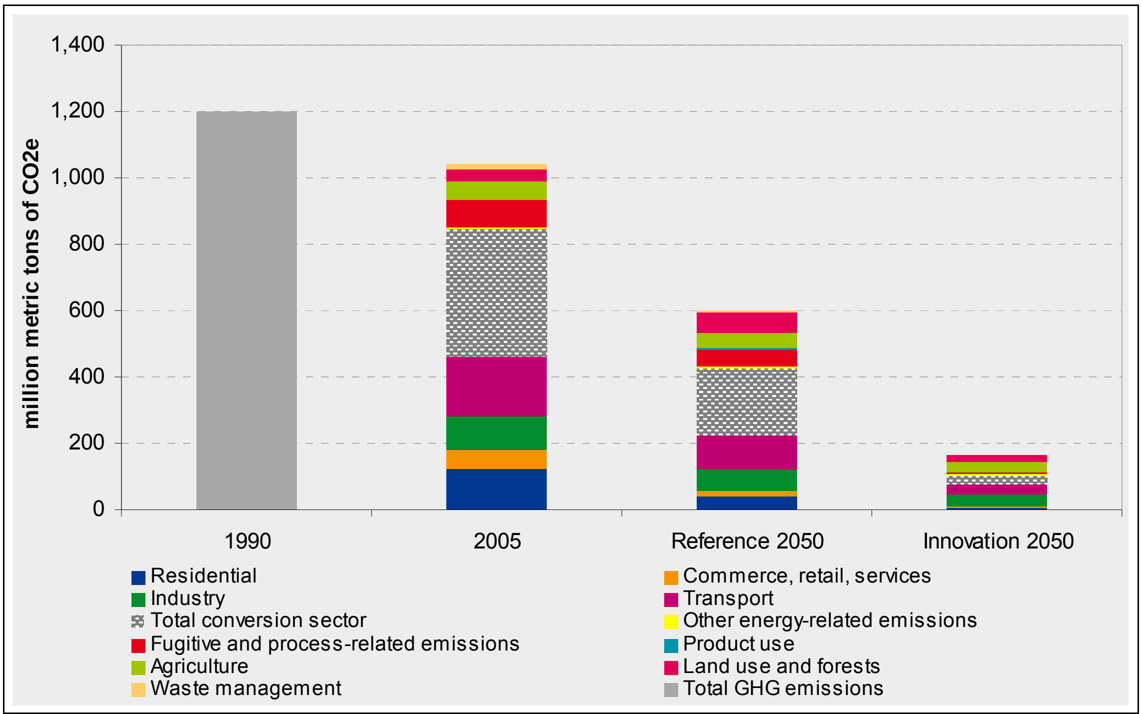
Source: Prognos/ Öko-Institut 2009

Developments vary greatly between scenarios in the demand sectors (Figure 6.4-1). In the residential sector, 2050 emissions in the innovation scenario are 93% lower than in the reference scenario, particularly due to savings in demand for space heating and a wider use of renewable energy sources. The parallel reduction in the service sector is 37%. The difference is comparatively small because here significant savings were already achieved in the reference scenario. In industry, innovations in processes and materials in the innovation scenario reduce emissions by 44% compared to the efficiency-driven reference scenario; emissions in the transport sector are 71% lower. This result reflects the joint effects of the strategic efforts to electrify passenger transport, the shift in freight transport, and the replacement of fossil fuels with biofuels for passenger cars and motorized freight transport.

Emissions for 2050 in the other conversion sector are 88% lower in the innovation scenario than in the reference scenario. This reduction is associated primarily with the lower use of petroleum products, since by definition the conversion of biomass to biofuels entails no direct CO2 emissions (indirect and other emissions are counted under the non-energy sectors; see Chap. 4, 5 and 6). Emissions are also lowered by the reduction of demand for district heating, and of coal use for electric power generation.

Methane and nitrous oxide emissions from combustion processes (energy-related CH4 and N_2O emissions) are significantly lower, but quantitatively are of only very minor importance.

Figure 6.4-2: Comparison of scenarios: Options with CCS, total greenhouse gas emissions, by sector, 1990 – 2050, in million metric tons of CO_2 equivalent



Source: Prognos/ Öko-Institut 2009

The differences in fugitive emissions from the energy sector, process-related emissions, and greenhouse gas emissions from product use are dominated by two developments in the comparison between the two scenarios. First, the changes in energy source structures again result in a substantial reduction of fugitive emissions from the energy sector, especially due to significantly lower methane emissions from the oil and gas sector. Second, process-related emissions are reduced substantially in some segments (cement production, the chemical industry, fluorinated gases). All in all, greenhouse gas emissions from these segments in 2050 are 82% lower in the innovation scenario than in the reference scenario.

There are also substantial emission reductions in the agricultural sector. Here the 2050 figures in the innovation scenario are 37% lower than in the other scenario, especially because of changes in animal husbandry and soil management.

Net emissions in the land use and forestry sector are reduced to about 18 million metric tons of CO_2 equivalent in the innovation scenario, about 71% less than in the reference scenario. Even though the forests' sink function cannot be expanded in comparison to the reference scenario, the results clearly show that substantial reductions of greenhouse gas emissions can be achieved by appropriate measures in land use.

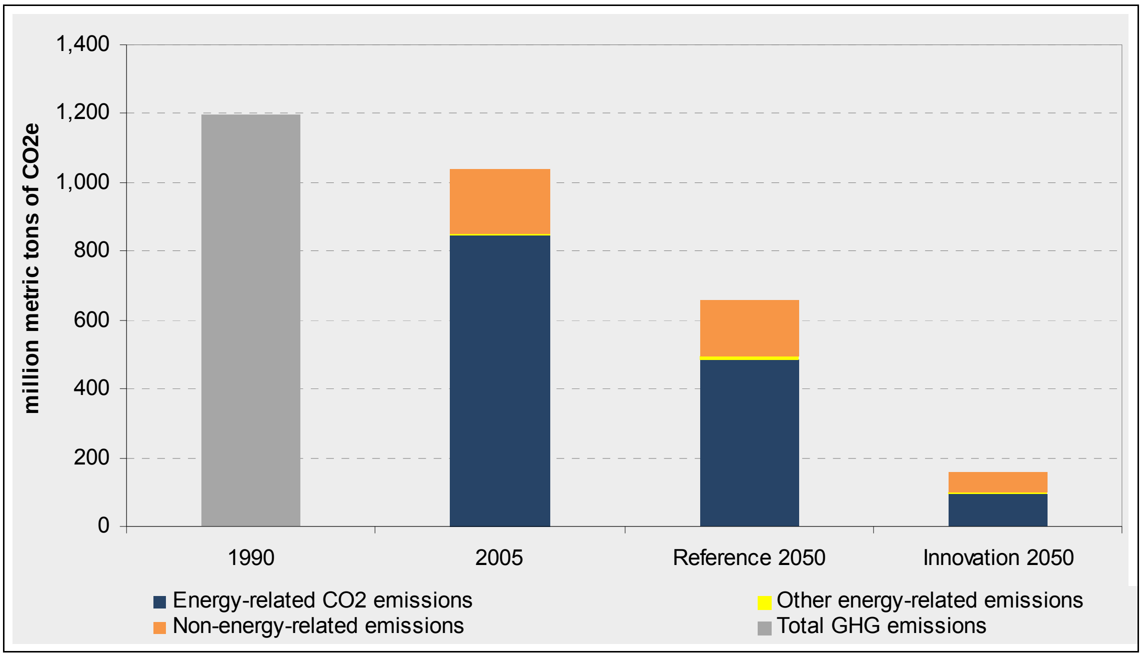
The reduction in emissions from waste management between the two scenarios is large in specific terms (–28%), but in absolute terms the 2050 emissions in the innovation scenario are only about 1 million metric tons of CO_2 equivalent below the levels within the reference scenario.

A comparison of how individual greenhouse gas emissions change once again shows the overwhelming role of CO_2 emissions. The reductions in the comparison between scenarios for 2050 are 80% in the option without CCS and 76% in the option with CCS. Higher specific reductions appear only for the fluorinated gases. But the large specific reductions (–81% to –90% for the innovation scenario in 2050) correspond to limited absolute emission savings, which total 13 million metric tons of CO_2 equivalent.

In comparative terms, the smallest differences between the innovation scenario and the reference scenario are in N_2O emissions. Here the difference between the scenarios in 2050 (depending on the CCS option) is between 14 and 15 million metric tons of CO_2 equivalent, or a specific reduction of 37% to 38%. The emission differences for methane are greater in specific terms (–44%), but less in absolute terms (–11 million metric tons of CO_2 equivalent).

The largest contributions to emissions in 2050 will come from industry (energy-related emissions of 34 million metric tons of CO2 equivalent), agriculture (30 million metric tons of CO_2 equivalent) and transport (30 million metric tons of CO_2 equivalent); in the case of transport, emissions come primarily from road freight and aviation.

Figure 6.4-3: Comparison of scenarios: Options without CCS, total greenhouse gas emissions, divided into energy-related and non-energy-related emissions, 1990 – 2050, in million metric tons of CO_2 equivalent

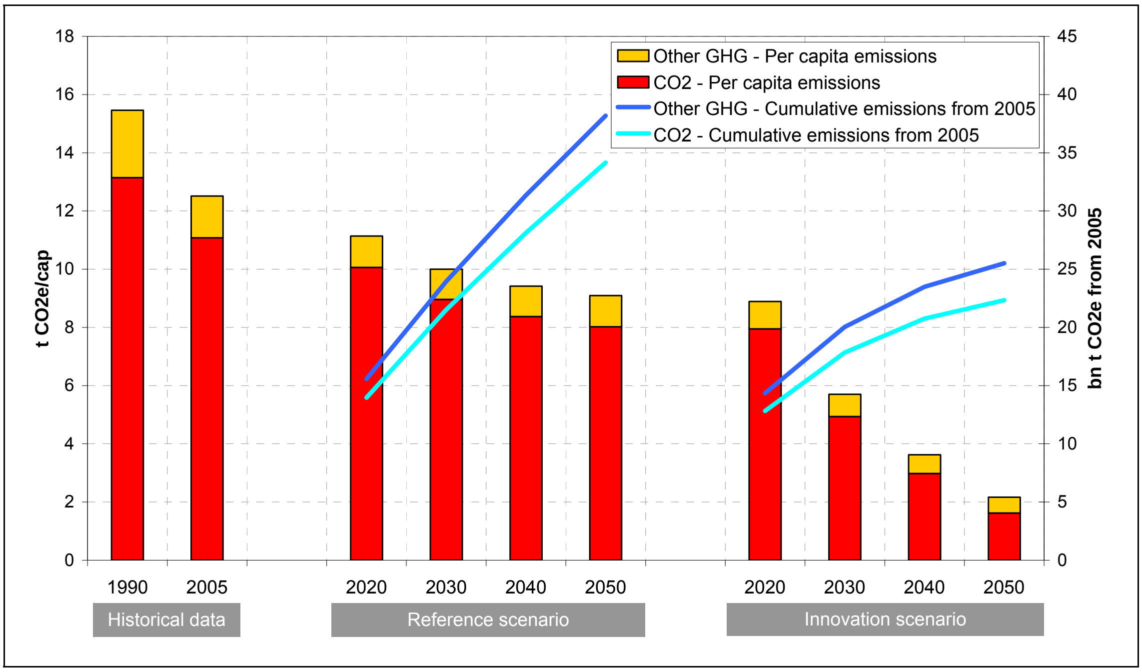


Source: Prognos / Öko-Institut 2009

Both per capita emissions and cumulative greenhouse gas emissions (since 2005) are important indicators in categorising scenario results. Per capita emissions, and their development over time, are a robust indicator of whether emission mitigation efforts are being allocated properly. By contrast, cumulative greenhouse gas emissions provide a precise measure of various polluters' share in global warming, and their contributions to the efficacy of a climate protection strategy. Figure 6.4-4 clarifies the fundamentally different development tracks of greenhouse gas emissions.

In the reference scenario, per capita emissions decrease to 9.1 metric tons of CO_2 equivalent by 2050. This represents a reduction in specific emissions of about 41% from 1990. The overview makes clear once again that the major reductions occur in CO_2 emissions; changes in other greenhouse gases are small. Cumulatively over the period from 2005 to 2050, total greenhouse gas emissions come to more than 38 billion metric tons of CO2 equivalent; CO_2 emissions come to about 34 billion metric tons. Based on a carbon budget of about 800 billion metric tons of CO_2 or 1,230 billion metric tons of CO_2 equivalent for the period from 2005 to 2050, Germany alone would take up a rather significant share of the entire remaining emission budget compatible with limiting global warming to less than 2ºC.

Figure 6.4-4: Comparison of scenarios: Emissions per capita and cumulative emissions (from 2005 onwards), 1990 – 2050



Source: Prognos / Öko-Institut 2009

The drastic emission reductions by 2050 in the innovation scenario result in per capita emissions of 1.6 metric tons of CO_2 and 2.2 metric tons of CO_2 equivalent of total greenhouse gases. This is equivalent to an 86% reduction from 2005. But looking at cumulative emissions, the necessary transition process in the development of greenhouse gas emissions leads to far less massive decreases. In the period from 2005 to 2050, about 22 billion metric tons of CO_2 are emitted in the innovation scenario. The value for all greenhouse gases is 25.5 billion metric tons of CO_2 equivalent. Thus for the full scenario period, about 35% less CO_2 and 33% less greenhouse gases are emitted in the innovation scenario than in the reference scenario.

The emission base up to 2020 makes such a large contribution to cumulative total emissions until 2050 that it underscores the great importance of not just massive, but fast emission reductions. Thus in a climate policy assessment of emission paths, central importance must be given not just to the emission reductions achieved by a given year, but also to the cumulative emissions, and thus the trajectories of emission reduction.

6.5 Added costs and cost savings

The added cost to the economy of the innovation scenario compared to the reference scenario is estimated at the sector level. For this purpose the investments needed for implementation, plus financing costs, are determined over service life. These investments are countered by avoided costs of energy-source transport, especially for petroleum products and natural gas, as savings to the economy. In general, added costs are estimated conservatively on the high side.

For power generation, full costs of production are compared between the two scenarios. These costs include fuel cost. Duplications of avoided energy-source imports are eliminated.

6.5.1 Added cost in the residential sector

Additional investments occur in three areas of the residential sector:

- For higher thermal insulation standards of buildings, in both new buildings and upgrades;
- For generating heat from renewable energy sources;
- For appliances that use electricity more efficiently.

The increase in thermal insulation standards for buildings is estimated as a mean added cost referred to living space. For new buildings, it is currently assumed that the added cost of implementing a highly energy-efficient standard (about 30 kWh/m^2/yr, all the way to a passive house standard) will add about 8 to 10% to construction costs. For a mean construction cost of EUR 1,100 – 1,250 / m^2 the resulting added cost is about EUR 100 / m^2. It should be pointed out that costs may diverge widely depending on both building type and region, and that the figures mentioned here are upper ends of a broad mean range. The innovation scenario assumes that the goal of zero-emission buildings is adopted as a policy goal at an early date, and is assisted with appropriate research. For that reason, it can be assumed that the specific added cost can be reduced over time thanks to appropriate materials and construction techniques (modularisation, prefabrication, etc.) and qualification of the participating tradespeople. Moreover, standards gradually become more rigorous in the reference scenario as well, so that the energy difference in new buildings between the two scenarios decreases.

In energy upgrades of existing buildings, two effects must be taken into account. First, energy standards for upgrades are tighter in the innovation scenario than in the reference scenario. This results in cost differences due to energy. These may diverge considerably depending on building age, project complexity, and the structural and energy condition of the building before and after; the literature and experts indicate a range of about EUR 20 – 44 / m^2. This represents about 15 – 35% of the total renovation cost. As a mean, once again at the upper end of the range, we initially assume EUR 35 / m^2. When the “second wave” of upgrades begins around 2035, they will start with a better initial level all around, in terms of both structure and energy, so the specific costs can be assumed to be lower.

The second aspect of upgrades is the doubling of the upgrade rate, so that demand for space heating is almost eliminated in the entire building stock by about 2050. The additional full costs associated with the additional upgrades compared to the reference scenario are attributed to the innovation scenario. In practical terms, these are the full upgrade costs for half of the inventory. Here too, there is a very great range in full cost, between EUR 150 and 500 / m^2. As an "upper mean" we adopt EUR 300 / m^2 for our estimates here. Due to the complexity and variability of the existing buildings, as already discussed above, we do not expect renovations to see the kinds of systematic cost decreases that will occur in new buildings; for that reason, specific full and added costs of upgrades are kept constant.

The resulting "pure" energy-related investments are then annuitised at an economic interest rate of 1.5% p.a. over the service life of the work (annual instalments), and integrated so they can be compared later with savings.

It should be pointed out that the added investment cost taken into account here will occur irrespectively of whether the cost can pay for itself in individual cases, from the decision-maker's perspective, by way of saving on energy costs or raising rents. The range in regard to this individual cost-effectiveness is very broad (see box), and depends heavily on the decision-maker's own economic rationality and on the general circumstances.

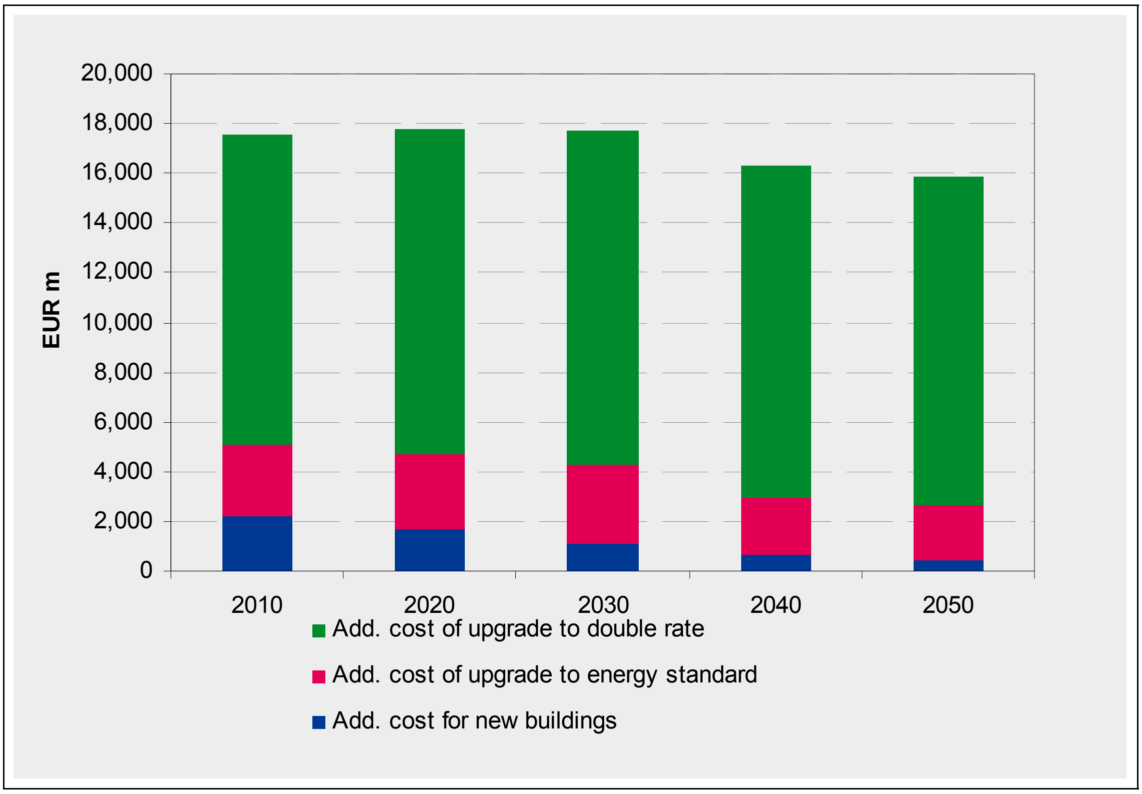
The added cost pool calculated in this way is shown in Table 6.5-1 and in Figure 6.5-1 and Figure 6.5-2.

Table 6.5-1: Energy-related added cost in housing sector and determining factors, 2010 – 2050

	Unit	2010	2020	2030	2040	2050
Residential buildings						
New buildings	million m2	21.9	18.9	15.4	11.4	9.2
Existing buildings	million m2	3,328	3,485	3,583	3,576	3,525
Specific additional costs						
Specific add. cost for new buildings	EUR/m2	100	90.4	73.9	60.3	49.3
Specific add. cost for upgrades	EUR/m2	35	35	35	25	25
Specific full cost of upgrades (normal)	EUR/m2	300	300	300	300	300
Investment						
Add. cost for new buildings	EUR m	2,190	1,705	1,141	690	454
Add. cost of upgrade to energy standard	EUR m	2,912	3,049	3,135	2,235	2,203
Add. cost of upgrade to double rate	EUR m	12,482	13,068	13,436	13,409	13,219
Total	EUR m	17,584	17,822	17,712	16,334	15,876
Total annual instalments (25 annual, flat rate)	million €	1,172	13,069	17,712	16,334	15,876
Total annuitised annual installment	EUR m	1,260	14,049	19,039	17,558	17,066

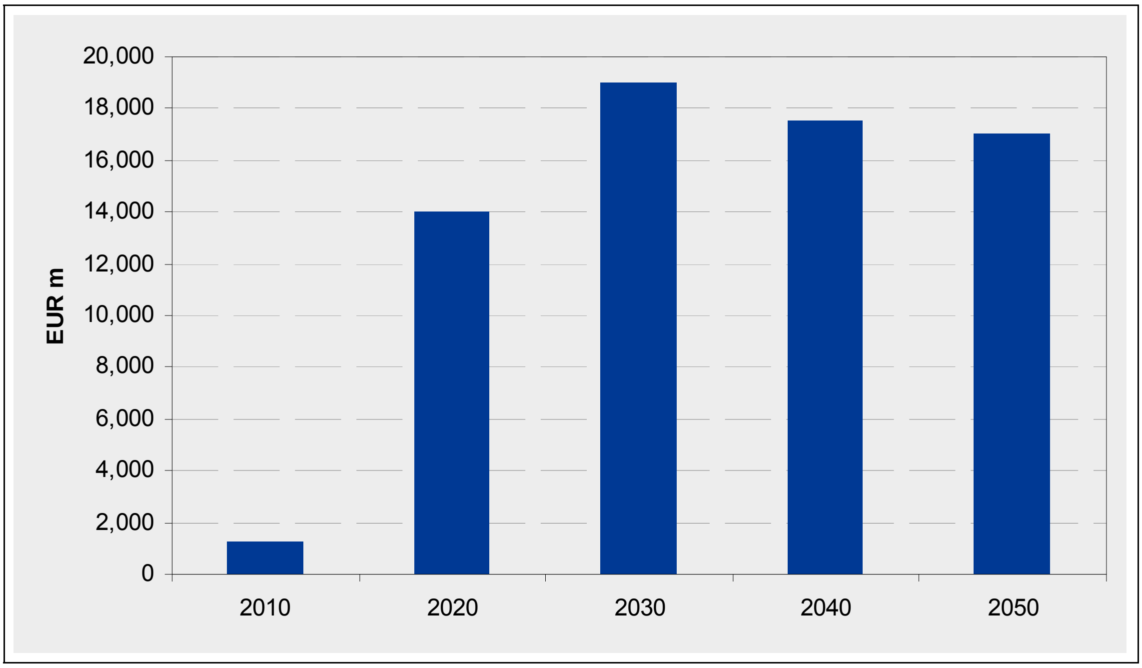
Source: Prognos 2009

Figure 6.5-1: Energy-related annual new investment to reduce space heating in the residential sector, by type of use, 2010 – 2050, not annuitised, in EUR million



Source: Prognos 2009

Figure 6.5-2: Energy-related investment to reduce space heating, 2010 – 2050, annuitised, in EUR million



Source: Prognos 2009

The additional cost comes to nearly EUR 20 billion a year. In the annuitised consideration, it should be taken into account that additional costs will still arise after 2050, albeit to a slowly declining degree.

In **heat generation** for space heating and hot water, the differences in the use of renewable sources – solar heat and ambient heat (heat pumps) – will increase costs for the innovation scenario compared to the reference scenario. The mean heat production costs assumed here are levels for a mix of small and large systems with moderate cost declines, based on the studies by Nitsch [Nitsch/DLR 2007]. The same levels were used in the energy scenarios [Prognos 2007b]. These are to be understood as full costs, including finance costs. Cost decreases are assumed to be rather moderate. For solar heat, it is assumed from 2025 onwards that the technology will be mature and achieve high market penetration, and will permit no further cost decreases; the same is assumed for heat pumps as early as 2020. There is less use of ambient heat and heat pumps in the innovation scenario than in the reference scenario, because of the reduction in demand for space heating. The result will be a reduction in costs. In the case of solar heat, a large share will be used for hot water heating, so that a “base” of additional consumption will remain.

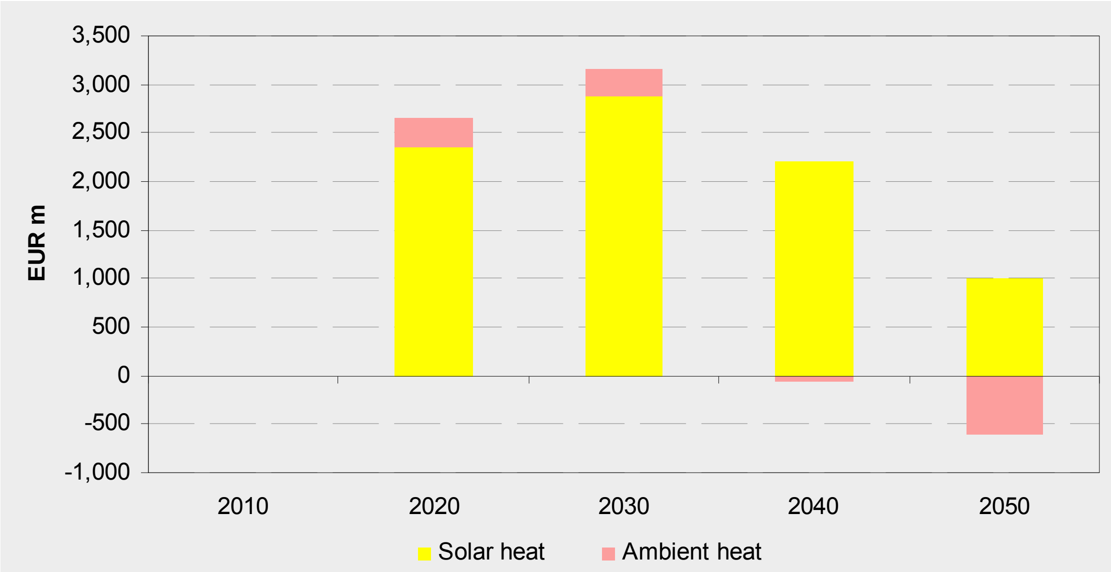
The associated added costs and cost savings are shown in Table 6.5-2 and Figure 6.5-3. The additional costs come to more than EUR 3 billion per year, and gradually decrease from 2030 onwards because of the reduction in demand for space heating.

Table 6.5-2: Energy-related additional costs and savings for renewable energy generation in the housing sector, and their determining factors, 2010 - 2050

		2010	2020	2030	2040	2050
Difference in final energy consumption – Innovation / Reference						
Solar heat	PJ	0	80	127	97	44
Ambient heat	PJ	0	13	13	-3	-29
Specific cost – Solar heat	EUR / kWh	0.18	0.11	0.08	0.08	0.08
Specific cost – Ambient heat	EUR / kWh	0.10	0.08	0.08	0.08	0.08
Spec. costs solar heat	million €/PJ	49.167	29.438	22.778	22.778	22.7785
Spec. costs environm. heat	million €/PJ	28.889	23.604	20.91	20.91	20.9097
Additional cost of heat from renewables, annual instalments						
Solar heat	EUR m	0	2,350	2,889	2,202	997
Ambient heat	EUR m	0	306	269	-63	-599
Total	**EUR m**	**0**	**2,656**	**3,157**	**2,138**	**398**

Source: Prognos 2007, Nitsch/DLR 2007, Prognos 2009

Figure 6.5-3: Energy-related additional costs and savings for renewable heat generation in the housing sector, in EUR million



Source: Prognos 2009

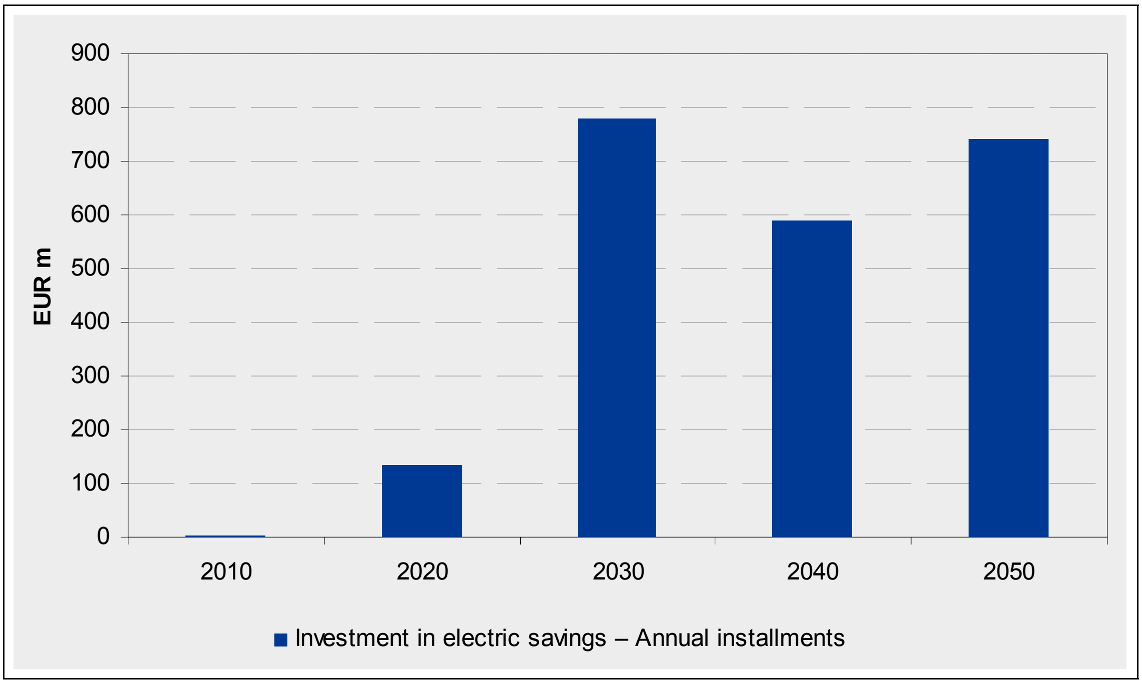
The added costs associated with saving electricity are more difficult to estimate. Current electricity-saving technologies are sometimes highly economical compared to less electricity-saving applications in lighting, appliances, ICT, etc., with amortisation times of one to two years (lighting, video screens); in other cases, the amortisation periods are longer (e.g. refrigerators, heat-pump washer-dryers), and in still others, the additional cost cannot be recovered out of savings within the equipment's service life. In the case of new technologies that have not yet achieved market maturity, such as waterless washing machines, magnetic refrigerators, viewer technology, or new light sources, it is almost impossible to weight added costs and cost savings against one another. For that reason, we use the "applicable cost" method here: we assume that as a consequence of development efforts and economies of scale, electricity-saving technologies will be allowed an average of about five years of amortisation time to get established in the market. There will also be a number of technologies that have substantially shorter amortisation times (such as lighting, viewers instead of screens, building automation) because of miniaturisation, automation, and changes in materials. This assumption is used to determine the permissible investment "instalments" (with financing costs, annuitised) for each case from the annual changes in savings between the scenarios. The savings and investments in annual instalments are shown in Table 6.5-3 and Figure 6.5-4.

Table 6.5-3: Electricity savings and investments for electricity savings in the residential sector, 2010 – 2050

		2010	2020	2030	2040	2050
Saving between Innovation and Reference	PJ	0.0	-1.3	18.0	57.9	80.6
Total annual investment instalments incl. cost of capital for 5 years						
Investments annuitised	million €	2	133	780	590	740

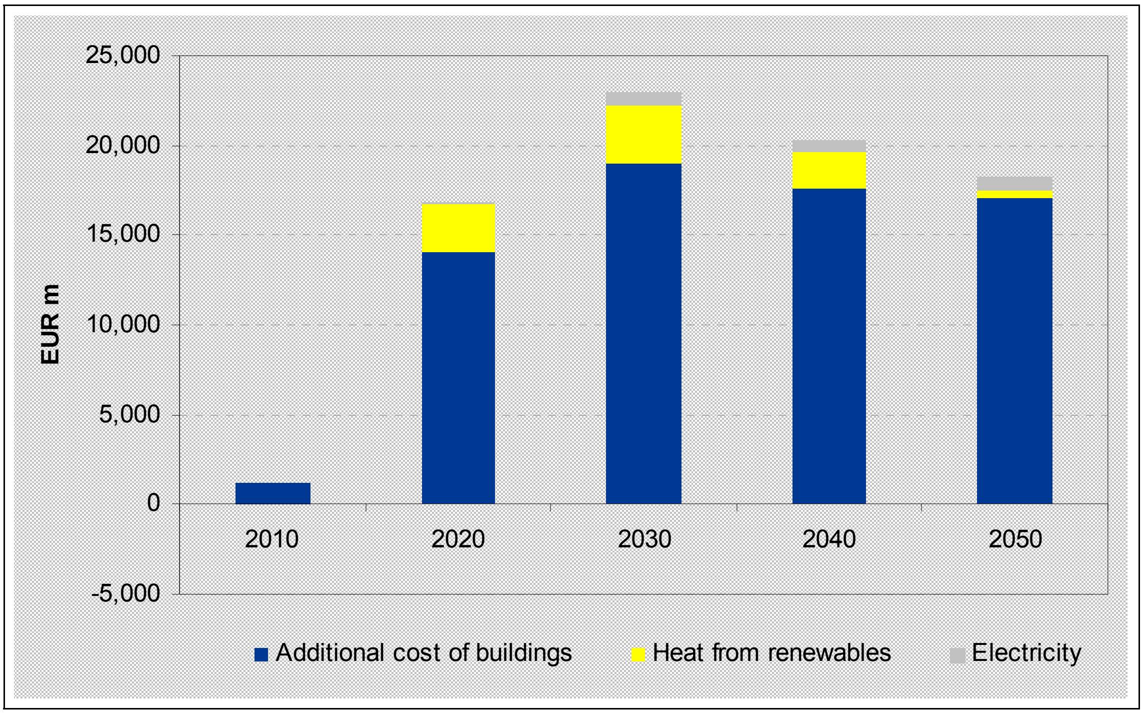
Source: Prognos 2009

Figure 6.5-4: Investments for electricity savings in the residential sector, 2010 – 2050, in EUR million



Source: Prognos 2009

Figure 6.5-5: Additional investment for energy savings and heat from renewable energy sources (aggregate) in the residential sector, 2010 – 2050, in EUR million



Source: Prognos 2009

Total investments (in annuitised annual instalments) in the residential sector come to not more than EUR 23 billion in 2030 (see Table 6.5-5, Figure 6.5-5).

Table 6.5-4: Additional investment for energy savings and heat from renewable energy sources (aggregate) in the residential sector, 2010 – 2050, in EUR million

		2010	2020	2030	2040	2050
Additional cost of buildings	EUR m	1,260	14,049	19,039	17,558	17,066
Heat from renewables	EUR m	0	2,656	3,157	2,138	398
Electricity	EUR m	2	133	780	590	740
Total	EUR m	**1,262**	**16,837**	**22,977**	**20,287**	**18,204**

Source: Prognos 2009

6.5.2 Service and industry sectors

It is very difficult to estimate the added cost in the service and industry segments, because in general, investments in plants and equipment are subject to a production-oriented calculus more than an energy-oriented one. For that reason, here too we work with the “applicable cost” method. Even today, added costs for individual plant and equipment investments, referred purely to energy savings, are practically unknown. The exceptions occur in some cross-application technologies like electric motors, pumps and air compressors. But their involvement in plant and equipment technology is as diverse as the industries, production processes and companies themselves. In general, it can be assumed that energy-related or raw material-based investments and additional investments will be made only if they pay for themselves through savings within relatively short cycles. By implication, this means that the associated technologies will not have a chance of implementation through research efforts, market launches and economies of scale, unless they meet commensurately rigorous criteria of cost-effectiveness. To estimate the appropriate investments conservatively (i.e., on the upper side), and also to keep from running up the charges to these industries unrealistically high, a period of about 4 years is assumed for the equipment to pay for itself.

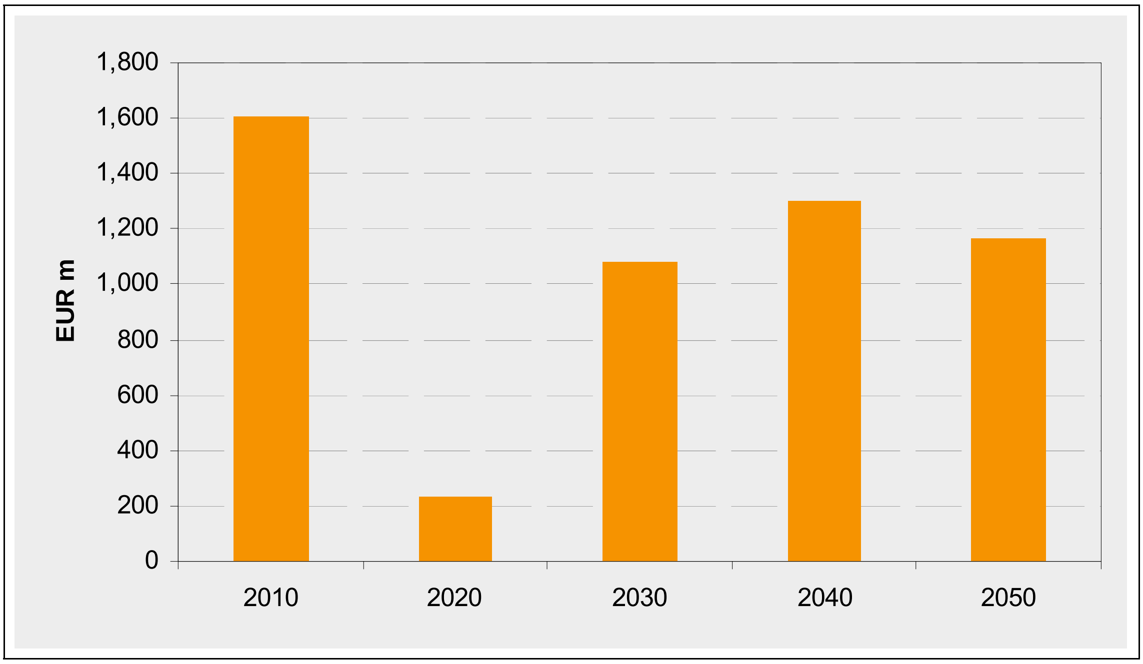
Annual investments are calculated on the basis of the annual additional savings on fossil energy sources and electricity, based in each case on mean consumer prices for the sector. “Negative savings” imply zero investments. The savings on energy sources and the consequent annuitised investments in the two sectors are shown in Table 6.5-5 and Table 6.5-6 and in Figure 6.5-6 and Figure 6.5-7.

Table 6.5-5: Savings and additional investment for energy savings in the service sector, 2010 – 2050

Service sector	Unit	2010	2020	2030	2040	2050
Savings on energy sources						
Coal	PJ	0	0	0	0	0
Oil	PJ	1	19	22	11	5
Gas	PJ	3	44	55	30	17
Electricity	PJ	11	62	116	183	210
Investments in services, annuitised	**EUR m**	**1,610**	**236**	**1,078**	**1,304**	**1,166**

Source: Prognos 2009

Figure 6.5-6: Additional investment for energy savings in the service sector, 2010 – 2050, in EUR million



Source: Prognos 2009

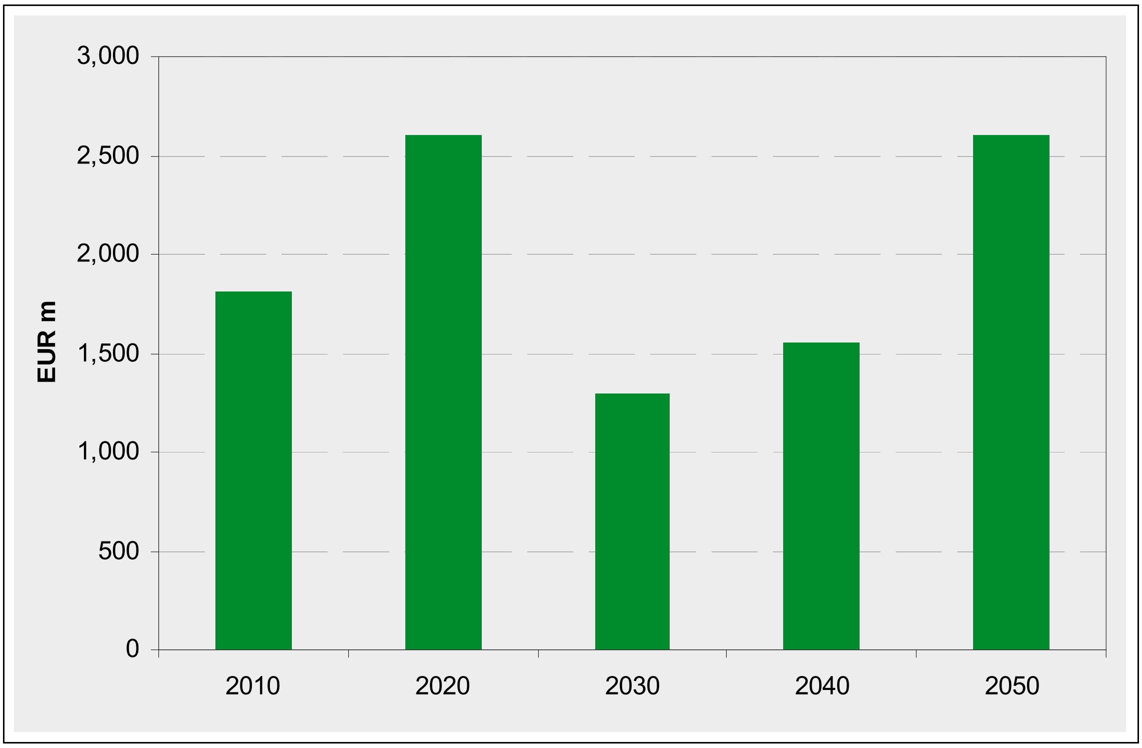
The additional annual savings result from several effects, some of them operating in contrary directions: the effects of industry structure, different "savings paces" for different energy sources, and substitution effects which especially benefit electricity and gas. Since the various energy sources are weighted at different prices, the cumulative annuitised investments do not run uniformly in one direction.

Table 6.5-6: Savings and additional investment for energy savings in the industry sector, 2010 – 2050

Industry sector	Unit	2010	2020	2030	2040	2050
Savings on energy sources						
Coal	PJ	15	55	75	86	92
Heating oil, light	PJ	5	19	23	22	18
Heating oil, heavy	PJ	4	16	18	17	15
Natural gas	PJ	43	183	240	258	252
Electricity	PJ	45	191	257	281	281
Investments in industry, annuitised	**EUR m**	**1,816**	**2,608**	**1,299**	**1,557**	**2,600**

Source: Prognos 2009

Figure 6.5-7: Additional investment for energy savings in the industry sector, 2010 – 2050, in EUR million



Source: Prognos 2009

In the industry sector, energy consumption and energy savings are considerably higher than in the service sector, but energy prices are lower, with a consequent impact on acceptable investments. Thus the various investments for energy savings in the two sectors are of similar orders of magnitude, and in any case in the lower single-digit billions.

6.5.3 Transport sector

In the transport sector, three main factors play a role in distinguishing the scenarios:

- The changeover of passenger cars to electricity,
- Greater use of rail for freight transport,
- The changeover to biofuels.

The last point does not result in an added cost compared to the reference scenario, since even that scenario assumes that processes will be developed for the industrial-scale use of biofuels, and will be available to the market, albeit to a lesser degree. The greater amounts in the innovation scenario, combined with the high prices of oil and motor fuels towards the end of the study period, mean that cost neutrality is assumed here.

The added cost of electric mobility is estimated on the high side, on the basis of today's cost differences in available vehicles (according to information available to the public from the automotive industry), with declining costs. Today's electric vehicles are around 60 to 65% more expensive than conventional vehicles in the same class (e.g., the Lotus Elise, EUR 55,000; Tesla Roadster, EUR 90,000; analogous considerations apply for the Polo class). A large portion of this added cost is associated with the small volumes in which these vehicles are produced at present. If electric vehicles become established with transitional forms like plug-in hybrids, etc., it can be assumed that the cost differences will become less and gradually vanish, because the technology as a whole will become simpler and more manageable (no more combustion, lower volumes occupied by drive equipment, easier steering). The innovation scenario assumes that the added cost will decrease up to 2045 and be zero thereafter. In regard to the introduction of electric vehicles, we assume that the small-vehicle classes will be more often "electrified" at first, until the proportions among vehicle classes even out around 2040.

Thus a mixed calculation yields a mean additional price per vehicle that declines (in real terms) from EUR 12,800 in 2020 to EUR 2,500 in 2040. In an annuitised computation equivalent to the previous considerations (in annual instalments over 10 years), the added costs for 2020 to 2050 are as shown in Table 6.5-7.

Table 6.5-7: Additional cost of electric vehicles, with determining factors, 2010 – 2050

		2020	2030	2040	2050
Avg. add. cost per electric car, annuitised	EUR	1,281	769	256	0
No. of electric vehicles	000	499	4,182	12,975	21,041
Added cost of cars	EUR bn	0.6	3.2	3.3	0.0

Source: Prognos 2009

In addition, a filing-station infrastructure must be set up. We assume that the existing infrastructure can be used and expanded or adapted for this purpose – in other words, it will not be necessary to build significantly more electric filling stations than there are currently filling stations for conventional motor fuels. Assuming about EUR 25,000 per filling station per year (i.e., an investment of about EUR 250,000 over ten years, which we consider generous), this means an added cost of EUR 300 million per year for the 13,000 filling stations that are assumed for the future in Germany.

The added cost for the greater use of rail for freight transport is difficult to estimate. Since we assume no large-scale rail infrastructure will be installed, and that investments will go primarily into controls, passing tracks, higher utilisation of capacity, and possibly loading and unloading structures, we initially set these investments at about EUR 1.5 billion per year. This is equivalent to about 60% of the funds provided annually by the federal government for maintaining and updating the existing network [BMVBS 2009].

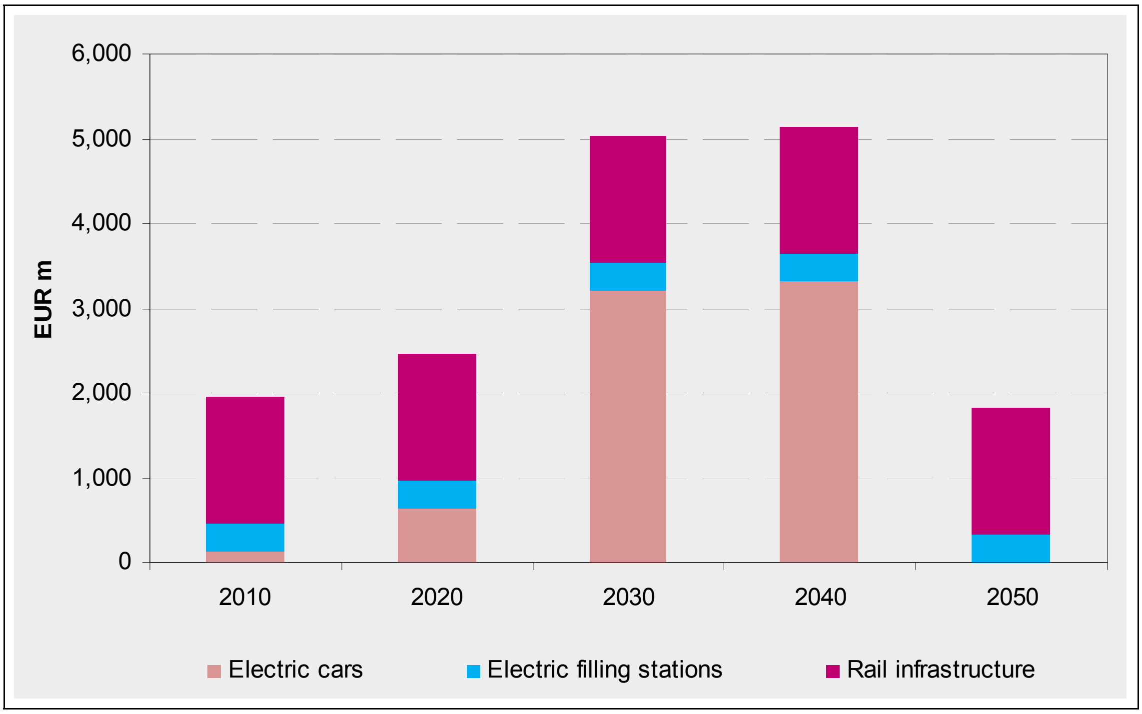
All together, the total added cost in the transport sector will be at most a solid EUR 6 billion in 2035.

Table 6.5-8: Additional investment in the transport sector, 2010 – 2050, in EUR million

		2010	2020	2030	2040	2050
Electric cars	EUR m	128	639	3,216	3,325	0
Electric filling stations	EUR m	325	325	325	325	325
Rail infrastructure	EUR m	1,500	1,500	1,500	1,500	1,500
Total	**EUR m**	**1,953**	**2,464**	**5,041**	**5,150**	**1,825**

Source: Prognos 2009

Figure 6.5-8: Additional investment in the transport sector, 2010 – 2050, in EUR million



Source: Prognos 2009

6.5.4 Added cost in all demand sectors

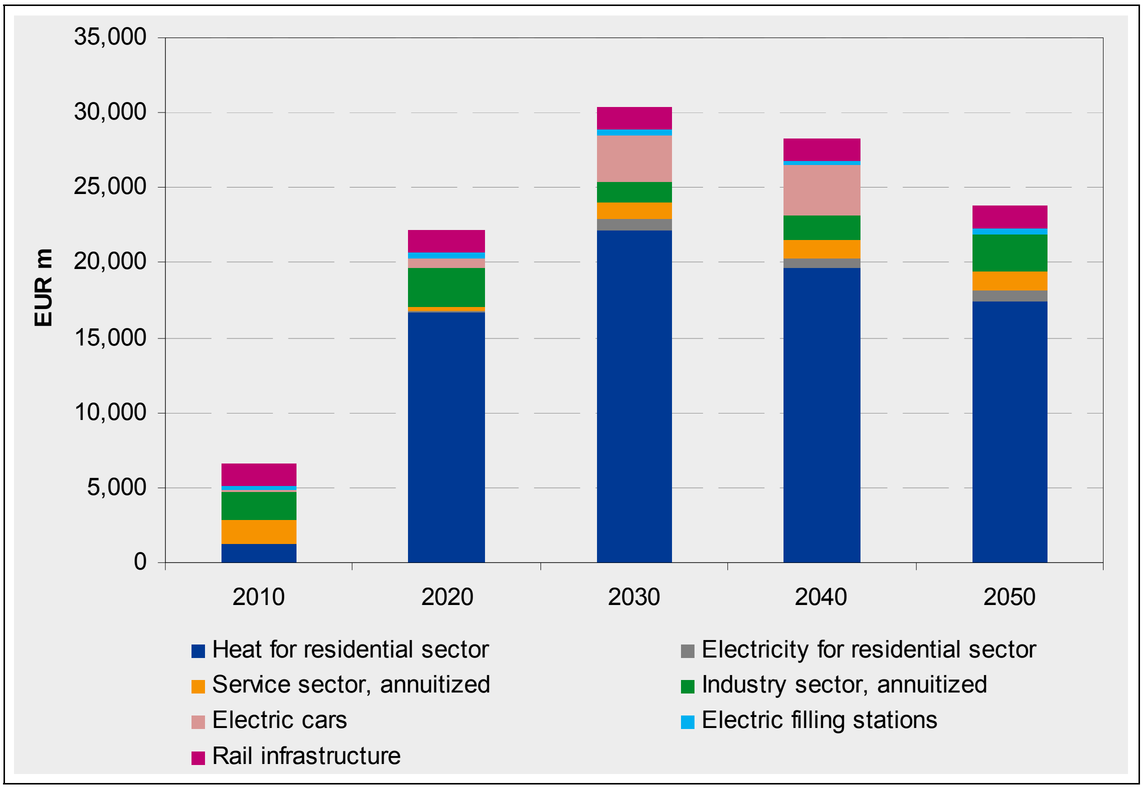
Totaled for all sectors, therefore, the annual added cost is no more than EUR 30.4 billion in 2030 (Table 6.5-10, Figure 6.5-10 and Figure 6.5-11).

Table 6.5-9: Additional investment in all sectors, 2010 – 2050, in EUR million

		2010	2020	2030	2040	2050
Heat for residential sector	EUR m	1,260	16,704	22,197	19,696	17,464
Electricity for residential sector	EUR m	2	133	780	590	740
Total	EUR m	1,262	16,837	22,977	20,287	18,204
Service sector, annuitised	EUR m	1,610	236	1,078	1,304	1,166
Industry sector, annuitised	EUR m	1,816	2,608	1,299	1,557	2,600
Electric cars	EUR m	128	639	3,216	3,325	0
Electric filling stations	EUR m	325	325	325	325	325
Rail infrastructure	EUR m	1,500	1,500	1,500	1,500	1,500
Total	**EUR m**	**6,641**	**22,145**	**30,395**	**28,297**	**23,796**

Source: Prognos 2009

Figure 6.5-9: Additional investment in all sectors, 2010 – 2050, in EUR million



Source: Prognos 2009

The sector comparison clearly shows that the building segment (due to the full cost of greater upgrades) represents the largest share of added investments. Electric mobility likewise represents a significant cost factor in these segments in the period from 2020 to 2040. Here instruments and mechanisms (including intertemporal mechanisms) are needed to enable these measures to be implemented without major upheavals.

6.5.5 Counter-items: Savings and net costs

The investments calculated according to criteria of the general economy are countered by savings due to lower imports of fossil energy sources and savings on the full cost of power generation (power plants not built, owing to lower demand). The savings to the economy on fossil energy sources are valued at cross-border prices. All other price components, such as margins, refining, taxes and transport costs are redistributions from the viewpoint of the economy as a whole, and represent no net cost to the economy. The full cost of power generation takes account of plant and equipment investments, including financing, operating costs and fuel costs. Storage costs are calculated as plant and equipment costs, and are estimated on the high end, using the production cost of peak energy at gas power plants. Loads taken off the grid are not taken into account.

The resulting savings are shown in Figure 6.5-10 and Figure 6.5-11 and in Table 6.5-10.

The comparison of added costs and savings yields a maximum net added cost of about EUR 15 billion in 2024. From 2044 onwards, the savings exceed the added costs (Table 6.5-11, Figure 6.5-12).

Table 6.5-10: Savings to the economy, 2010 – 2050, in EUR million

Savings on energy sources		**2010**	**2020**	**2030**	**2040**	**2050**
Oil	EUR m	189	4,416	10,407	13,042	13,489
Gas	EUR m	305	2,808	4,101	4,120	4,031
Coal	EUR m	34	155	282	434	622
Savings on full cost of power generation						
Electricity w/o CCS	EUR m	451	4,330	3,520	5,732	10,807
Electricity w/ CCS	EUR m	390	4,330	4,953	7,478	12,006
Total w/o CCS	**EUR m**	**979**	**11,710**	**18,310**	**23,328**	**28,949**
Total w/ CCS	**EUR m**	**918**	**11,710**	**19,743**	**25,074**	**30,148**

Source: Prognos 2009

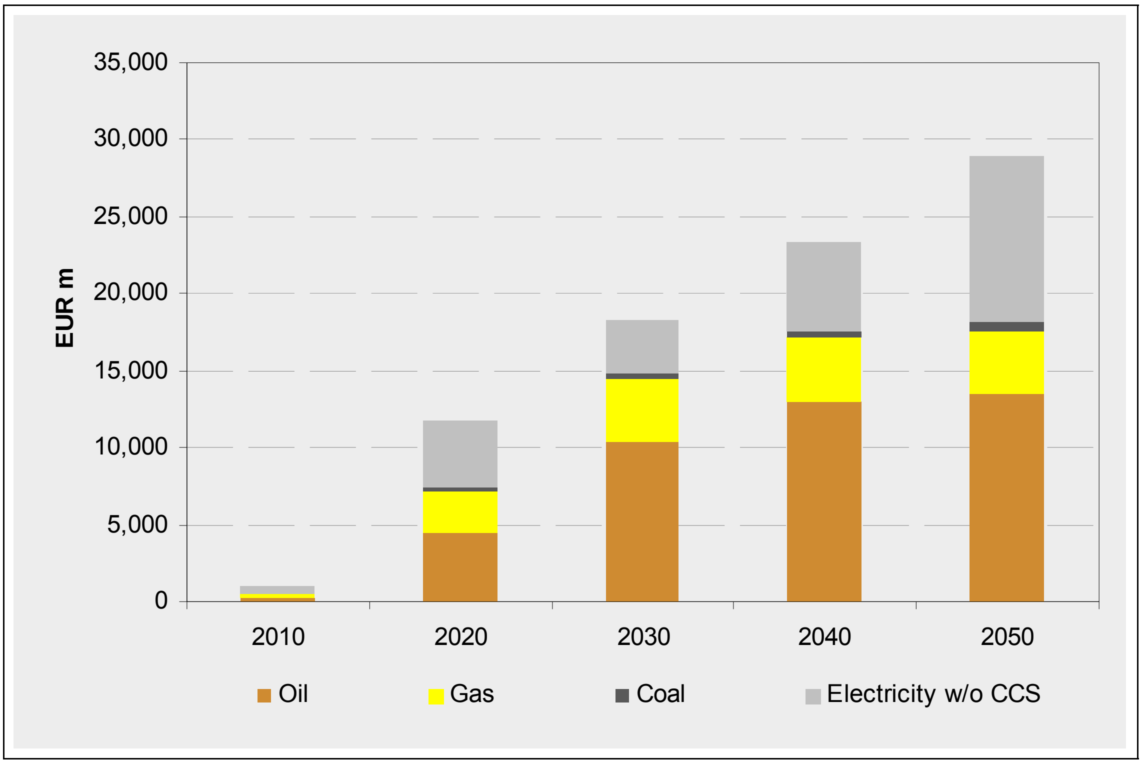
Table 6.5-11: Investments, savings to the economy, net result with and without CCS, 2010 – 2050, in EUR billion

		2010	**2020**	**2030**	**2040**	**2050**
Investments	EUR bn	6.6	22.1	30.4	28.3	23.8
Savings w/o CCS	EUR bn	-1.0	-11.7	-18.3	-23.3	-28.9
Savings w/ CCS	EUR bn	-0.9	-11.7	-19.7	-25.1	-30.1
Resultant w/o CCS	EUR bn	5.7	10.4	12.1	5.0	-5.2
Resultant w/ CCS	EUR bn	5.7	10.4	10.7	3.2	-6.4

Source: Prognos 2009

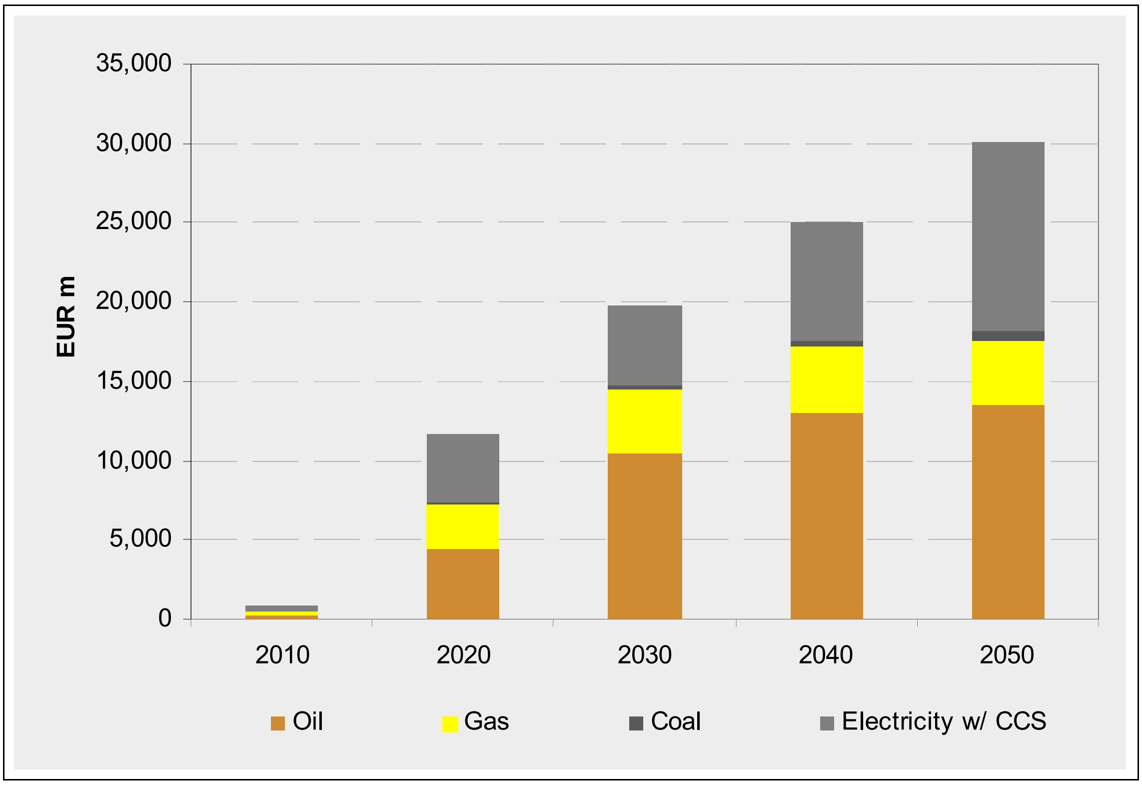
Referred to GDP, the resulting maximum net charge is 0.62% in 2024. Referred to the entire study period, the additional emission reduction in the innovation scenario (integrated and discounted) is associated with net additional costs of 0.3% of GDP.

Figure 6.5-10: Savings to the economy, options without CCS, 2010 – 2050, in EUR million



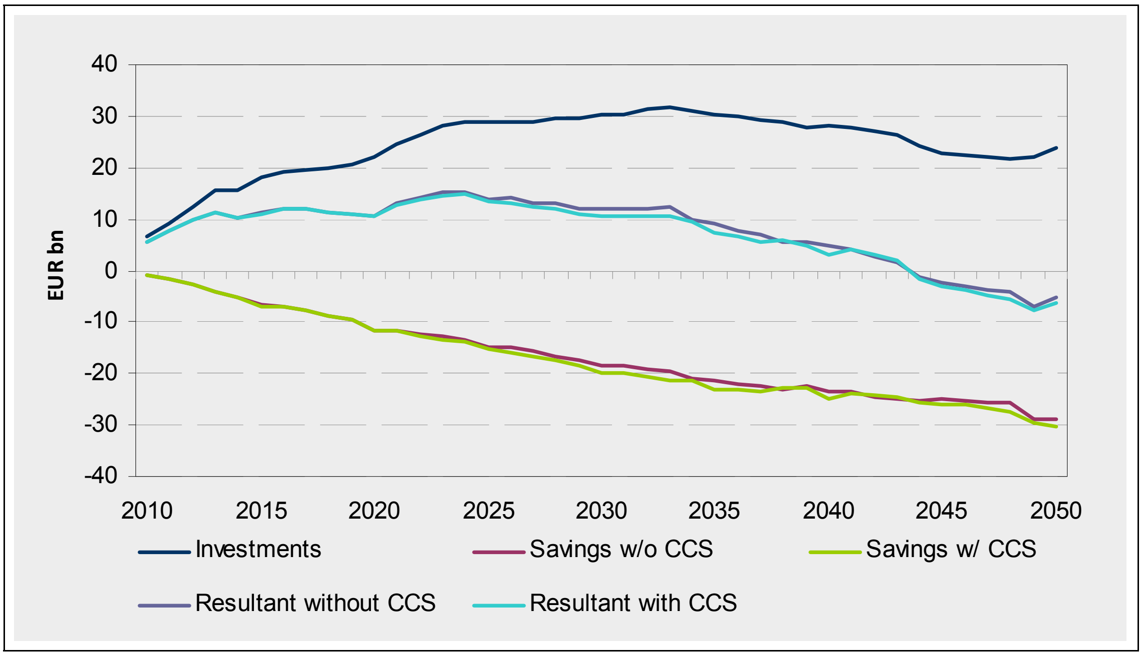
Source: Prognos 2009

Figure 6.5-11: Savings to the economy, options with CCS, 2010 – 2050, in EUR million



Source: Prognos 2009

Figure 6.5-12 *Added cost to the economy, savings with and without CCS, and net cost, 2010 – 2050, in EUR billion*



Source: Prognos 2009

III Conclusions and recommended action

7 Decomposition analysis and target achievement for the development of greenhouse gas emissions in Germany

7.1 Opening remarks

The detailed analyses carried out for the reference and the innovation scenarios have shown that substantial reductions of greenhouse gas emissions are technically and economically possible and can be achieved on the basis of very ambitious climate protection targets. However, analysis of the data also makes clear that substantial developments and progress are required in terms of the policy framework as well as technically, economically, structurally, and otherwise for it to be possible to meet ambitious targets of this kind in the comparatively short time frame of four decades.

In the following, starting points and the results of two analytical steps are shown.

Firstly, a decomposition analysis is carried out to identify and quantitatively assess the key starting points for the re-organisation of the German energy system along with other starting points for the industry sectors that are particularly important sources of greenhouse gas emissions. Through this analysis the contributions to emission reduction of different approaches of energy and climate policy are quantified. These contributions can then be analysed from different perspectives in order to determine more precisely the significance of, for example, time and innovation factors in the context of emission reduction strategies.

Secondly, a number of first, additional analyses are undertaken to address the question of how the reduction efforts of the strategies modelled in the innovation scenario can be made even stronger. In the foreground three questions are examined, namely what the starting points are for closing existing gaps between the emission reductions achieved in the innovation scenario and the long-term climate protection target of a 95 % reduction compared to 1990 levels; what further potentials for emission reductions could be tapped; and what implications such additional measures have.

The analyses presented in this chapter predominantly focus on the question of what insights and findings can be drawn from the scenario and data analyses in terms of strategies and policy instruments.

7.2 Decomposition analysis for the scenarios

7.2.1 Opening remarks on methodology

A sector-specific decomposition analysis forms the basis of the analyses that follow. Using such a methodology, historical developments and the results of detailed sector modelling of greenhouse gas emissions can be "decomposed" with a view to different impact mechanisms (so-called "decomposition analysis").

On the basis of decomposition analysis greenhouse gas developments can be accounted for using so-called social and economic drivers and efficiency and decarbonisation indicators. In this way, decomposition analysis shows which shares of a particular emission development are to be attributed to which different factors of influence. It also enables counter-productive or increasing impact mechanisms to be identified and interaction effects to be reduced. Finally, the decomposition analysis can also be used to make approximate first estimations of possible emission developments for the various options within the context of different impact mechanisms.

For the decomposition analysis presented here, analyses were carried out for the following five sectors and sub-sectors or energy use areas in Germany:

1. Residential sector
   - Existing buildings
   - New buildings
   - Hot water
   - Cooking
2. Service sector
   - Room heating
   - Process heat
   - Non-electric drives
3. Transport
   - Passenger cars
   - Public passenger transport
   - Freight transport by road
   - Freight transport by rail
   - Domestic maritime transport

- Aviation

4. Industry

5. Electricity production

For each of these sectors or areas, the trends of energy-related emissions in the reference and innovation scenarios were analysed in terms of their contributions to the following components:

1. Demand

   - social and economic activities (living space, value added, transport volume, etc.)

   - electricity demand (as a driver of electricity production)

2. Energy productivity (as a measure of the development of energy efficiency in the different sectors or areas)

3. Share of renewable energies (both in the sectors and electricity production)

4. Electrification (option of emission shift from consumption sectors to electricity production)

5. District and local heat (option of emission shift from consumption sectors to the energy transformation sector)

6. Hydrogen (option of emission shift from consumption sectors to the energy transformation sector)

7. Nuclear energy (only for the electricity production sector)

8. Fossil fuel change (in consumption sectors and electricity production)

A detailed description of the decomposition analysis methodology used here and the specific results of the decomposition analysis are provided in Annex F of this report.

The factors which tend to increase emissions (described in more depth in each case), the results of the reference and the innovation scenarios, and the quantification of components which substantially determine a change in emission development are shown and discussed.

7.2.2 Results of decomposition analysis for the German residential sector, with a focus on households

With regard to households in the German residential sector (referred to hereafter as “residential buildings”), it is necessary and helpful to differentiate first of all between two sub-sectors. In the subsequent analyses existing residential buildings are understood as buildings which were built prior to 2005. Of these existing buildings, a small share will be demolished in the coming decades; a larger share will continue to be used and, where appropriate, rehabilitated. New buildings are understood in the following as all residential buildings which were or are built from 2005 to 2050.

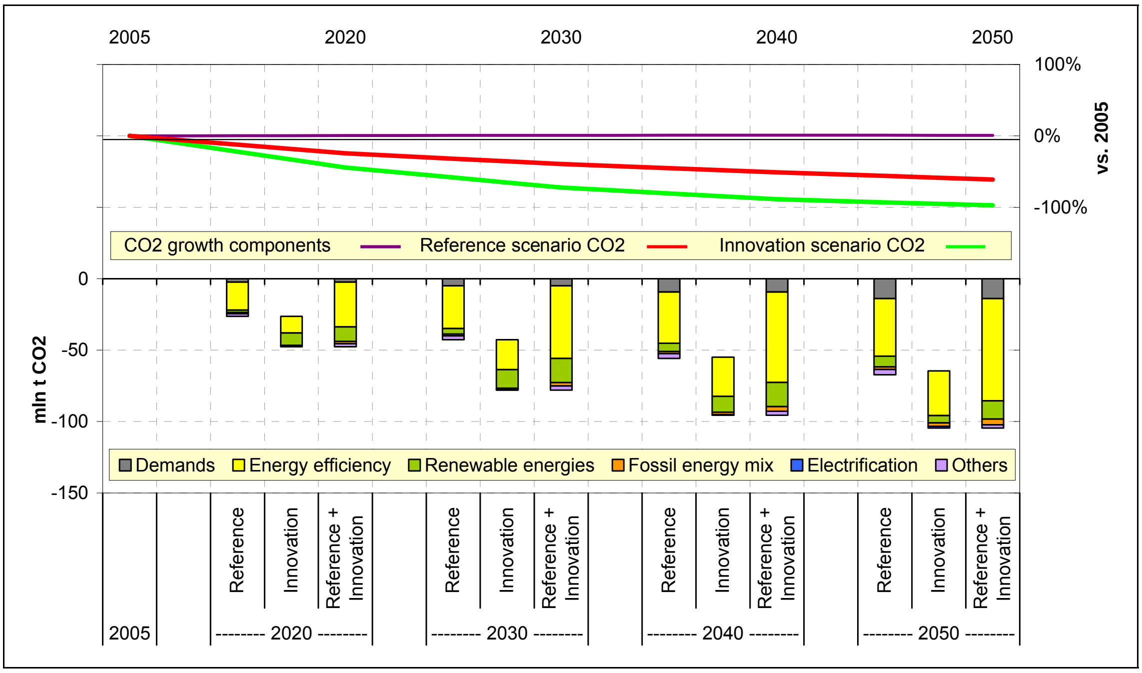
In Germany, existing buildings are an important sub-sector in terms of greenhouse gas emissions. In 2005 existing buildings gave rise to approx. 107 million t CO_2 emissions in Germany. Living space is reduced (as a key driver for emissions) in the scenario time frame from approx. 3.4 billion m^2 in 2005 to approx. 3 billion m^2 in 2050. However, existing buildings still have an 82 % share of the total living space in 2050. For existing buildings there are no growth components in the scenarios; therefore, all factors of influence have the effect of reducing the emissions of existing buildings. Overall, (direct) greenhouse gas emissions are reduced by more than 60 % in the reference scenario.

Figure 2.6-1 shows the impact of the components for the reference scenario. The contributions (columns) represent the total contribution to emissions reduction in Germany, which leads to the resulting CO_2 emission development in each scenario. The total contribution to emission reduction comprises both the emission reductions offset by hypothetical increases in emissions from 2005 onwards that are brought about by different growth components, and the contributions to emissions reduction which lead to the actual change in the emissions of each scenario compared to 2005 levels. The overview demonstrates that the emission reductions of existing buildings are predominantly determined by two components. Firstly the key demand factor – living space in Germany – decreases in the time period by approx. 13 %; secondly, there are substantial improvements to efficiency during this time as a result of rehabilitation measures. The final average energy demand per square metre of living space is reduced by approx. 50 % from 2005 to 2050. Renewable energies, fuel switch, etc. play only a secondary role for existing buildings in the reference scenario. Of the overall emission reduction in the 2005 - 2050 time period (which totals approx. 67 million t CO_2), approx. 21 % stems from the decrease of living space in existing buildings, approx. 60 % from improvements in energy efficiency and 11 % from the use of renewable energies.

In the innovation scenario increased rehabilitation in Germany will bring about a further emission reduction of approx. 40 million t CO_2 with the result that there is an overall emission reduction of close to 105 million t CO_2 in the 2005 - 2050 time period. This corresponds to a reduction of approx. 97 %, brought about by the additional effects of a further increase in energy efficiency and increased use of renewable energies in room heating. The relative energy consumption in existing residential buildings is reduced by 86 % up to 2050 in the innovation scenario; the remaining energy demand is covered by renewable energies (58 %) and grid-bound heat supply (district and local heat supply) (17 %).

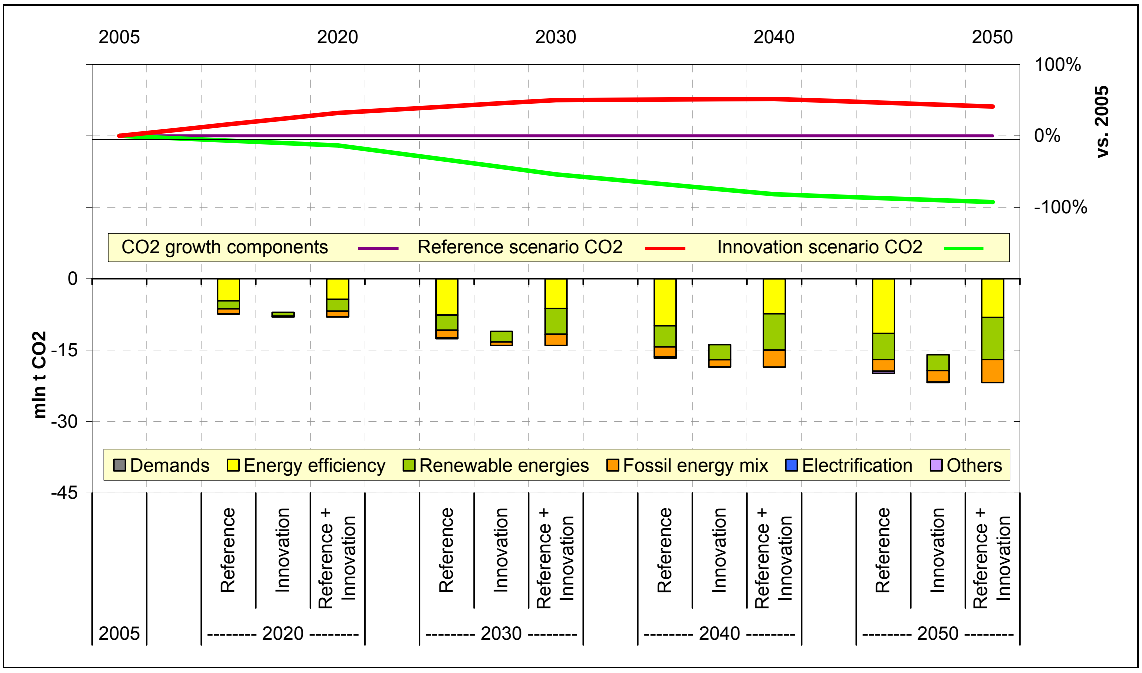
In the innovation scenario overall, the reduction of living space in existing residential buildings contributes approx. 13 %, increased energy efficiency approx. 69% and increased use of renewable energies approx. 12 %. Other impact components (grid-bound heat supply, etc.) do not play a significant role in terms of emission reduction. Finally, a huge increase in energy efficiency is the crucial determinant of the almost full-scale reduction of CO_2 emissions up to 2050 in this context.

Figure 7.2-1: Decomposition analysis for emission development in existing buildings in Germany, 2005 – 2050



Source: Öko-Institut 2009

Figure 7.2-2: Decomposition analysis for emission development of new buildings in Germany, 2005 – 2050



Source: Öko-Institut 2009

A very different situation arises for new residential buildings in Germany. The available living space in buildings built from 2005 onwards increases to approx. 670 million m^2 up to 2050. In the reference scenario there is significant emissions growth, amounting to 1.5 million t CO_2 in 2050. However, compared to existing buildings this emission volume is very low; in 2050 the emissions per square metre of living space amount – in the reference scenario – to a fraction (approx. 16 %) of comparable levels for existing buildings. A fundamental driver of the low level of greenhouse gas emissions of new buildings is the further significant increase in energy efficiency within the time period. Increased use of renewable energies for room heating also plays a significant role. Compared to the situation at the start of the scenario time period (2005) improved energy efficiency and the increasing share of renewable energies in the reference scenario facilitate an emission reduction of approx. 20 million t CO_2. The largest contributions to this (fictive) emission reduction are brought about by energy efficiency (58 %) and renewable energies (approx. 28%).

In the innovation scenario the CO_2 emissions of new buildings are reduced to 0.1 million t CO_2 up to 2050. The key driver of this reduction is above all the increased use of renewable energies, which are used to meet approx. 90 % of the remaining energy demand in the innovation scenario. Overall in this scenario, 37 % and approx. 40 % of the total emission reduction stems from increased energy efficiency and increased use of renewable energies respectively.

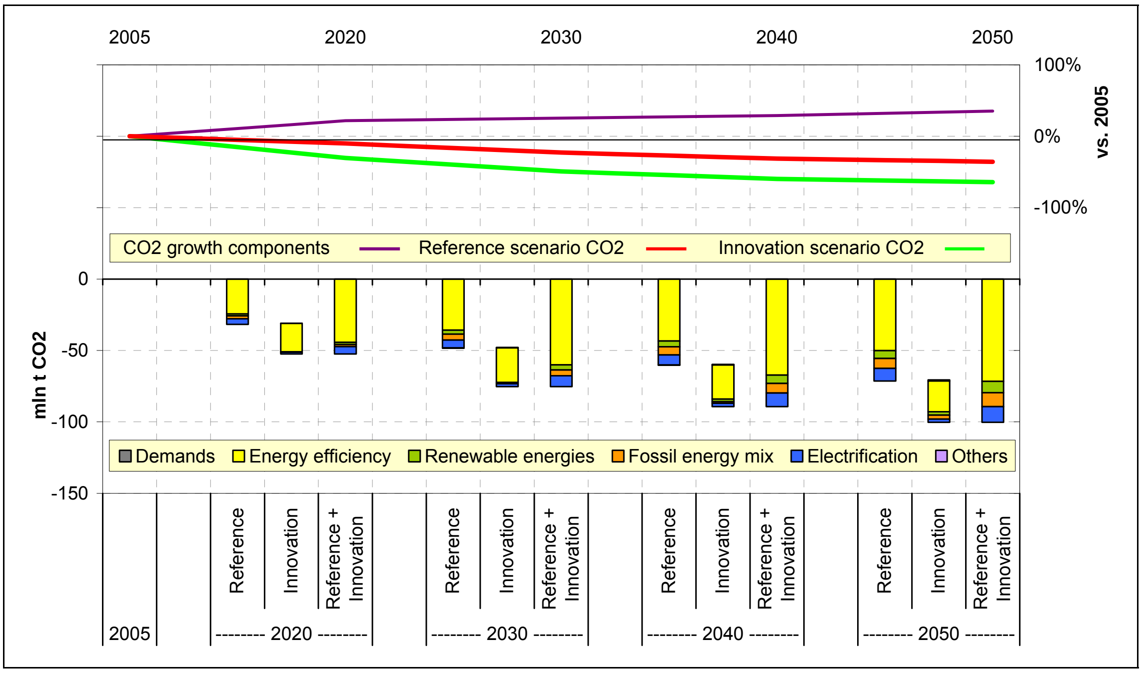
For the German residential sector overall, a huge increase in energy efficiency is decisive if the emission reductions of the innovation scenario are to be realised. Although the (relative) contribution of renewable energies increases somewhat in the comparison of the innovation and reference scenarios, it remains limited for residential buildings; renewable energies chiefly become significantly relevant when the emission reduction of new residential buildings is considered.

7.2.3 Results of decomposition analysis for industry in Germany (energy-related emissions)

In contrast to the residential sector, the significantly increasing value added is a huge growth driver for emissions in industry. If all other factors remained the same, the CO_2 emissions of industry in Germany in 2050 would be approx. 35 % above 2005 levels. An increase of this kind would have a quantitatively substantial effect in a sector which contributed approx. 101 million t CO_2 to the total greenhouse gas emissions in 2005. However, in the reference scenario CO_2 emissions are reduced by approx. 36 % to approx. 65 million t in the time period from 2005 to 2050. In the innovation scenario CO_2 emissions are reduced to approx. 36 million t up to 2050.

Figure 7.2-3 shows the contributions of different components to emission reduction in Germany. The emission reduction in the reference scenario (compared to the strongly increasing development when structures remain unchanged) is largely brought about by the increase in energy productivity of industry. In the reference scenario the energy demand per unit of value added is reduced – due to technical efficiency improvements and intersectoral structural change – by more than 40 %. This huge increase in energy efficiency brings about approx. 70 % of the total emission reduction in the reference scenario. The contributions of other factors (renewable energies, the fuel switch to energy carriers with lower CO_2 emissions) are substantially lower in comparison, but are nonetheless significant. Renewable energies contribute approx. 8 %, the switch of the fossil mix of energy carriers approx. 9 % and the increasing electricity share approx. 12 % of the emission reduction achieved in the reference scenario.

Figure 7.2-3: Decomposition analysis for emission development in industry in Germany (energy-related emissions), 2005 – 2050



Source: Öko-Institut 2009

The additional emission reductions in the innovation scenario predominantly stem from the increasing contributions of energy efficiency. The structure of additional reduction contributions is very nearly congruent to that of the reference scenario. Only the contribution made by the electrification of production processes decreases slightly, to 8 %; however, the reduction effect increases to approx. 72 % as a result of increased energy savings.

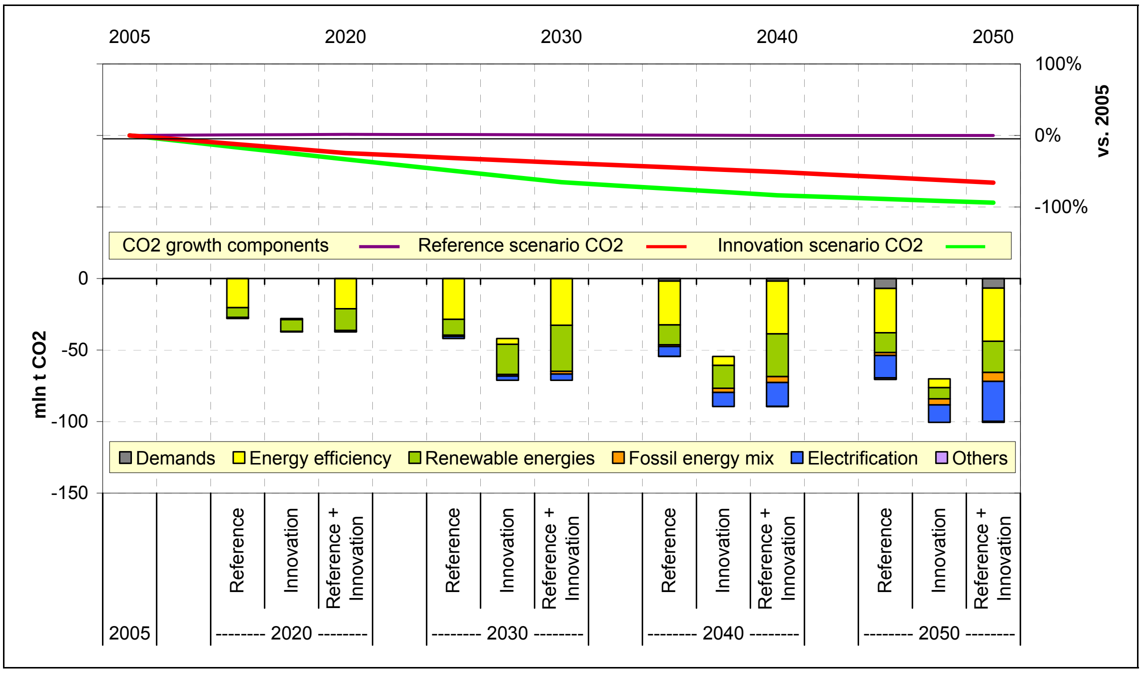
Overall the emission reduction realised in the innovation scenario largely results from improvements to energy efficiency in industry and to a far lesser extent from the contributions of renewable energies, fuel switch, and increased electrification.

7.2.4 Results of decomposition analysis for passenger cars in Germany

In 2005, motorised individual transport – referred to hereafter as “passenger cars” – has an emissions volume of approx. 107 million t CO_2, making up approx. 85 % of the total passenger car volume. In 2005 in Germany, the total passenger car volume is approx. 880 billion pkm travelled; the remaining 155 billion pkm travelled occurred in public transport.

For the time period up to 2030, only a very weak increase or subsequent stagnation of the passenger car volume is assumed in the scenarios. After 2030 the transport volume for Germany falls slightly again; in 2050 it is approx. 6 % below 2005 levels. There are also no or only very low growth components for passenger cars in Germany (Figure 7.2-4).

Figure 7.2-4: Decomposition analysis for emission development of passenger cars in Germany, 2005 – 2050



Source: Öko-Institut 2009

The development of the reference scenario leads to an emission reduction of approx. two thirds up to 2050 to approx. 36 million t CO_2. This reduction of greenhouse gas emissions is largely caused by the significantly improved efficiency of (conventional) passenger cars. The corresponding contribution to emission reduction amounts to approx. 31 million t CO_2 for the 2005 - 2050 period or 44 % of the emission reduction realised overall in the reference scenario. In the reference scenario substantial contributions to reduction are brought about by the increased use of biofuels (20 %) and the increased share of electric mobility (22 %). The emission-reducing effect of the decreasing volume of passenger cars (10 %) is also relevant in this context.

In the innovation scenario the additional emission reductions are predominantly brought about by significant increases in the contributions of electric mobility, which amount to approx. 28 % of the total emission reduction (slightly more than 100 million t CO_2-eq) in the innovation scenario. This level is somewhat above that of the contribution to emission reduction made by renewable energies (22 %), but is significantly below the contribution brought about by the increased efficiency of conventional drives.

Thus, the strong emission reductions in passenger cars – in both the reference and the innovation scenario – are the result of significant improvements to conventional drives, electric mobility, and the increased use of renewable energy carriers (biofuels).

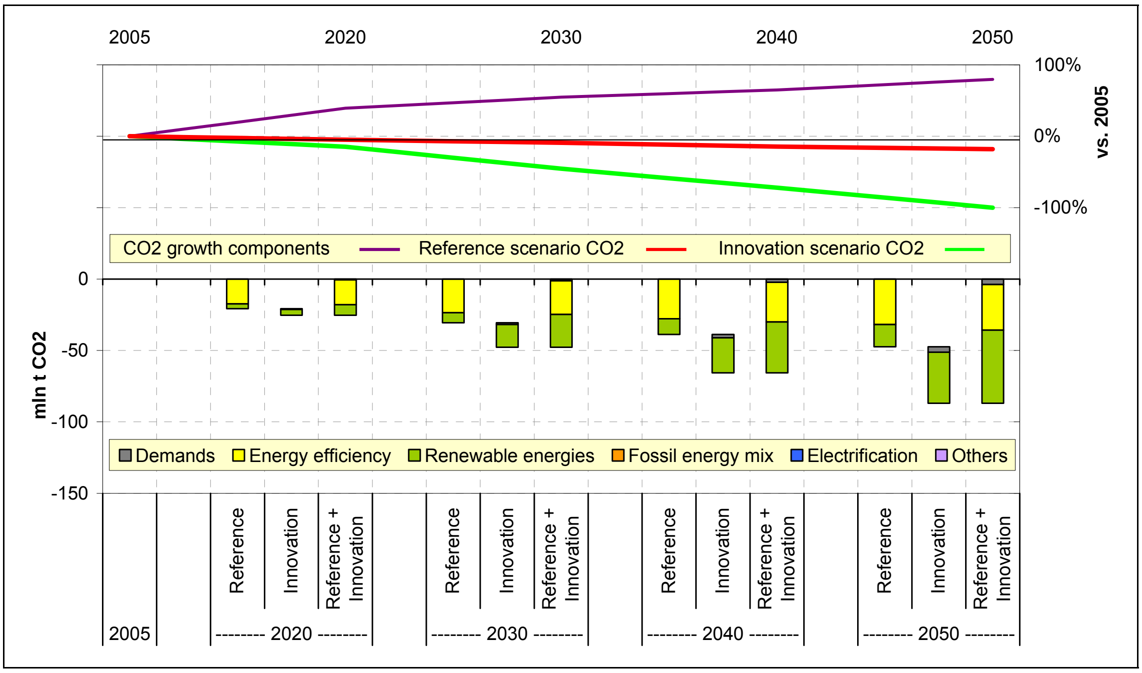
7.2.5 Results of decomposition analysis for freight transport by road in Germany

In contrast to passenger cars, there is a strong increase in the transport volume of freight transport by road (the second largest emitter within the German transport sector, amounting to 46 million t CO_2). In the reference scenario the transport volume increases by approx. 85 %. In the innovation scenario the increase of the transport volume of freight transport by road is somewhat lower, but is nevertheless 67 % above 2005 levels in 2050.

The emission reduction realised in the reference scenario (compared to static development) amounts to approx. 47 million t CO_2, but only leads to an 18 % decrease in absolute emissions due to strong increases in transport volume up to 2050 compared to 2005. The lion's share of the emission reduction (67 %) is achieved through improved vehicle efficiency; the remainder stems from the increased use of biofuels in freight transport by road (Figure 7.2-5).

In the innovation scenario CO_2 emissions are reduced almost completely up to 2050. The additional reduction of emissions of 40 million t CO_2 stems predominantly from a strong increase in the share of biofuels; approx. 10 % of the additional emission reduction is brought about by demand reduction or the modal shift of freight transport by road. In the innovation scenario the largest share of the total emission reduction in 2050 originates in the use of biofuels (59 %).

Figure 7.2-5: Decomposition analysis for emission development of freight transport by road in Germany, 2005 – 2050



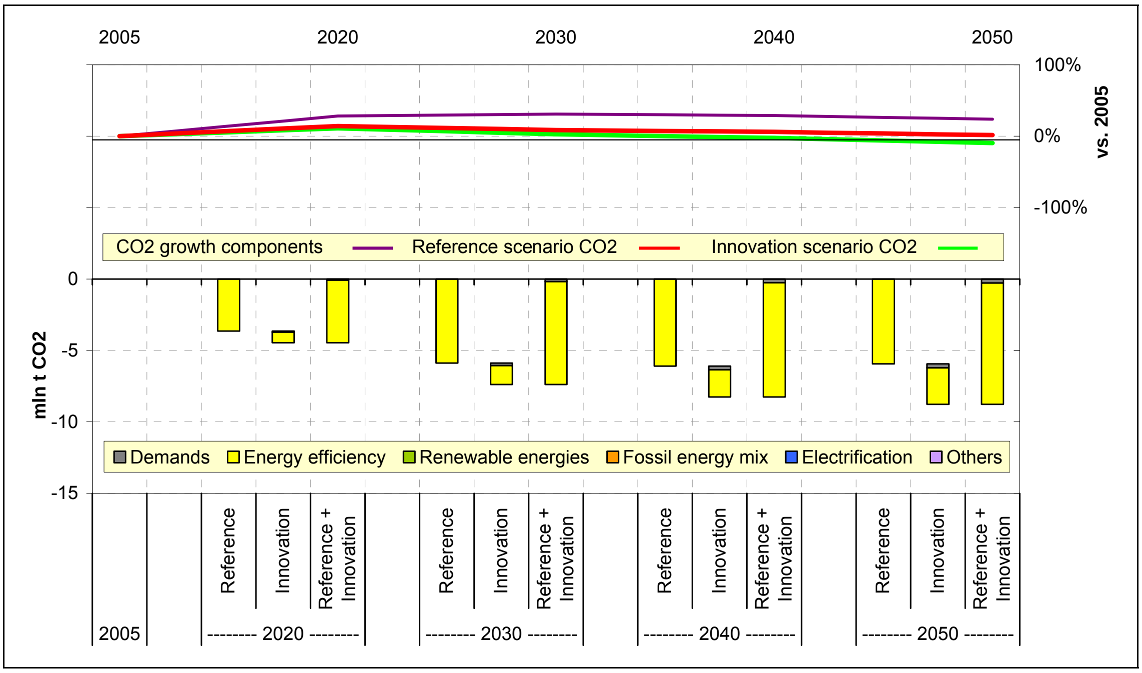
Source: Öko-Institut 2009

7.2.6 Results of decomposition analysis for aviation in Germany

With an emission level of approx. 25 million t CO_2 aviation is one of the largest sources of emissions in the German transport sector. In recent years aviation experienced significant increases in transport volume in Germany. In the reference scenario an additional growth of 30 % is expected up to 2025, followed by stagnation and then a slight decrease, with the result that the transport volume for aviation is approx. 25 % above 2005 levels in 2050.

In the reference scenario this growth driver is offset by the improved energy efficiency of aircrafts (approx. 20 %), meaning that by the end of the time period covered in the scenario (2050) emissions are approx. 2 % above 2005 levels (Figure 7.2-6).

Figure 7.2-6: Decomposition analysis for emission development of aviation in Germany, 2005 – 2050



Source: Öko-Institut 2009

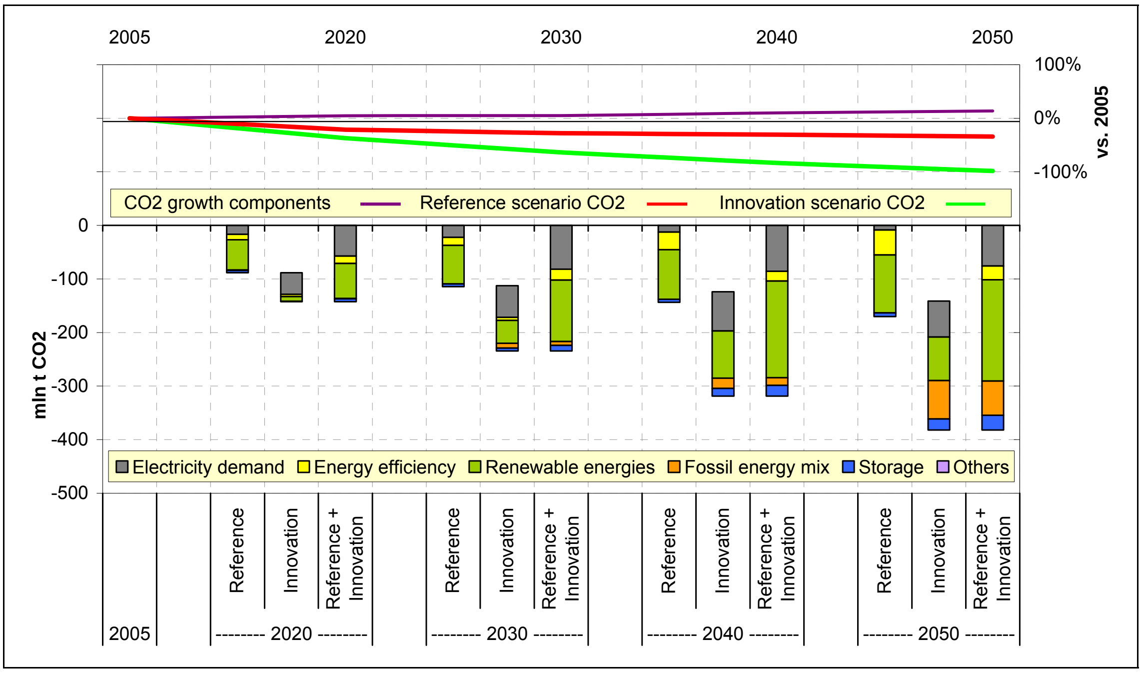
In the innovation scenario further potentials for increasing energy efficiency are tapped; a lower contribution to total emission reduction is explained by the decrease in transport volume for aviation in Germany. However, almost all of the total contribution to emission reduction (98 %) realised by aviation (approx. 9 million t CO_2) is brought about by efficiency improvements.

7.2.7 Results of decomposition analysis for electricity production in Germany

Electricity production is one of the largest sources of greenhouse gas emissions in Germany. In the reference scenario it is assumed that electricity consumption generally remains constant and decreases slightly at the end of the time period covered by the scenario. Nevertheless, lower growth components need to be taken into account in the electricity sector in Germany, which predominantly arise from the decreased share of nuclear energy in the component analysis.

In the reference scenario (the “without CCS” option) total CO_2 emissions are reduced by 34 % up to 2050. The corresponding contribution to emission reduction – approx. 170 million t CO_2 – stems from increased electricity production based on renewable energies (63 %). Lower contributions result from the improved efficiency of fossil fuelled power plants (27 %), reduced electricity demand (5 %) and stored electricity (4 %).

Figure 7.2-7: Decomposition analysis for the emission development of electricity production in Germany, 2005 – 2050



Source: Öko-Institut 2009

In the innovation scenario the reduced electricity demand makes a substantial contribution to emission reduction (Figure 7.2-7).

The indirect effects of electricity savings on demand comprise approx. 20 % of the total emission reduction realised in the innovation scenario. At the same time the increased use of renewable energies (50 %) makes a substantial contribution to emission reduction once again. An additional contribution is made in the innovation scenario by the continued use of fossil fuelled power plant capacities in the German electricity production system with low CO_2 emissions; this is shown in the substantial contribution made by the fossil power plant fleet to emission reduction in Germany (17 % of the total reduction in the innovation scenario).

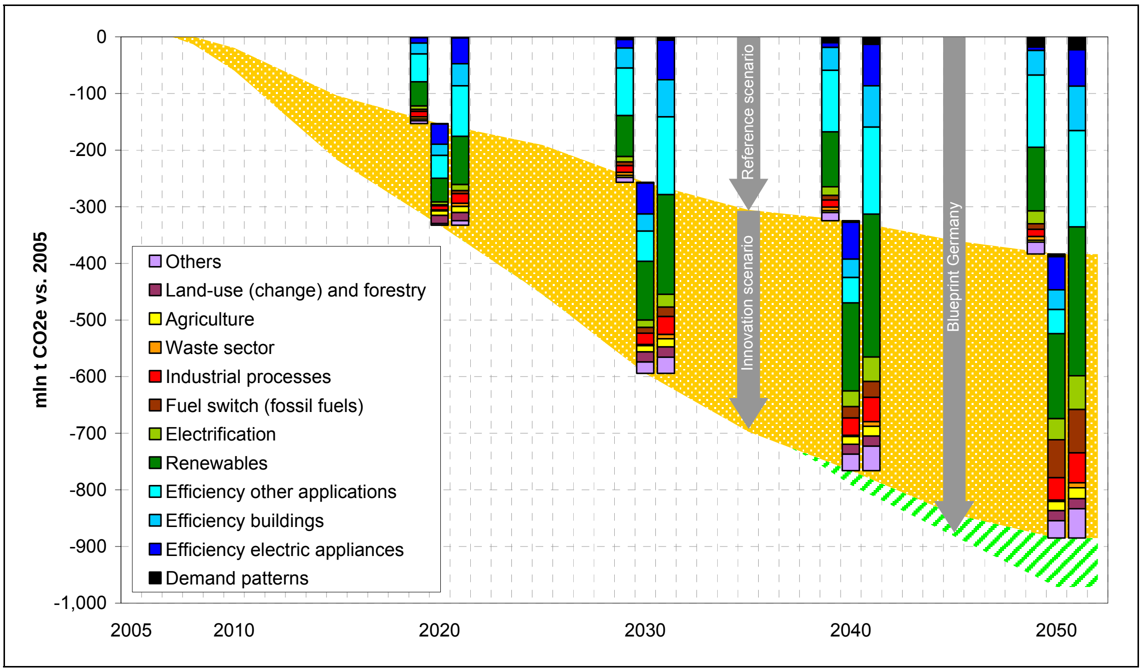
In terms of reduction contributions, the improved efficiency of fossil fuelled power plants is a particular idiosyncrasy of the electricity production sector. Since significantly fewer new power plant capacities come into operation in the innovation scenario compared to the reference scenario, the efficiency of the fossil power plant fleet improves to a lesser extent in the innovation scenario than in the reference scenario. Accordingly, the contribution of the improved efficiency of fossil fuelled power plants is lower in the innovation scenario (25 million t CO_2) than in the reference scenario (47 million t CO_2).

In order to realise ambitious emission reduction targets in electricity production, the increased use of renewable energies is decisive, along with the reduction of electricity demand and the fuel change to fossil power plants with low CO_2 emissions. In these approaches, the increased use of renewable energies takes the centre stage.

7.2.8 Results of decomposition analysis for total greenhouse gas emissions in Germany

Figure 7.2-8 shows the overall decomposition analysis for the two scenarios, taking into account the sectors and sub-sectors which make smaller contributions to emission reduction and are not discussed in greater depth in the previous chapters, and the reduction options for non-energy-related or non-CO_2 emissions.

Figure 7.2-8: Decomposition analysis for total emission development in Germany in the reference and innovation scenarios, 2005 – 2050



Source: Öko-Institut 2009

This overview shows that approx. half (46 %) of all reduction contributions stem from energy efficiency (in electricity, buildings, etc.) in the reference scenario. 29 % of the reduction contribution originate in increased use of renewable energies and approx. 6 % in electrification (above all in the transport sector). It should be noted that above all in the first decades of the time frame covered by the scenario the different areas covered by energy efficiency comprise more than 50 % and renewable energies approx. 30 % of the total contribution to emission reduction.

In the innovation scenario a significantly different path is followed:

- The contributions of renewable energies to emission reduction are substantially larger than those made by energy efficiency (35 % compared to 30 % in the reference scenario).

- In terms of the contributions made by energy efficiency, increased efficiency in electricity use has a significantly larger impact in the innovation scenario (7 % compared to 2 %).

- Fuel switch from fossil fuels which have high CO_2 emissions to fossil fuels which have lower CO_2 emissions (to the extent that they are still being used in 2050) leads to additional substantial contributions in the innovation scenario (9 % compared to 2 %).

- By reducing the greenhouse gas emissions in industry processes, additional significant contributions are made (6 % compared to 3 %).

- Land-use and forestry also deliver reduction contributions that should not be overlooked (2 % in the innovation scenario only).

The contributions of the whole panoply of energy efficiency options to emission reduction and the widespread use of renewable energies are key building blocks in both the reference and the innovation scenarios. However, the huge emission reductions realised in the innovation scenario (87 % compared to 1990 or 73 % compared to 2005 levels) require – alongside greater tapping of energy efficiency potentials – the significantly increased use of renewable energies, the electrification of transport, fuel switch, and the tapping of other emission reduction options in industry processes, land use, agriculture, etc.

Finally, the overview provided in Figure 7.2-8 also shows that the remaining gaps that need to be closed to reach the 95 % emission reduction target are predominantly to be found in the years after 2040. For this (long-term) time frame additional reduction potentials need to be identified and assessed.

The reduction contributions identified using decomposition analysis can also be analysed from other perspectives. A key question, particularly in terms of realising ambitious emission reduction targets, is what the time frames are for tapping reduction potentials. Especially for emission reductions in those areas with a particularly durable capital stock or the indirect effects on such areas, well-timed implementation measures are very important. Without them, the tapping of emission reduction potentials would either be rendered impossible or would lead to comparatively high costs due to the destruction of capital that would follow.

Figure 7.2-9 shows the grouping of reduction potentials according to the durability of capital stock. The following contributions to emission reductions involve particularly durable capital stock:

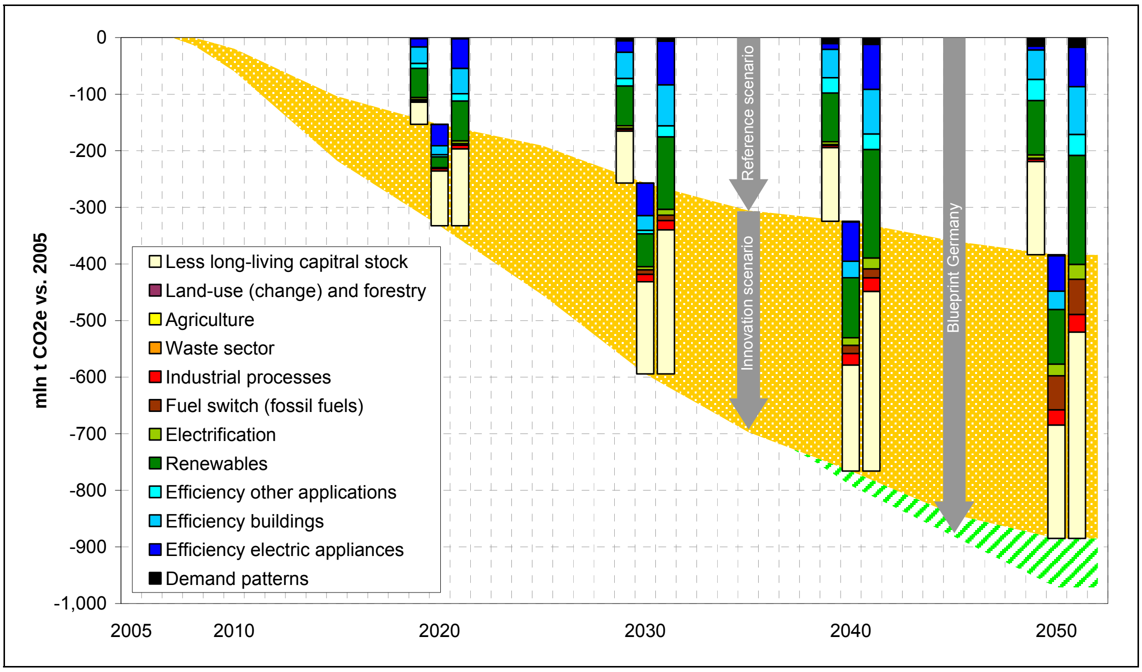
- contributions in the residential sector;

- contributions in electricity production (including demand);

- contributions in rail transport; and
- contributions in process-related CO_2 emissions.

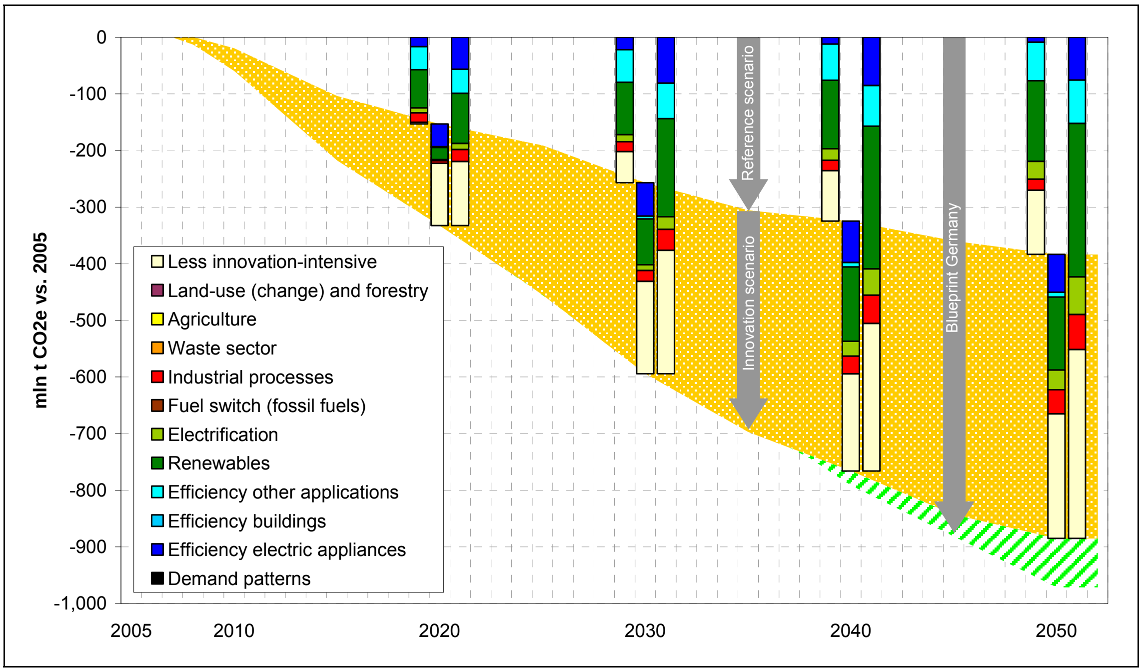
The results of this analysis (which is inevitably of an approximate nature) clearly show that approx. 60 % of the modelled emission reductions are contributions which involve a particularly durable capital stock in the long term. Alongside effective approaches to action, the appropriate timing of intervention when tapping reduction potentials is particularly and increasingly important.

Figure 7.2-9: *Decomposition analysis for total emission development in the reference and innovation scenarios in Germany, taking into account durability of capital stock, 2005 – 2050*



Source: Öko-Institut 2009

Figure 7.2-10: Decomposition analysis for total emission development in the reference and innovation scenarios in Germany, taking into account innovation intensity of reduction contributions, 2005 – 2050



Source: Öko-Institut 2009

The question of necessary innovation intensity is also important in this decomposition analysis. Substantial innovations are required in terms of technology, costs, environmental quality, etc. for a number of contributions to emission reduction. The innovation intensity of these contributions in Germany is shown in Figure 7.2-10.

The following reduction contributions were categorised as requiring intense innovation:

- renewable energies, electrification, etc. and the industry sector;
- increased efficiency standards for conventional passenger cars and electric mobility in passenger cars;
- efficiency improvements in freight transport by road;
- production of biofuels of high environmental quality;
- efficiency increases in aviation; and
- reduction of CO_2 and N_2O emissions from industry processes and fluorinated greenhouse gases.

This – initial – categorisation shows that over 60 % of the reduction contributions needed in the long term require substantial innovations. In this regard the key challenges concern renewable energies in electricity production, biofuels of high environmental quality, energy efficiency (above all in electricity applications), electric mobility and the reductions of non-energy-related emissions from industry processes.

7.3 Further analyses

7.3.1 Estimation of additional emission reduction potentials for Germany

In the reference scenario substantial emission reductions are realised. However, given that greenhouse gas emissions are reduced to approx. 45 - 50 % below 1990 levels (in the "without CCS" and "with CCS" options), the reductions are nowhere near the 95 % target for 2050. In the innovation scenario the gap is closed to a large extent; but even when emission reductions of 86 – 87 % are realised, an additional reduction is still necessary to meet the target.

In the following a number of further emission reductions are considered, discussed and assessed. An integrated consideration within the scope of new modelling work will not be undertaken; rather, rough estimations and impact analyses will be provided.

In a number of sectors in Germany, there is an almost full-scale reduction of emissions in the innovation scenario, with the result that further emission reductions in these areas are not an option. These include:

- the residential sector;
- the tertiary sector;
- electricity production;
- passenger cars; and
- freight transport by road.

However, significant levels of emissions remain, above all in industry and aviation.

Closer analysis of the development of energy consumption and emissions in the industry sector in Germany shows that the remaining emission levels are relatively high. There are predominantly two reasons for this:

- The switch from hard coal to other energy carriers is only partly possible in iron and steel production because this energy carrier is also used as reducing agents for pig iron production (the use of coal in the balance for energy-related CO_2 emissions is therefore included in the national greenhouse gas inventories under process-related emissions). The only emission reduction measures to be considered in this context are the switch from steel to other materials, additional steel savings or the use of CCS in pig iron production.
- For a number of industry processes, natural gas is used for process heat production. Alongside all the measures for saving electrical heating or using it in sub-sectors – the use of biomethane as a substitute for natural gas is a possibility in the future.

In terms of aviation emissions, the use of biofuels is a key option for 2050 although high standards to guarantee the sustainability of biomass are required – as for all other uses of biomass. In both the reference and the innovation scenarios only mineral oil is used in aviation for Germany; as in freight transport, for example, the exclusive use of biofuels can be pursued.

Table 7.3-1: Further CO_2 emission reduction options in Germany (based on the innovation scenario), 2020 - 2050

		Additional mitigation options			
		2020	2030	2040	2050
Iron and steel industry					
CO_2 emissions from iron and steel production (reduction agents) - Innovation scenario	mln t CO_2	33	28	22	17
CO_2 emissions from iron and steel production (limestone use) - Innovation scenario	mln t CO_2	2	2	1	1
Potential CO_2 emission reduction from CCS	mln t CO_2		15	16	16
		0%	50%	70%	90%
Process heat in industry					
Natural gas use - Innovation scenario	PJ	606	520	456	445
Oil use - Innovation scenario	PJ	28	21	17	16
	mln t CO_2	36	31	27	26
Substitution by bio-methane	PJ		216	378	438
			40%	80%	95%
Potential CO_2 emission reduction by bio-methane	mln t CO_2	0	12	21	25
Additional use of biomass	PJ		309	541	626
Motor fuels in aviation					
Aviation fuel use - Innovation scenario	PJ	383	354	336	312
	mln t CO_2	28	26	25	23
Substitution by bio-fuels	PJ		142	269	296
			40%	80%	95%
Potential CO_2 emission reduction by bio-fuels	mln t CO_2	0	10	20	22
Additional use of biomass	PJ		236	448	494
Additional options total					
Potential CO_2 emission reduction	mln t CO_2		37	58	63
Additional final energy use of biomass	PJ		358	647	735
Additional primary energy use of biomass	PJ		545	989	1,120

Source: Öko-Institut 2009

In Table 7.3-1 the CO_2 reductions that could be achieved by using these measures (based on the innovation scenario) are shown. The overview demonstrates that in 2050 additional emission reductions of approx. 60 million t CO_2 could be realised in total. However, there are two requirements which need to be met before it is possible to implement these measures: CCS has to be available and the corresponding quantities of biomass have to be made available on the consumption or primary energy level in compliance with sustainability standards.

The availability of additionally required biomass raises substantial questions about domestic potentials. Therefore the quantities of biomass which could be made available from other sectors on the basis of further measures should be analysed in a further step. To this end, sensitivity analyses were carried out using the decomposition analysis model, the results of which are shown in Table 7.3-2. Four different parameter options were analysed:

- Supported introduction of electric drives in passenger cars amounting to a 20 % share: The transport volume powered by electric drives increases from 354 to 425 billion pkm in 2050.

- Transport demand reduction or modal shift of 20 % of the transport volume in passenger cars and freight transport by road.

- Improvement of energy efficiency for the conventional drives of passenger cars and lorries.

- The combination of the last two parameter options.

These first calculations show that based on the sensitivity analyses for 2050 approx. 350 PJ of biomass (on the consumption level) could be made available for other uses. This quantity would be sufficient to cover, for example, the above-mentioned additional biofuel demand for aviation. At the same time, a substantial additional demand for biomass still needs to be met if the strategy of using biomethane in industry is to be applied.

The other effects shown by the parameter analysis would not have a crucial impact on the structures of the energy industry or long-term emission development. The additional electricity demand of 20 PJ (6 TWh) would not significantly change the situation in the electricity industry. The additional emission reductions generally apply to 2020/2030; however, they decrease substantially after this time due to strong increases in the share of renewable energies or zero emission fuels.

Table 7.3-2: Effects of different options on the transport sector in terms of CO_2 emissions and demand for biofuels and electricity in Germany, 2020 – 2050

		Motorised private transport				Road freight transport			
		2020	2030	2040	2050	2020	2030	2040	2050
Biofuel use (PJ)									
Enforced electric mobility	20%	-1	-14	-51	-84	-	-	-	-
Reduced transport servives	20%	-36	-72	-70	-56	-23	-59	-89	-124
Improved efficiency of conventional drives	20%	-36	-72	-70	-56	-23	-59	-89	-124
Reduced transport services & improved efficiency	20% each	-65	-129	-125	-100	-41	-106	-161	-224
Effects on electricity use (PJ)									
Enforced electric mobility	20%	0	3	12	20	-	-	-	-
GHG emissions (mln t CO_2e)									
Enforced electric mobility	20%	-	-	-	-	-	-	-	-
Reduced transport servives	20%	-14	-7	-4	-1	-8	-5	-3	0
Improved efficiency of conventional drives	20%	-26	-13	-6	-2	-8	-5	-3	0
Reduced transport services & improved efficiency	20% each	-26	-13	-6	-2	-14	-9	-5	0

Source: Öko-Institut 2009

Another possibility for realising further emission reductions is storage in geological formations of biogenic carbon arising from biofuel production. Based on this use of CCS, a net carbon sink would be created. Table 7.3-3 shows an approximate estimation of the realistic CO_2 reduction potential of such an option.

Table 7.3-3: CCS potentials for (biogenic) CO_2 emissions from biofuel production in Germany, 2020 – 2050

		Additional emission mitigation options			
		2020	2030	2040	2050
Biofuel use					
Bio-ethanol (Innovation scenario)	PJ	86	227	258	242
Biodiesel (Innovation scenario)	PJ	214	442	559	689
Additional biofuel use from aviation	PJ	383	354	336	312
CO_2 from production					
Bio-ethanol	mln t CO_2		7	7	7
Biodiesel and aviation biofuels	mln t CO_2		23	26	29
CCS for CO_2 from biofuel production					
CO_2 capture and storage - upper range	mln t CO_2		15	23	32
			50%	70%	90%

Source: Öko-Institut 2009

If these additional CO_2 reduction potentials are consistently tapped, a total potential of approx. 80 million t CO_2 could be realised for 2050, thereby closing the gap to the 95 % reduction target.

However, the additional reduction contributions involve considerable uncertainties and require flanking measures to a large extent, particularly with regard to biomass and CCS development.

Table 7.3-4: "Blueprint Germany": Greenhouse gas emissions in the innovation scenario including the reduction potentials from further analysis, 1990 – 2050

	Historical data		Innovation scenario			
mln t CO_2e	**1990**	**2005**	**2020**	**2030**	**2040**	**2050**
Szenario analysis						
Combustion processes w/o CCS in power generation	1,018	843	589	353	199	97
Combustion processes /w CCS in power generation	1,018	843	589	357	201	106
Fugitive and industrial process emissions, product use	107	84	54	37	23	10
Agriculture	62	53	39	36	33	30
Land use, land use change and forestry	-28	39	21	18	18	18
Waste sector	40	13	6	4	3	3
Total w/o CCS in power generation	**1,199**	**1,031**	**709**	**447**	**276**	**157**
Total /w CCS in power generation	**1,199**	**1,031**	**709**	**451**	**278**	**166**
Total w/o CCS in power generation						
Change against 1990	-	-14.0%	-40.8%	-62.7%	-77.0%	-86.9%
Change against 2005	16.3%	-	-31.2%	-56.6%	-73.3%	-84.8%
Total /w CCS in power generation						
Change against 1990	-	-14.0%	-40.8%	-62.4%	-76.8%	-86.2%
Change against 2005	16.3%	-	-31.2%	-56.3%	-73.1%	-83.9%
Additional options 'Blueprint Deutschland'						
CCS for process-related CO_2 from iron and steel industry				-15	-16	-16
Bio-methane for remaining process heat supply in industry				-12	-21	-25
Biofuels for aviation				-10	-20	-22
CCS at biofuel production (w/o deduction)				-15	-23	-32
Total w/o CCS in power generation	**1,199**	**1,031**	**709**	**395**	**195**	**62**
Total /w CCS in power generation	**1,199**	**1,031**	**709**	**399**	**197**	**71**
Total w/o CCS in power generation						
Change against 1990	-	-14.0%	-40.8%	-67.0%	-83.8%	-94.8%
Change against 2005	16.3%	-	-31.2%	-61.7%	-81.1%	-94.0%
Total /w CCS in power generation						
Change against 1990	-	-14.0%	-40.8%	-66.7%	-83.6%	-94.1%
Change against 2005	16.3%	-	-31.2%	-61.3%	-80.9%	-93.1%

Notes: emissions data for 2005 from national greenhouse gas inventories; energy-related emissions include CO_2 from fluegas desulphurization

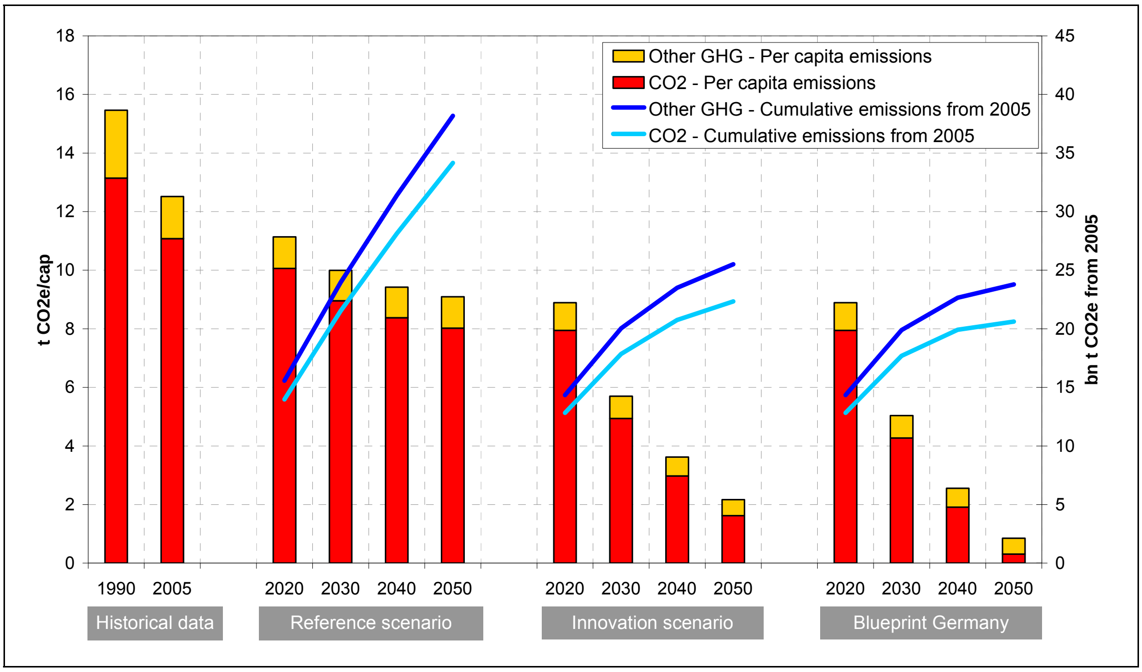
Source: Prognos and Öko-Institut 2009

Table 7.3-4 places the results of the further analyses in the context of the innovation scenario results. Based on the CCS- and biomass-related measures adopted in the medium term (i.e. after 2030), greenhouse gas emissions can be further reduced in

2050 by approx. 90 million t CO_2e. As a result, an emission reduction of approx. 95 % in the “without CCS” option (in electricity production) and an emission reduction of approx. 94 % in the “with CCS” option (in electricity production) compared to 1990 levels can be realised. If the lower estimate is applied to CO_2 abatement based on the use of biomass combined with CCS, the reduction contributions are approx. 1.5 percentage points lower.

The scenario and further analyses show that emission reductions of approx. 95 % are technically and economically possible for Germany and that a number of development options lead to similar results. However, with regard to biomass and CCS there are critical (and controversial) areas in which they could be used and which are crucial for reaching the climate protection target of approx. 95 % compared to 1990 levels, even if the reduction potentials of energy efficiency, renewable energies, etc. are tapped on a huge scale.

Figure 7.3-1: Comparison of scenarios, per capita emissions and cumulated emissions in Germany (from 2005 onwards), 1990 – 2050



Source: Prognos/Öko-Institut 2009

Figure 7.3-1 provides an overview of the effects of the further calculations for the “Blueprint Germany” option on the per capita and cumulated greenhouse gas emissions.

In the “Blueprint Germany” option, the specific greenhouse gas emissions are reduced to 0.9 t CO_2-eq/EW in the case of all greenhouse gas emissions and 0.3 t/EW in the case of CO_2. This very low level is explained by the fact that in this scenario option the creation of a net carbon sink was incorporated for the first time. Overall approx. 0.4 t CO_2/EW are transferred from biogenic sources to geological carbon storage sites in 2050, thereby making a carbon sink. Together with the remaining CO_2 emissions from fossil fuels which amount to approx. 0.8 t/EW, the balance is approx. 0.3 t CO_2/EW as stated above. Compared to 1990 levels, there is a reduction of per capita emissions amounting to 96 % for the total greenhouse gas emissions or 98 % for CO_2 emissions.

In the “Blueprint Germany” option the cumulated greenhouse gas emissions for the 2005 - 2050 period amount to 23.8 billion t CO_2-eq, and CO_2 emissions to 20.6 billion t. Thus, the cumulated emissions in this scenario option are approx. 7 % below the level for the innovation scenario and 38 % below the level for the reference scenario. The additional emission reductions, which generally apply in their entirety towards the end of the 2005 - 2050 period, mean that the share of cumulated emissions arising in the first decades of this time period is greater. Of the above-mentioned cumulated GHG emissions for the 2005 - 2050 period, a share of approx. 60 % stem from the period up to 2020 period and 84 % up to 2030.

7.3.2 Biomass-related analyses

Limiting biomass use to the potential for energy use that can be sustainably produced in Germany was one of the building blocks upon which the development of the scenarios was based. However, the analyses for the innovation scenario showed that a huge reduction of CO_2 emissions by more than 85 % can only be realised when additional quantities of biomass are used in those areas where no carbon-neutral or low-emission alternatives have been identified (most notably in freight transport by road and the share of passenger cars that cannot be tapped by electric mobility). This is even more so the case when the results of the further analyses for the “Blueprint Germany” option are taken into account. These analyses have shown on the one hand that an additional demand for biomass arises when the remaining fossil energy carriers in aviation and industry (jet fuel and natural gas for use in industrial process combustion systems) is subject to fuel switch. The sensitivity calculations have shown, on the other hand, the quantities of biofuels that can be made available by huge changes in transport demand reduction/modal shift, additional improvements to efficiency in conventional vehicle drives and further promotion of electric mobility.

Table 7.3-5 shows a biomass balance for both scenarios and the additional calculations for the “Blueprint Germany” option. The amounts for total primary energy demand for biomass contain – alongside the final consumption of biomass and biomass products and the use of biomass in electricity production – the quantity of biomass needed to produce biofuels and biogas in the relevant transformation processes.

In the reference scenario the primary energy demand for biomass amounts to approx. 1,090 PJ in 2050. This level is only slightly below that on which the potential quantity of sustainably produced biomass in Germany was based (see chapter 2.5.2). In the innovation scenario the level is approx. 43 % above this total potential, predominantly as a result of the huge additional demand for biofuels and despite the decreasing use of biomass in electricity production. This trend is even stronger in the “Blueprint Germany” option. Without taking into account the quantities of biomass which become available through far-reaching measures in transport demand reduction/modal shift, vehicle efficiency and the promotion of electric mobility, the primary energy demand for biomass would exceed 1,200 PJ by more than 120 %. Even when some relief is provided by drawing upon the above-mentioned ways of freeing up additional biomass (the complete realisability of which has not been assessed in detail), demand would overshoot the sustainable domestic potential by approx. 80 %.

Table 7.3-5: Balance of biomass demand for the reference and the innovation scenario and the additional measures of "Blueprint Germany", 2005 – 2050

		Reference scenario			
PJ	**2005**	**2020**	**2030**	**2040**	**2050**
Final energy use					
Biomass	178	184	188	189	188
Biofuels	77	193	268	321	340
Biogas	0	7	16	11	5
Power generation from biomass	136	486	468	432	415
Primary energy	**414**	**908**	**1,042**	**1,092**	**1,089**
		Innovation scenario			
Final energy use					
Biomass	178	189	171	122	66
Biofuels	77	318	708	867	987
Biogas	0	7	16	11	5
Power generation from biomass	136	486	444	394	379
Primary energy	**414**	**1,097**	**1,608**	**1,675**	**1,720**
		Blueprint Germany			
Final energy use					
Biomass	178	189	171	122	66
Biofuels	77	318	850	1,136	1,283
potential additional biofuel savings		-107	-246	-326	-391
Biogas	0	7	232	389	443
Power generation from biomass	136	486	444	394	379
Primary energy (/w additional biomass savings)	**414**	**958**	**1,761**	**2,099**	**2,161**
Primary energy (w/o additional biofuel savings)	**414**	**1,097**	**2,099**	**2,529**	**2,664**
National biomass potential 2050 (rough estimate)					**1,200**

Source: Prognos and Öko-Institut 2009

Even if all biomass from electricity production or the huge electrification of process heat operations in industry were made available – which is scarcely realistic if the power plant mix shown in the innovation scenario is considered – it would not change the fact that demand will exceed the national potential of sustainably produced biomass. This overview shows that a strategy for reducing national greenhouse gas emissions in Germany by 95 % cannot be based solely on the domestic biomass potential. The import of biomass – in whatever quantity – and the elaboration of framework conditions will have to become, at least in the medium term, part of the overall strategic plan for emission reduction.

Against this background, a number of challenges arise:

- Sustainably produced biomass is, within the scope of ambitious climate protection strategies, a limited resource that has to be strategically managed;
- Implementation of the option for importing biomass requires careful analysis of the extent to which the necessary quantities can be guaranteed (also in terms of quality) in other countries using similar strategies;

- If there are national and international markets for biomass products, the standards and rules for guaranteeing sustainability and the social acceptability of biomass production have to be made binding for each of the relevant markets.

Although strategic resource management and the elaboration of framework conditions for national and international biomass markets involve policy strategy and instruments (see sections 88.4 and 9), only a first estimation of biomass potentials can be provided here. If the biomass potentials that can be made available on a sustainable basis for Europe and the states of the former Soviet Union are considered together, the potential could amount to approx. 20,000 PJ for 2050 (EEA 2006, WGBU 2009). Based on a total population of 770 million for the total period and assuming a similar development in the energy industry as shown in the “Blueprint Germany” option, a first estimation of the potential for Germany would be approx. 2,100 PJ per annum for 2050. Against the background of this (very approximate) estimation, the quantities of sustainably produced biomass in the “Blueprint Germany” option are at least generally feasible. The geographical position of Germany with its proximity to Poland and the Ukraine could prove to be a significant advantage in this regard.

Finally, it should be noted that the levels of biomass demand shown in Table 7.3-5 only hold when technologies are used which realise the highest possible standard of transformation efficiency (especially in the case of biofuel production), involve low levels of greenhouse gas emissions in the process chain, and can make substantial use – ultimately as a priority – of residual biomass as a raw material (second and subsequent generations of biofuels). Without this innovation both limiting the primary energy demand for biomass to the levels shown and the pursued reductions of greenhouse gas emissions cannot be realised.

In this way, both a proactive approach to the question of importing biomass and the necessary framework for guaranteeing high standards of biomass production in Europe and internationally from the start, and the targeted and well-timed development of new transformation technologies for biofuel and biomethane production and their availability are a strategically important pillar of a successful climate protection strategy.

7.3.3 CCS-related analyses

The technology of carbon capture and (safe) storage (CCS) in geological formations assumes varied significance in the calculations for the scenarios and options.

The sensitivity analysis for the development of electricity production costs and demand for stored electricity for the German electricity supply system is interesting in electricity production terms for options with CCS when the electricity production options with fluctuating feed-in are less significant than in the options without CCS. At the same time CCS power plants are a fall-back option both in the reference scenario (with a climate policy of limited ambitiousness) and the innovation scenario (with a policy framework strictly geared to a 95 % reduction target) to be applied in the case that the development of renewable energies falls short of the expectations modelled in the scenarios in terms of technological development, costs, system integration or successful implementation in electricity savings.

Use of CCS technology for the remaining CO_2 emissions from **industry processes** after implementation of all other – foreseeable – reduction measures (from product substitution, through the basic re-organisation of production processes to the transition to the renewable production of hydrogen for certain production processes) is not an option, but rather an important and – in the context of the 95 % reduction target – essential climate protection measure. Furthermore, the use of CCS in conjunction with biomass transformation is already an important option in the medium term for creating additional **carbon sinks**.

Nevertheless, CCS technology is still in the development stage and faces different challenges in terms of the different process steps. With regard to **carbon sequestration**, a number of – predominantly economic but also technological – questions need to be addressed before CCS is made generally available for use. These challenges are greater for electricity production than for processes in which CO_2 normally arises in concentrated form already. **Carbon transport** by pipeline is by contrast a tested technology, which mainly faces key challenges in terms of the cost of long distance transportation in densely populated regions, acceptance, and the organisation and regulation of infrastructure systems. **Carbon storage** above all faces problems not only of acceptance, but also in terms of the identification and selection of suitable storage sites which are safe in the long term, and the development of a regulatory framework for all long-term issues (ownership, liability, etc.).

Table 7.3-6: Balance of carbon storage when CCS is used in the reference and innovation scenarios and the additional measures of "Blueprint Germany", 2005 – 2050

	Reference scenario				
mln t CO_2	**2020**	**2030**	**2040**	**2050**	**2100**
CO_2 storage					
Power generation	-	19	51	73	-
Industrial processes	-	-	-	-	-
Biomass transformation	-	-	-	-	-
CO_2 storage (/w CO_2 from CCS power plants)	**-**	**19**	**51**	**73**	**-**
cumulative	-	94	445	1,070	2,939
CO_2 storage	**Innovation scenario**				
Power generation	-	23	56	62	-
Industrial processes	6	17	27	37	37
Biomass transformation	-	-	-	-	-
CO_2 storage (w/o CO_2 from CCS power plants)	**6**	**17**	**27**	**37**	**37**
cumulative	6	117	334	655	2,508
CO_2 storage (/w CO_2 from CCS power plants)	**6**	**39**	**83**	**100**	**37**
cumulative	6	231	844	1,758	5,006
CO_2 storage	**Blueprint Germany**				
Power generation	-	23	56	62	-
Industrial processes	6	31	43	53	53
Biomass transformation	0	15	23	32	32
CO_2 storage (w/o CO_2 from CCS power plants)	**6**	**46**	**67**	**85**	**85**
cumulative	6	264	827	1,588	5,850
CO_2 storage (/w CO_2 from CCS power plants)	**6**	**69**	**123**	**148**	**85**
cumulative	6	378	1,337	2,691	8,348

Notes: data for 2050 are rough estimates to illustrate the magnitude of storage capacity needs, the estimates are based on a 40 years operational lifetime for new CCS power plants and no replacement after this period.

Source: Prognos and Öko-Institut 2009

In this context, the question of what storage capacities are needed in order to be able to realise, if necessary, the CCS development assumed in the scenario- and option-based calculations is also very important. Should national storage potentials not be sufficient, the issue of cross-border transport of CO_2 for storage purposes would be another very significant problem area (that cannot be ruled out even if national storage potentials are assessed as sufficiently large, although it may make it a problem of less significance).

In Table 7.3-6 the carbon storage volumes for the different scenarios and options are shown.

In the “with CCS” option of the reference scenario, the annual carbon storage volume amounts to 73 million t; the cumulated storage volume up to 2050 amounts to approx. 1.1 billion t CO_2. If storage of such levels continued in the long term, safe, and long-term storage of approx. 4.7 billion t CO_2 would be possible up to 2100. If CCS is only used for one power plant generation (i.e. the CCS power plants are removed from operation after 40 years without being substituted by new CCS power plants), the cumulated storage volume amounts to almost 3 billion t CO_2.

For the option “without CCS” in the innovation scenario, the carbon storage volume from industry processes would amount to 37 million t and the cumulated storage volume would be approx. 0.7 billion t CO_2 in 2050. If these storage levels were continued, approx. 2.5 billion t CO_2 would have to be stored up to 2100. If CCS is also to be used in electricity production in the innovation scenario (the “with CCS” option), the annual storage volumes increase to approx. 100 million t CO_2 in 2050, corresponding to a cumulated storage volume of approx. 1.8 billion t CO_2 up to 2050. Assuming that storage of CO_2 from industry processes continues, and the use of CCS in electricity production is still limited to one power plant generation, the result is a storage demand of approx. 5 billion t CO_2 up to 2100.

In the “Blueprint Germany” option when no CCS power plants come into operation, the annual carbon storage increases to 85 million t CO_2 in 2050. Up to then approx. 1.6 billion t CO_2 would need to be stored. Continued use of this approach results in a storage demand of approx. 5.9 billion t CO_2 up to 2100. If additional quantities of CO_2 from CCS power plants (based on the volume parameters determined in the innovation scenario) are to be stored as part of this option, the annual volume of carbon to be stored in safe geological formations increases to 148 million t in 2050. Up to this time approx. 2.7 billion t CO_2 would be stored in total; assuming that CCS is used for one generation of power plants, the storage demand would increase to approx. 8.3 billion t CO_2 up to 2100.

Based on the lower (current) estimations for carbon storage potentials in Germany (12 billion t CO_2 for saline aquifers and approx. 2 billion t for depleted natural gas reservoirs) and deducting a safety margin of 50 % (the actual suitability of each geological formation, competition for use, etc.), it could be – at least roughly – assumed that carbon storage without the cross-border transport of CO_2 for storage purposes could be possible for all options with a carbon storage demand that is below 7 billion t CO_2. In the case that, alongside its use for industry processes and biomass, CCS is also used or has to be used for significant electricity production, it is highly probable that it would only be possible to solve the issue of carbon storage through European cross-border cooperation (depleted gas fields under the North Sea, etc.).

Carbon storage can also prove to be a limited resource, with the result that careful management with a focus on the long term is necessary and useful, alongside essential efforts in research, pilot and demo projects. This also holds against the background of the fact that additional limits can apply to carbon storage – a resource which is already limited – if there is substantial competition for use or huge acceptance problems emerge which lead to further limitations.

8 Goals and strategic approaches for meeting climate protection targets

8.1 Opening remarks

The scenarios and decomposition analyses provide a wealth of quantitative material, based on which the changes to framework conditions and the policy interventions needed to realise the 95 % emission reduction target can be identified and analysed. Policies and measures which are to ensure realisation of radical emission reductions over a comparatively long time period (from the perspective of policy and those involved) will prove highly dynamic over time. Framework conditions will change, technologies and markets will develop dynamically and not necessarily symmetrically, changes in technologies and markets will bring new stakeholders into the frame and different stakeholder groups will gain significance.

Against this background it is helpful to carry out implementation analyses on two levels. For the long term it is useful to develop strategic directions. Here, strategies are understood as the targets and boundaries of action which can initially be described independently of concrete implementation and the specific policy instruments to be used, and thereby are (or have to be) of a general nature. Strategies serve to structure necessary activities and at the same time create a suitable basis for examining concrete implementation steps with a view to meeting the target and their consistency in the long term.

To help the development of long-term strategies for implementing the climate protection measures analysed, three different strategy segments can be differentiated:

- **strategic targets**, based on which it is possible to assess target achievement and progress made in different sectors in a way that is both sufficiently general yet sufficiently sector-orientated,
- **implementation strategies**, which address the interactions of different areas in which action is taken; and
- **instrumentation strategies**, which contain long-term guidelines for policy implementation instruments.

8.2 Strategic targets

With a view to the general strategic targets, the following boundaries of action are derived from the analysis of the innovation scenario and the additional potentials assessed within the “Blueprint Germany” option:

- reducing total greenhouse gas emissions by 40 % up to 2020, 60 % up to 2030, 80 % up to 2040 and 95 % up to 2050 (based on 1990 emission levels);

- improving overall energy productivity by 2.6 % per annum;
- increasing the share of renewable energies within total primary energy consumption to 20 % by 2020, 35 % by 2030, 55 % by 2040 and above 75 % by 2050.

These overarching strategic targets represent, on a very abstract level, key directions for the re-organisation of the energy system and in the end of the entire economy. On a very aggregate level the strategic targets also serve as indicators, on the basis of which successful implementation, for example, can be assessed.

However, against the background of the short time period in which the above-mentioned re-organisation is to be carried out, it is also useful for indicators and sub-targets to be developed for each sector. This can create a sufficiently specific basis for the monitoring of target achievement and assessment of progress made during this time. However, these sectoral targets should not be understood as a kind of straitjacket or fixed program for steering necessary change on a micro level, which (can) lead to over-determination of the system and a failure to do justice to the necessary dynamics of change. The sectoral targets specified below are reliable indicators for re-organisation, on the basis of which it is possible to identify and limit delays to necessary changes at an early stage, analyse them, and provide for swift readjustment. Based on the scenario analyses (innovation scenario and additional measures of “Blueprint Germany”), the following sufficiently robust targets and indicators can be identified for Germany:

In the **residential sector**

- an average annual final energy consumption of 20 kWh/m^2 should be achieved for the room heating of new buildings from (approx.) 2015, approx. 10 kWh/m^2 from 2020, with the 2025 target being zero and plus energy houses;
- the final energy consumption of existing buildings should be reduced by more than a half from 2005 to 2030 and by approx. 90 % up to 2050;
- the share of renewable energies and zero emission energy carriers (district and local heat, electricity) within the total energy demand for the production of room heating should be increased to approx. 40 % up to 2030 and at least 75 % up to 2050.

In the **industry sector**

- the current energy productivity should be approximately doubled up to 2030 and trebled up to 2050;
- the share of renewable energies and zero emission energy carriers (district and local heating, electricity) within the total final energy demand should increase to approx. 60 % up to 2030 and 90 % up to 2050;
- carbon-intensive industry processes should only be carried out in combination with CCS up to 2050; and

- current process-related greenhouse gas emissions should be reduced by more than 50 % up to 2030 and by 90 % up to 2050.

In **passenger transport**

- transport volume should be reduced by approx. 20 % up to 2030 and by approx. 30 % up to 2050 based on transport demand reduction and modal shift;
- the final energy consumption of passenger cars (including the impact on efficiency of electric mobility, but without automatic classification of electric vehicles as zero emission, independent of the upstream chain) should be reduced by more than 60 % up to 2050;
- a 7 % share in 2030 of and an approx. 50 % share in 2050 for electric drives in the total transport volume should be pursued;
- almost all of the final energy demand in 2050 should be met by using renewable (biofuels) or zero emission (electricity, hydrogen) energy carriers.

In **freight transport by road**

- the transport volume in 2050 should be no more than a third above current levels;
- the current energy consumption of freight transport by road should be reduced by 30 % up to 2030 and by approx. 50 % up to 2050;
- the total remaining fuel consumption should be completely based on renewable energies (biofuels, hydrogen) by 2050.

In **aviation**

- the energy consumption of all aircrafts should be reduced by 20 % up to 2030;
- the supply of aviation fuel should be entirely based on renewable energies (biofuels) by 2050 at the latest.

In the **electricity supply system**

- electricity demand (including new consumption areas such as electric mobility) should be reduced by more than 25 % up to 2030 and by a further 10 percentage points up to 2050;
- in electricity supply a share of renewable energies amounting to 60 % up to 2030 and 95 % up to 2050 should be pursued;
- the remaining capacities of fossil electricity production can only be tapped after 2040 if CCS is fitted;

- the capacity of existing sinks (up to now predominantly pump storage power plants) should be doubled up to 2030 and increased by a factor of 4 up to 2050 to offset huge growth in the contributions of fluctuating electricity production.

In **agriculture** greenhouse gas emissions should be reduced by more than 30 % up to 2030 and by over 40 % up to 2050 compared to 2005 levels.

With regard to emissions arising from **land use, land use changes and forestry** CO_2 emissions should be reduced by 70 % from 2005 to 2050.

8.3 Implementation strategies

A particular challenge in the development of implementation strategies for achieving the 95 % reduction target is that the weightings and emission reduction potentials in the different areas are – in terms of different dimensions (level of reduction potentials, time requirements and time windows for implementation, etc.) – sometimes very different; and that a number of relationships and interactions in the overall system need to be considered.

In the strategic development of corresponding climate and energy policies, above all the following aspects have to be taken into account:

In **all sectors** significant efforts have to be made to reduce emissions. However, given that large contributions to emission reduction are necessary, the measures in the electricity sector (demand and production), residential sector (new and existing buildings), passenger cars, freight transport by road, aviation, industry (including process emissions), agriculture, and land use and forestry are especially significant.

Without radical progress made in **energy efficiency** and a concomitant huge increase in the share of **renewable energies**, the emission reduction targets cannot be achieved by 2050. The necessary action in energy efficiency involves both highly standardised energy uses and reduction measures (buildings, electrical appliances, vehicles, etc.) and very heterogeneous energy uses (e.g. in industry). Particularly strong action is needed to increase the use of renewable energies, most notably in electricity production and the transport sector.

A very high share of emission reductions that are additionally necessary involve **durable capital stock**, both directly (buildings, power plants, infrastructures, etc.) and indirectly (more or less efficient electricity applications which tend to have less durable capital stock have significant effects on the durable capital stock of power plants, infrastructures, etc.). Thus, delays to implementation measures lead either to a failure to achieve the target or to strong increases in the costs of climate protection policy. Therefore, the measures related to electricity demand (efficiency on the one hand and electrification on the other hand), electricity production, the residential sector (new and existing buildings), infrastructures (electricity, gas, heat, CO_2, transport) and modal shift in the transport sector are particularly urgent.

The emission reduction options, for which substantial **innovations** still have to be achieved in terms of technology, costs, system integration/infrastructure, market and business models or user behaviour, are expected to deliver a very high share of the emission reductions that are additionally necessary, particularly from 2030 onwards. This concerns above all electricity production based on renewable energies, electricity storage and electricity infrastructure, the sustainable production of biofuels and biomethane, energy efficiency in industry, energy efficiency in conventional and electric vehicles, and CCS technology.

For a number of key emission reduction options, progress cannot be considered, assessed or developed further in isolation. The tapping of many emission reduction potentials is inescapably linked to one or more complementary options. Against this background the development of **systematic strategy approaches** is crucial**:** without them, the pursued emission reductions will not be reached:

- The electrification of passenger cars is generally linked to two areas: increase of electric mobility is only then useful (or not counter-productive) when it successfully taps the electricity production potentials that are additionally necessary – with a corresponding supply of both electricity production and available capacity – based on renewable energies or CCS-based electricity production. In addition, electric mobility requires very decentralised load management and thus the development of sophisticated electricity distribution networks.

- The substantial use of biofuels in road transport and aviation, which is necessary to meet the 95 % emission reduction target – even in the case of strong modal shift, a significant increase in electric mobility, and huge improvements in vehicle efficiency – requires the availability of biofuels which are produced with high transformation efficiency and satisfy high sustainability standards. If, for example, next generation biofuels are not successfully produced in large quantities at the right times, the emission reduction strategy will not be effective, particularly in freight transport by road and aviation.

- The use of decentralised energy supply technologies, which are not based on renewable energies from the outset (e.g. decentralised combined heat and power using natural gas), can bring about lock-in effects in the medium and long term, which are highly problematic when the necessary quantities of biomethane cannot be fed into the gas networks in the medium and long term (for technical or economic reasons or due to strategies and priorities for the use of the limited resource of bioenergy being geared to other ends). A similar situation arises in the continued use of certain process technologies in industry (process heat production based on natural gas, etc.).

- The introduction of new decentralised and centralised electricity production options or emission reduction in certain industry processes require a very long lead time for infrastructural development (transport and distribution network for electricity, carbon infrastructure for CCS, etc.). The development and reorganisation of such infrastructures will often have to be carried out under substantial uncertainties (in terms of volume and availability times, etc.). The same holds for the infrastructures of district and local passenger and freight transport.

The priorities, requirements, facts of exclusion and necessary developments do not remain static in the time up to 2050. For 2030 substantial emission reduction contributions can be achieved using development strategies which are no longer of great significance in the subsequent period. In this regard, it is especially important to prevent the actual emergence of lock-ins – e.g. through capital-intensive or very durable plant investments or infrastructures – which lead to counter-productive effects in the long term. Thus, for all strategies geared to specific time periods long-term and clear phase-out strategies and options have to be developed. At the same time contributions to solutions which are necessary in the long term can lead to problematic structures in the short and medium term (e.g. biofuels in the context of insufficient sustainability standards). Thus, targeted approaches to policy and innovation with clear time goals are indispensable starting points to this end.

For at least two key emission reduction options, the use of biomass and the introduction of CCS, limitations on potentials have to be taken into account. Since the scenario analyses have shown that these options are essential in a long-term emission reduction strategy for different reasons and in different sectors and areas, a pro-active approach to strategic resource management has to be taken:

- If the re-organisation of the energy system is to restrict – limited – biomass potentials to those available domestically or in Europe (particularly Central and Eastern Europe), not only do high sustainability standards have to be guaranteed, but also priority rankings for use have to be established. In the long term those uses of biomass have to be prioritised for which there are inadequate alternatives. This means both the remaining fuel use in passenger cars (after huge electrification) and aviation. Process heat applications (above all in industry) are the next priority, only then followed by electricity production from biomass. But increased efficiency requirements also apply to biomass use in electricity production; and the conversion of biomass into electricity without combined heat and power is not consistent with a climate protection and energy strategy geared to the long term.

- The available underground carbon storage sites required for CCS technology are (also against the background of competition for use of these underground areas) a limited resource, for which priorities of use and management approaches also have to be developed. In this context, process-related CO_2 emissions and the storage of CO_2 from biomass conversion processes (biofuel production, conversion of biomass into electricity) have first priority. These priorities should also be taken into account when determining what contribution CCS is to make within the climate protection and energy strategy. Limiting the contributions made by CCS to climate protection is both a requirement of developing priorities of use for carbon storage and a solution to competition of use that neither restricts too strongly the expansion of other uses competing with CCS, nor excludes from the beginning the necessary contributions to emission reduction to be made by CCS.

A substantially **improved efficiency in use of energy-intensive materials and products** is a requirement of a climate-friendly re-organisation of the energy and transport systems in Germany. Improved material and resource efficiency and the substitution of materials and raw materials can make a substantial contribution to energy saving and be a crucial option in the reduction of process-related emissions (e.g. from steel, cement and lime production).

8.4 Instrumentation and stakeholder-related strategies

Boundaries of intervention also have to be developed for policy implementation strategies and for addressing implementation stakeholders. Even though the orientation and specification of these intervention boundaries as well as the design of necessary policy instruments will change and have to change in the course of time, the development of a number of strategic approaches is nevertheless of general and long-term significance.

The challenges faced by a huge reduction in emissions are so large and multifarious that achievement of the necessary emissions reductions will only be possible when a **broad and varied spectrum of stakeholders** can be engaged as agents of change. In particular the (necessary) robustness of climate protection strategies has to be guaranteed in such a way that the emission reductions are never dependent on specific stakeholders or their target-orientated behaviour in any sector. During policy implementation, care must always be taken to prevent the development of obstructive positions. Thus, the creation of structures geared to competition with low barriers to entry is a basic requirement for strong implementation strategies. Further, competitive structures and a variety of stakeholders are key requirements for the creation of an environment that promotes innovation and the wide-scale implementation of innovations as an integrated process of development and wide-scale commercialisation. If the stakeholders are insufficiently diverse, it will increase the danger of lock-in effects in the short, medium and long term and can obstruct or delay the necessary innovation processes.

A **continual and targeted innovation process** must be included in all policy implementation measures of an ambitious energy and climate strategy in all areas. This is both to further develop incremental innovations and, primarily, trigger (radical) innovations which aim to be path-changing. Accordingly, increased efforts are needed in research and development; at the same time early introduction onto the market and flanking of innovative technologies and business models have proven to lead to comprehensive learning curve effects, sustainable innovation successes, and accelerated market maturity. The costs of innovation strategies structured in this way should be explicitly understood as “learning curve investments” and not as factors which reduce efficiency.

With regard to the major aspects of the necessary policy mix, the following aspects need to be highlighted:

- Attributing a significant **price** to greenhouse gas emissions is a necessary basis for an ambitious and successful climate policy. The EU Emissions Trading Scheme for greenhouse gases (for large sources) and taxes (for diffuse sources) are basic instruments for tapping emission reduction options close to the market and incremental innovations.

- For technologies and climate options which are very homogenous and decentralised, strong **regulatory approaches** are – to the extent that special support measures are required or there are particular structural barriers to be overcome – useful and necessary.

- Regulatory provisions should be introduced if certain market developments in very durable, and at the same time very capital-intensive, investments or infrastructural developments that can only be reversed with great difficulty lead to the danger of **lock-in situations**, which make achievement of ambitious climate protection targets impossible in the long term or which prevent later re-adjustment because of their extremely high costs.

- For the development of climate protection options that are important in the future **specific innovation approaches** geared to clearly defined targets, precise milestones and which also include clear opt-out opportunities are required.

Extensive necessary changes, the limited time period, and necessary systemic perspectives also have consequences for the **design of energy and climate policy instruments**. Particularly those regulatory measures (buildings, vehicle efficiency, etc.) that have been recently developed or newly structured often contain flexibility options. Certain heating technologies or heat supply options can be accounted towards binding thermal insulation targets; electric vehicles or the use of biofuels can be accounted towards efficiency improvements in vehicle manufacture. Using flexible approaches like these, potential efficiency benefits can be tapped.

However, upon closer analysis a whole array of flexibility options of this kind are counter-productive when placed in the context of a strategy geared to the long-term necessities of climate policy. This is particularly true when measures which involve durable property (buildings, etc.) or innovation-intensive sub-sectors (vehicle efficiency, etc.) can be compensated by complementary measures which have less durable components (heating systems, etc.) or parallel technologies (electric mobility, etc.) To achieve long-term climate targets, both huge improvements in the efficiency of buildings and power plants based on renewable energies are necessary. For vehicles, huge efficiency improvements, the development of electric mobility and the use of biofuels are necessary.

Thus, against the background of sector-specific targets, compensation measures of this kind should be excluded from the design of policy instruments in the future when they lead to effects that are counter-productive in the long run.

Alongside wide-ranging **technology-neutral approaches to instruments**, **technology-specific strategies** should also be explicitly strengthened – particularly in terms of targeted innovation strategies, but also with regard to climate protection options that have strong infrastructure components, thereby requiring a substantial lead time, and climate protection options which can only contribute to emission reduction within a system perspective or which have a long economic or technical lifetime. Only when combined in this way will it be possible to develop strategies which lead to target achievement.

In the analysed paths for meeting the 95 % reduction target, substantial quantities of energy sources which involve fluctuating production (because they are strongly dependent on wind or the sun) have to be made available. The profitability of such energy sources can often only be calculated in current markets with difficulty (when the wind supply is very large, the electricity market prices fall and along with them, the opportunities for wind power plants to cover their capital costs – even in the case of very high CO_2 prices which push up the electricity price in the remaining time). In such cases, it could be that interventions **to change the market design** (e.g. markets for power generation from particular power plant capacities) or pursued **expansion of the market** (creation of liquid storage markets with a high competition intensity) are necessary.

A basic and essential component of ambitious emission reduction strategies is the wide-scale and significant increase of energy efficiency. This can only be realised when it is possible, in a targeted way, to develop a hugely expanded, strong and sustainable **market for energy efficiency.** This market has to be organised in such a way that clear demand can be created and diverse stakeholders offering specific services can develop new business areas. Extensive realisation of the necessary increase in energy efficiency is only possible when an energy efficiency market of this kind with all its knock-on effects can be established.

In many cases the measures required within the context of a 95 % emission reduction strategy depend on infrastructures which have to be re-structured, expanded or newly created. The **re-organisation and expansion of infrastructures** require a long lead time in many cases and inevitably involve uncertainties, which hugely exacerbate or prevent isolated action. At the same time, the dependencies on infrastructures mean that it is no longer possible for policy strategies – in the relevant cases – to focus on technology-neutral instruments. Long lead times, extensive investments and significant uncertainties related to infrastructures require robust technological visions, comprehensive planning of developments in supply and demand, and effective approaches to the regulation of infrastructures. Increasing the capacities analysed as well as in the end the courage to take path-making decisions are important and – in spite of all the risks in some areas – essential aspects of strong implementation strategies for ambitious emission reductions within the comparatively short time of four decades.

A key strategic aspect of implementation strategies is that **state tasks** are clearly determined. Although decentralised stakeholders in competitive structures and market- and price-based information are an important component of the necessary policy strategies and one which should be increased, state planning processes are of increasing significance. The targeted promotion of innovation processes, the identification and accelerated development of particularly important technologies, market models or market designs, and the comprehensive and future-orientated development of infrastructures are – alongside determination of targets and framework conditions – all tasks for the state in future and have to be carried out comprehensively and with high priority.

Looking beyond emission reduction potentials to be tapped technologically and economically and the policy instruments needed to realise them, the **acceptance** of the general population is also essential to the necessary re-organisation process. For this purpose, a wide-scale social discussion process is crucial. Initiating such a process with different social groups and accompanying it is a long-term and strategic task.

In the development, design and assessment of specific instruments of climate and energy policy, checking that all targets, instrument approaches and estimated effects are consistent with achievement of a 95 % reduction target will prove essential in an ambitious climate and energy policy geared to ambitious targets. Systematic analysis of policy instruments with a view to their strategic long-term consistency with target achievement must be an integral part of relevant impact assessments.

9 Major aspects of an integrated climate and energy program for 2030

9.1 Opening remarks

The conceptual framework and requirement level of specific policy measures are formed by long-term strategic approaches for meeting ambitious climate protection targets. The selection and design of specific policy measures are determined by very different aspects:

- the economic and political environment, which also leads to certain instruments being preferred;
- integration in general policy frameworks, e.g. in the EU;
- progress achieved in the reduction of greenhouse gases in the different sectors, which can require shifts of focus over the course of time;
- technical, economic, and structural innovations achieved;
- changes in markets and in terms of key stakeholders; and the
- interactions of different instruments, which complement and strengthen each other, but can also hinder each other.

Since the interactions between different instruments have taken on substantial importance and the necessity of comprehensive policy approaches has become clear in energy and climate policy, the approach of integrated policy packages has been applied in Germany and the European Union. In Germany this was the case when the German government initiated the “Integrated Energy and Climate Program” (IECP) within the scope of the “Meseberg Decisions” of 2007; in the European Union the “Green Package” of the EU, proposed by the the European Commission in January 2008 and implemented in December 2008, created an extensive policy framework for climate policy. Previously the policy packages and related targets were geared to 2020 and designed with that time horizon in view.

The following sections will attempt to detail the major aspects of an integrated climate and energy program for 2030 (ICEP 2030).

The basis of this program geared to 2030, i.e. an intermediate period of the long-term strategy, is on the one hand the target and implementation vision for a reduction of greenhouse gas emissions by 95 % compared to 1990, described in the innovation scenario and the further measures (“Blueprint Germany”) and on the other hand the sub-targets and strategies derived from them. The program is geared to the goal of reducing total greenhouse gas emissions in Germany (including international aviation and the emission sources / sinks of land use and forestry) by 60 % up to 2030 compared to 1990 levels.

The key aspects of ICEP 2030 do not comprise a complete and all-encompassing bundle of measures – rather, they detail the key measures of such a policy program. In many cases these measures require additional and flanking policies and measures in order to allow the effects to unfold in the necessary breadth and intensity. This includes the total spectrum of educational, information and motivational programs or other measures for bringing stakeholders and markets to action. It is not intended that ICEP 2030 should replace all the policy instruments used up to now. Rather, based on the key instruments described therein, gaps in previous instruments are to be closed and existing instruments are to be adjusted or expanded. It is assumed that current policy instruments, which are not discussed in the following in greater depth, continue to be used. However, without the key instruments described in the following, it seems barely feasible that the necessary dynamics for emission reduction will be created.

Increasing integration of climate and energy policy in European frameworks continues to require, in many cases, consideration or integration of policies and measures positioned on a European level. In the following there will only be cursory discussion of this; although it will only be mentioned when necessary, the significance of this policy level will not be forgotten or underestimated.

Furthermore, it should be noted that the creation of policy instruments for emission reduction when there is already an emissions trading scheme in place can still be useful, also for the sectors covered by emissions trading. At the same time, it makes explicit legitimation necessary.

Description of this selection of key policy instruments is limited to basic starting points, functionalities, and design features. The detailed development of instruments has to occur – in a similar way to existing policy packages in energy and climate protection – in an elaboration phase, which falls outside the analytical framework of the present study.

The selection, design and creation of parameters for the instruments described in the following are consistent with the developments and volumes specified in the innovation scenario and further calculations for additional potentials and measures. Against this background it should be noted that several instruments which involve not unsubstantial contributions (design of the EU ETS for aviation, the taxing of jet fuel, etc.) are not discussed in greater depth. However, they remain – as do a number of additional flanking policy measures, some of which are important – part and parcel of the comprehensive bundle of measures for ambitious climate protection strategies (see Öko-Institut et al. 2007, 2009) and should not be overlooked, even when they are not crucial.

9.2 Legal framework for medium- and long-term climate policy

The embedding of a program geared to 2030 (i.e. based on the medium term) in long-term climate protection targets requires a number of accompanying measures which are best consolidated in a national climate protection act.

In such an act, the Integrated Energy and Climate Program for 2030 is to be made legally binding, creating in the process a permanent evaluation and improvement process based on commitments. Germany's national climate protection act should incorporate the following facts of regulation:

- Medium- and long-term emission reduction targets for Germany should be made legally binding, i.e. at least 40 % by 2020, 60 % by 2030 and 95 % by 2050 as well as a binding cap for total emissions for the 2000-2050 time period, based in all cases on 1990 levels and including total greenhouse gas emissions from aviation, land use and forestry;

- the compulsory introduction of a comprehensive monitoring system for checking the success of different measures, based on key targets and indicators for the different sectors and an annual assessment of progress made;

- a council should be established which is not bound by instruction ("Expert Council for Climate Policy") for the medium- and long-term assessment of current and foreseeable trends in greenhouse gas emissions as well as current and foreseeable developments in energy, agricultural, waste, and forestry industries, paying particular attention to the incorporation of Europe and developments which could significantly hinder the achievement of long-term emission reduction targets; and the

- compulsory further development of the Integrated Energy and Climate Program based on current and foreseeable developments, fixed evaluation and revision times at five-year intervals as well as clear ministerial commitments.

In addition to the national climate protection act, the German government should also make target agreements with each federal state for responsibilities and areas where the relevant competencies are completely or predominantly at federal state level.

9.3 General instruments

In the medium term the price signals created by the **EU Emissions Trading Scheme** (EU ETS) for greenhouse gas emissions should continue to be a key basis of climate protection policy.

The EU ETS is the most important instrument for implementation of emission reduction potentials close to the market in the case of large emission sources. The framework conditions and the basic mechanisms of the EU ETS are already binding within the EU for the period up to 2020. For the further development of the scheme – also in the context of revising the scheme if a comprehensive international climate agreement is reached – the following points are particularly important:

- early introduction of caps for the longer term, alongside tightening the cap to 35 % below 2005 levels for the time period up to 2020 (in the case that an international agreement is reached), and particularly in the case of the emission target for 2030 which should be set at 60 % below 2005 levels.

- widespread discontinuation of free allocation to guarantee a consistently undistorted price signal for all areas (including material substitution, etc.) and the introduction of compensation measures (based on additional investment) for those industries proven to be at risk of carbon leakage;

- basic limitation of the use of emission allowances from international projects and huge improvement of the quality criteria used to assess such projects; and

- removal of regulatory gaps in the system, e.g. for the capture and storage of CO_2 from biogenic sources. For the storage of biogenic CO_2 emissions allowances should be allocated within the scope of national offsetting projects.

The impact of the EU ETS should be regularly assessed, also with a view to innovations and the necessity of additional instruments. Concurrently, instruments used to complement the scheme must be taken into account when each cap is set.

For the sectors and plants not covered by emissions trading, comprehensive **taxation of the greenhouse gas emissions of stationary power plants** should be introduced. The tax should be based on 30 €/t CO_2, be levied at the point of final consumption and be continually adjusted over time.

9.4 General instruments for increasing energy efficiency

9.4.1 Steering quantities of energy savings

A huge increase in energy efficiency – a key pillar of every ambitious climate protection policy – requires new approaches in energy efficiency policy. Experiences gathered in recent years and decades show that energy efficiency targets have regularly - and for a variety of reasons – not been achieved. Against this background it seems useful and necessary to introduce an instrument for steering quantities specifically for the area of energy efficiency. Based on a (new) instrument of this kind, two strategic goals are to be pursued. Firstly, the contribution of increases in energy efficiency to emission reduction can be quantitatively guaranteed and secondly an essential contribution can be made to the development of a market for energy services.

The basic approach of this instrument is to commit suppliers of energy for use in stationary plants of consumers (for electricity, district and local heat, fossil fuels and fuel from renewable energies) to providing proof of a contribution to energy efficiency. This contribution to energy efficiency is assessed on the basis of the quantities for each recent year determined in an appropriately standardised way. This proof should take the form of energy efficiency certificates (“white certificates”) which can be traded without restrictions. The linking of efficiency commitments with the (physical) sales of energy carriers enables the quantities of increases in energy efficiency to be steered. The reference level should be the commitment to an efficiency increase of 1 % of the energy supplied, which should be increased annually by one percentage point in subsequent years. At regular intervals (the first one being after five years) the efficiency commitments should be adjusted in the light of the absolute energy savings made and the strategic goals of increasing energy efficiency. With this tradable white certificate scheme, other policy instruments can be complemented and their contributions guaranteed.

Fulfilment of efficiency commitments can be proved on the basis of energy efficiency projects which generate white certificates. For these efficiency projects a “positive list” is created in which permitted project types and the baseline methodologies and parameters to be used for each project type are determined. The project list contains both project types for very common efficiency measures (buildings, appliances) and measures in more heterogeneous sectors or areas (industry, tertiary sector). This positive list for efficiency measures eligible for approval can be created relatively quickly with a portfolio that is initially small; it can then be systematically expanded and adjusted over time. Key focuses of energy efficiency can be systematically addressed through the positive lists.

Those covered by the scheme can decide whether they implement energy efficiency measures themselves, commission specialised service providers to this end or participate in large-scale efficiency programs via instruments such as an energy efficiency fund. The existence of different providers of efficiency measures and the demand for corresponding measures that can be planned in the medium term results in competition and tends to lead to decreases in costs and increases in market stakeholders geared to energy efficiency, whose business areas can be expanded to other sub-sectors or areas, too.

9.4.2 Re-introduction of increased taxed deductibility of energy efficiency investments and improvement of rules for investment grants

Practical experiences with the tax deductibility of household-related service providers and experiences gathered with the scrappage premium for passenger cars have shown that direct grants and direct tax incentives are an effective instrument for overcoming many complex barriers to the activities pursued in each case.

In the 1980s increased tax deductibility proved to be an effective means of promotion of energy efficiency investments. In accordance with § 82a of the German Federal Income Tax Ordinance (EStDV), taxable persons were able in the past to deduct for depreciation in the construction year and up to 10 % in each of the nine years that followed from the production costs for connection to a district heat supply, as long as it predominantly came from combined heat and power plants for the incineration of waste or the use of waste heat, for the installation of heat pump plants, solar power plants and heat recovery plants, for the construction of wind power plants and construction of gas production plants based on plant or animal waste. Corresponding tax regulations are to be extended to all energy efficiency investments, i.e. also to investments in which improved thermal insulation leads to a decrease in energy demand. An additional incentive could be created by shortening the period for the deduction of production costs. If necessary it could be tacked on to other support measures (e.g. the KfW support programs).

In the sectors in which investments can be deducted as operation costs anyway, a further tax deductibility can trigger additional efficiency investments. A similar effect would be created by the introduction of an investment grant geared to efficiency investments, as was previously the case in accordance with § 4a of the German federal law on investment grants (InvZulG).

9.4.3 Compulsory introduction of energy management systems in industry

In industry, energy efficiency measures are amongst the key available opportunities for tapping emission reduction potentials.

Above all in industry there are basic opportunities for energy savings and emission reduction if, instead of individual technologies or processes being improved, general processes are optimised, for example by means of systematic use of waste heat or the use of combined heat and power plants.

The tapping of these (often economically feasible) potentials is prevented by a multitude of barriers, especially in industry. Against this background, the introduction of certified energy management systems for all operations of manufacturing industry should be made compulsory.

9.5 Instruments for increasing the energy efficiency of buildings in Germany

9.5.1 Continuation and acceleration of support programs for the rehabilitation of buildings

Existing buildings are crucial to an efficiency strategy for the residential sector. Room heating has by far the largest share of final energy which can be absolutely and relatively saved on the basis of efficiency measures. In addition, a substantial increase in energy rehabilitation levels to more than 2 % per annum and a rehabilitation efficiency of at least 90 % in the long term compared to a reference development should be guaranteed. For this purpose, standards should be fixed for rehabilitation schemes of this kind. As regards the rehabilitation of buildings, the standard should be set at 60 kWh/m^2 from 2020 and at 40 kWh/m^2 from 2030. The long-term standard for 2050 is 10 kWh/m^2.

To increase profitability, this regulation should be flanked by continuation of and a significant increase in the funds of support programs geared to the rehabilitation of buildings. Based on the promotion of rehabilitation according to the lowest energy house standard, the path can be systematically paved for repeated tightening of energy efficiency standards.

As is the case for new buildings, consistent compliance checks and rigorous sanctions in the case of non-compliance with fixed standards is essential for existing buildings, too. Exhaustive checks do not need to be made; rather, effective spot checks should be sufficient.

Further, tax incentives should be created for energy rehabilitation of living space that is in use: To increase the energy rehabilitation level, particularly for the 14 million detached and semi-detached houses (from a total of 17 million residential buildings), experiences show that tax incentives are effective (see the additional capital grants provided for in § 82 of the EStDV in the 1980s).

Tax incentives are also important for the energy rehabilitation of existing (residential) buildings acquired as a capital investment. The immediate deduction of the costs of the energy rehabilitation of buildings as income-related costs, also for the first three years after purchase of the property, should guarantee this.

In terms of the rented buildings, contracting projects can help to tap the relevant energy saving potentials. The effect of using contracting projects in the form of energy supply contracts is generally based on the economic interest of the contractors themselves to fulfil their energy supply and service commitments using energy technology that is as efficient as possible. The efficiency increases arising from contracting lead to optimised annual use levels in the transformation of primary energy to heat.

However, the current legal situation does not allow for a comprehensive implementation of contracting projects in existing residential buildings that are rented. Thus, adjustment of the relevant regulations of the German Civil Code (Bürgerliches Gesetzbuch, BGB) to a compulsory transition to contracting in compliance with environmental and social goals is necessary. Additionally, a standardised regulation for all rental contracts should be created in Germany.

To strengthen and widely tap the efficiency-increasing effects of contracting (which has concentrated on heat supply to date), model activities for expansion to distribution systems and the building envelope should be implemented first of all, the key conditions for widespread implementation should be analysed and assessed, and the relevant legal frameworks should be developed.

A roadmap for "the residential sector as a climate protection market" could structure the process, strengthen (necessary) confidence in the development of this segment of the energy service industry, thereby substantially enhancing the dynamics for targeted tapping of efficiency potentials in existing buildings.

9.5.2 Increasing standards for new buildings in Germany

To guarantee the development of energy consumption and CO_2 emissions of new buildings shown in the innovation scenario, regulatory provisions – like those currently laid down in the German Energy Saving Ordinance (Energieeinsparverordnung, EnEV) – are necessary. Based on the revision of the EnEv, which was decided upon in 2007 and entered into force on 1 October 2009, the requirements for the maximum permitted annual primary energy demand and the maximum permitted U-values (also referred to as the overall heat transfer coefficients) for existing and new buildings has been reduced by 30 % to increase energy efficiency. For existing buildings it was also provided for that rehabilitation encompassing more than 10 % of the component area has to fulfil component requirements. For 2012 an additional reduction of the U-values by 30 % is planned. This corresponds to an annual primary energy demand of 50 kWh/m^2 at the most for new buildings.

Numerous analyses show that newly built passive houses are already profitable. With rising energy prices, it is likely that the extra costs will increasingly remain within acceptable parameters in the longer term, also in the case of buildings with a zero energy standard or even a plus energy standard (in this context, it should be required that the remaining (low) heat demand is met – or even a surplus be generated – by renewable energies). The goal has to be to tighten the standards for room heating in new buildings to a maximum final energy consumption level of 20 kWh/m^2 from 2015, 10 kWh/m^2 from 2020 and to the zero energy or plus energy standard from 2025 onwards. Compliance with these efficiency standards should be guaranteed without any compensation from the volume of energy production from renewable energies as it is laid down in § 5 of the German EnEV of 2009; exceptions should only be allowed when a plus energy standard has been reached.

As a general rule, heat supply to new buildings should no longer involve fossil fuels from 2020 onwards. Progress towards this goal can be made by means of a stepwise increase in the minimum share of renewable energies laid down in the German Renewable Energies Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG) which came into effect on 1 January 2009. The use of lower thermal insulation standards to offset increased shares of renewable energies is not helpful from a climate protection perspective.

The introduction of high standards for meeting the cooling demand is an important aspect of revising standards for new buildings, both in the residential and the non-residential sector. This is also an important requirement for the reduction of electricity consumption for cooling which will otherwise increase substantially in the future.

Both consistent compliance checks and rigorous sanctions in the case of non-compliance with these standards are needed. It is not necessary to carry out comprehensive checks for this purpose – rather, effective spot checks should be sufficient.

9.6 Energy efficiency program for electricity applications in Germany

9.6.1 Continual tightening of efficiency standards based on the top runner principle for all categories of electricity application

In spite of positive development in the efficiency of electricity appliances in the past, huge potentials for increasing efficiency can still be tapped, as demonstrated by comparisons of the specific consumption levels of appliances used for identical purposes.

In the case of homogenous mass products – at least in terms of common household electrical appliances – the most effective measure is generally the introduction of regulatory provisions which fix the maximum permitted electricity consumption for each appliance type, particularly as the best appliances are in many cases more profitable over their total lifetime than comparable appliances with higher electricity consumption levels.

However, minimum efficiency standards are not enforceable on a national level. Instead the EU-wide introduction of such standards is required. In the EU's Ecodesign Directive, the basic legal requirements for such standards have already been laid down. To enable complete implementation, all relevant appliances should be covered and dynamic, ambitious standards for their electricity consumption should be fixed.

These minimum efficiency standards should be introduced within the scope of so-called top-runner programs, whereby the electricity consumption levels of each of the best appliances are made the compulsory maximum consumption levels for all comparable appliances for a period of five years.

Improvement of the current energy consumption label (in which, for example, the life cycle costs are shown) could be a flanking measure to the above programs and expanded to cover all relevant electrical appliances. At the same time, it is also necessary to improve the information conveyed to consumers in the sale of such appliances.

Depending on the actual development in efficiency, additional incentives should be created to enable quicker market penetration of extremely efficient appliances on the basis of financial support drawn, for example, from an energy efficiency fund.

9.6.2 Banning the use electric night storage heaters in Germany

Electrical installations for room heating are one of the largest consumer segments in terms of the electricity demand of residential buildings in Germany (electricity consumption for room heating is estimated at 30 TWh). Thus, substitution of electric night storage heaters – which are highly problematic in view of their electricity consumption and environmental and social factors (electric night storage heaters are often used in low income households) – is an urgent task for energy policy as well as environmentally and socially.

Due to the EnEV 2009, it is no longer permitted for electrical storage heating systems to be operated in residential buildings which contain more than 5 accommodation units when the systems are used exclusively for room heating purposes. If the heating system was made before 1990, its operation has to be discontinued by the end of 2019. In the case of night storage heating systems installed from 1990 onwards, the storage heating system may not be operated 30 years after the installation date. In view of the fact that approx. 85 % of residential units built prior to 1979 use electric room heating, it is likely that in 2030 only a few electric night storage heaters will remain.

It should be taken into account that the substitution of electric night storage heaters with another heating system generally involves extra investment costs which are sometimes significant. Therefore, it will be necessary for support measures to flank this substitution procedure in the form of investment grants which cover approx. 40 % of the corresponding investment costs. Accordingly, the current support programmes of KfW should be further replenished via grants and grants combined with reduced-interest credit. Alternatively, the substitution of electric night storage heaters could be included in the list of deductable efficiency measures in the above-mentioned tax measures.

9.7 Measures for the German transport sector

9.7.1 Investment program for increasing the capacities of the German rail network

Increased use of transport by rail can make a substantial contribution to climate protection. Currently, approx. one fifth of freight is transported by rail and less than every tenth passenger kilometre is travelled by rail in Germany. In the past the German rail network has been reduced through closure of secondary lines. For a modal shift of passenger and freight transport to rail, maintaining and increasing capacities are very important; for this purpose an investment program should be created. Further measures to promote modal shift include, for example, an increase of the German mineral oil tax (see chapter 9.7.6) as well as a road use charges for lorries (see chapter 9.7.5).

The German government should initiate a program for expanding infrastructure and investment which aims to solve capacity shortages in rail infrastructure by 2020 and double the capacities of the German rail network by 2030. The program should not only cover the construction of new rail lines; it should also make better use of existing infrastructure.

To improve the current network, capacity shortages in the infrastructure should be resolved as a matter of priority by reactivating regional lines, particularly in urban agglomeration areas and handling centres for goods. In addition, basic improvements can be made to transport flow by removing temporary speed restrictions at relatively low cost.

By means of improved management and technical systems, better use can be made of the existing infrastructure in Germany. The investment program should support, for example, the increased use of satellite-based safety technology which facilitates a reduction of the intervals between trains without increasing safety risks. In freight transport further measures for increasing transport volume on existing lines – e.g. longer trains and shorter block intervals – should be tested and implemented.

Long-term expansion of the rail infrastructure should be carried out in such a way that fast and slow trains can use the network without obstructing each other. In order to facilitate freight transport by rail during the day, the separation of freight and passenger transport networks should be examined, in particular capacity shortages in the infrastructure and rail junctions. The modal shift of freight transport to rail also requires investments in railway sidings for companies and the expansion of existing – and building of new – transhipment terminals for intermodal transport; for this purpose, the investment program can provide financial support.

This investment program should be flanked by measures to improve rail services in Germany. This includes the removal of network access limitations, noise abatement of rolling stock, the stronger gearing of services to customer needs, the creation of denser networks which have high service frequencies, shorter journey times, standardised information for planning journeys and attractive prices.

9.7.2 Increasing capacities of local public transport in Germany by 25 % up to 2030 and improving its attractiveness

In German cities approx. half of journeys are made by car. In rural areas, the share is even higher. Based on a modal shift of short journeys made by car to bus and rail, significant emission reductions can be achieved. This requires that the local transport services are attractive and efficient as alternatives to using passenger cars in town and city centres. Local public transport in rural areas faces a particular challenge, especially in thinly populated areas. With low demand, maintaining an attractive local transport system in its conventional form is not only cost-intensive; environmental potentials also risk not being tapped when the system is only sparingly used.

The goal of a local transport development program of the German government and federal states should be to increase local public transport capacities in towns, cities and urban agglomerations by 25 % up to 2030. For local public transport in thinly populated areas, innovative transport concepts should be tested and implemented.

In the future, public funds should be allocated for the improvement of local transport within Germany on the basis of verifiable quality criteria. These criteria should be made compulsory in all relevant calls for tenders and flanked by sanction measures. The yardstick of an attractive local public transport service is high customer satisfaction. Basic factors for the attractiveness of local public transport in cities and urban agglomerations, and thereby also for a higher demand, are: a well-designed network with a high frequency service and short distances to the next stop, the safety and cleanliness of the vehicles and bus stops/train stations, and modern and efficient vehicles. Customer-orientated service means that the fare system should be easy-to-understand, passengers should be reliably informed of services, and transfer times within town and city centres and for regional and long-distance public transport should be optimised. A good local public transport service also includes integration of other mobility services such as car-sharing and bike hire.

At the same time the attractiveness of local public transport compared to passenger cars should be increased by re-organisation of city and town centres. The prioritisation of local public transport over passenger cars by granting the former priority lanes and time periods means that journey times can be shortened and the shift to bus and rail, in particular during peak hours, can be made attractive. In addition, limitations should be introduced for automotive transport such as a city toll, parking space management and decreasing the number of parking spaces. The free spaces that then become available (e.g. through reducing the number of available parking spaces) can be used to increase the attractiveness of city and town centres.

A special program should be established by 2020 in Germany which is specifically geared to providing rural areas with a public transport service. On this basis, alternative mobility concepts should be tested and implementation plans developed: the approaches that prove the most successful can then be implemented across the board up to 2030. Starting points for making local public transport services flexible and tailoring them to low customer numbers (in rural areas) are, for example, the use of smaller vehicles, community buses, and shared taxis, which operate on-demand and are complemented by other services such as car pooling.

9.7.3 Tightening emission standards for passenger cars in Germany

Passenger transport in Germany is dominated by passenger cars. Approx. three quarters of all passenger kilometres travelled in Germany occur with passenger cars; passenger cars currently produce 10 % of total emissions (based on the international GHG inventory definition, i.e. fuel tanked in Germany).

Therefore, alongside the modal shift of passenger cars to environmentally friendly modes of transport, reduction of relative energy consumption is very important in successful emission reduction. Passenger cars newly registered in Germany in 2008 consume on average 6.9 l petrol (per 100 km) or 6.3 l diesel. These levels correspond to total average CO_2 emissions of approx. 165 g CO_2/km for Germany, which is significantly above the EU average of 153 g CO_2/km.

The EU enacted a regulation for determination of emission standards for new passenger cars (EG Nr. 443/2009) in April 2009. It is planned that the regulation will lay down the binding reduction of average CO_2 emissions of all newly registered passenger cars to 130 g/km in 2015; the standard is to be set at 95 g/km up to 2020.

Since improving the efficiency of new passenger cars is a crucial measure for reducing greenhouse gas emissions in passenger transport and the technical potentials are still high in this context, this regulation should be further developed and tightened. In particular the type approval test should be revised and the emission standards for passenger cars should be tightened.

The current type approval test – the new European driving cycle – underestimates actual vehicle energy consumption, partly because it does not cover the energy consumption of auxiliary components such as air conditioning. Therefore, a new driving cycle which reflects actual energy consumption levels as closely as possible and includes new propulsion technologies should be developed and implemented. Moreover, electric cars should not be automatically classified as zero emission, independent of the upstream chain.

To decrease the emissions of conventional passenger cars, the emission standards for passenger cars should be set at 80 g CO_2/km in 2020 and 70 g CO_2/km in 2030 in the revised test. The double counting of measures and the automatic classification of electric vehicles as zero emission (independent of the upstream chain) should be ruled out in the future.

Finally, a regulation should be introduced which makes the use of high quantities of biofuels binding for vehicle manufacturers from 2020 onwards.

9.7.4 Introduction of emission standards for all lorries in Germany

Currently approx. two thirds of freight is transported by road. Alongside modal shift to other means of transport, the increase in the energy efficiency of lorries is essential, also in light of the fact that widespread electrification of freight transport by road does not seem likely at the moment.

Like passenger cars, lorries also have technical reduction potentials in terms of energy consumption. These potentials are smaller than is the case for passenger cars because they have already been extensively tapped in the past, but it is likely that they will amount to at least 30 % in 2030 compared to current levels. These efficiency improvements can be achieved by improving the efficiency of the engine, auxiliary components, and power train as well as by reducing driving resistance. The use of low-resistance tyres and low-resistance oils can be made compulsory for all vehicles through adjustment of the type approval requirements.

A requirement of the introduction of an emission standard for heavy utility vehicles and additional steering measures such as the emission-based vehicle tax is a type approval test for determining fuel consumption that applies to all of the EU, and covers the entire vehicle. Up to now there have been no standardised efficiency norms for newly registered lorries and articulated lorries. Such a norm should be developed and implemented without delay.

For utility vehicles, a binding emission standard should be introduced based on this type approval test, which provides for continual improvement of efficiency. Up to 2030 the energy consumption of newly registered lorries and articulated lorries should be reduced by 30 % compared to current levels.

Finally, a regulation should be created which makes the use of high shares of biofuels compulsory for vehicle manufacturers from 2020 onwards.

9.7.5 Increasing the efficiency-based lorry toll and expanding it to include all lorries and roads in Germany

To increase energy efficiency in transport, three factors are particularly crucial: a modal shift to more energy-efficient transport modes, technical improvements to vehicles, and an increase of the vehicle load factor. A toll for all lorries that is valid on all motorways as well as other major and country roads and which gives a bonus to all particularly efficient vehicles can provide incentives for all three reduction options.

The fuel consumption and greenhouse gas emissions per transported tonne of freight generally depend on the load factor of the lorries. In terms of commercial transport, only two thirds of the capacities are used on average. A better load factor and a decrease in empty journeys are beneficial to the environment and are cost-saving for companies. A higher toll charge requires incentives for better organisation of different transport options, e.g. by means of telematics, bundling orders, paired transport (i.e. fewer empty runs) and the selling of empty run capacities to other companies via online exchanges.

EU Directive 2006/38/EG enables Member States to pass on to emitters the costs of maintaining and expanding the road network, and external costs caused by noise and air pollution, traffic congestion, and road accidents, according to the polluter pays principle. In a first step the toll charge should internalise the external costs for utility vehicles up to 2020 and increase per kilometre travelled by € 0.37 on average. Against the background of the reduction or modal shift of 20% of the transport volume in freight transport by road that was additionally applied in the calculations for "Blueprint Germany", the toll charge should be further increased – on the basis of steady rates of increase – to € 0.50 per km up to 2030 in order to provide necessary incentives.

In addition, the toll duty should be extended to all vehicles with a permissible total weight of 3.5 tonnes or more and should cover all motorways as well as major and country roads. Up to now a toll is only levied in Germany for lorries with a total permitted weight of 12 tonnes or more which are journeying on German motorways and designated through-roads. Both restrictions have been circumvented in the past to avoid paying the toll. Since the toll was introduced in Germany in 2005, an increasing number of lorries with a total permitted weight of 10 – 11.99 tonnes have been registered. Furthermore, heavy load transport has partly shifted onto subordinate roads – where, like all German through-roads, ecological sensitivity and specific journey costs are higher. Collecting data on all lorries and the subordinate roads is essential to the effectiveness of this instrument.

By adding a 20% efficiency bonus to the toll system, additional incentives are to be created for use of more fuel-efficient lorries. The granting of the toll bonus should be based on the standard of 10 % of the most efficient vehicles in each case (top runner approach).

9.7.6 Increasing the German mineral oil tax

In spite of all the structural specifics of the transport sector, which make strong regulatory interventions necessary in this sector, the price signal for energy consumption is also an essential component of the policy mix for the transport sector. A strong price signal can not only create incentives for purchasing efficient vehicles, but also contribute to transport reduction and modal shift. It is also effective in terms of energy-efficient driving behaviour. The latter two points can prove important in the future if, within the scope of the developments assumed in the innovation scenario, the relation between original and operation costs significantly shifts in the direction of original costs, by means of which the incentives for reducing transport demand decrease and rebound effects may take hold.

Against the background of the necessarily broad approach of this instrument (vehicle efficiency, supported introduction of zero emission energies, etc.) and the limited choice of energy carriers, a non-standard situation arises for the transport sector – namely that a CO_2-based tax does not provide significant benefits compared to taxes based only on energy, which as a result enables the further development (and change) of existing fuel taxation instruments. Alternatively, however, gearing taxation to carbon content could be pursued – both options are equally valid in terms of the following considerations and have only marginally different effects.

The last increase in the German mineral oil tax was decided upon in 1999; it was increased in five steps from 1999 to 2003. Since then the rate has not changed. If inflation is taken into account, the rate has in fact fallen in the last six years; if the GDP is applied, the resulting decrease is approx. 8 %.

Furthermore it should be noted that the current under-taxation of diesel (based on volume) is counterproductive to climate policy and problematic in terms of energy policy, since diesel produces approx. 13 % higher CO_2 emissions than petrol per litre of fuel consumption due to its higher carbon content. Currently, the difference between the tax rate for diesel and lead-free super petrol (based on volume) corresponds to a carbon-related cost difference of approx. 104 € per t CO_2, which is not justifiable in the final analysis. In terms of energy policy, the substantial differences between the tax rates lead to substantial asymmetries between product demand and refinery emissions, with the result that substantial trade flows for mineral oil products have arisen globally. Due to shortages the price differences between petrol and diesel have become more moderate in recent years.

Therefore, as a first adjustment step the German mineral oil tax should be automatically adjusted according to inflation, which first of all ensures the tax rate in real prices.

As a second adjustment step the rate of the mineral oil tax for diesel (based on energy content) should be adjusted to the tax rate for petrol so that the emission-based distortions are removed (the energy-related differences between diesel and petrol in terms of CO_2 emissions are not significant, amounting to a maximum of 3 %).

As a third adjustment step the mineral oil tax should be increased in such a way that there is a real price of 2.00 €/l in 2020 and a price of 2.50 €/l for 2030 for conventional petrol. The corresponding diesel tax rates would then be determined on the basis of energy content. Compared to the price level assumed for the scenario development (see chapter 3.2), this corresponds to a price increase of 25 % in 2020 and 39 % in 2030. With price levels of this kind, rebound effects stemming from huge vehicle-based efficiency increases could be avoided and a further small transport demand reduction and modal shift could be brought about (Öko-Institut 2009).

9.7.7 Increasing the biofuel share alongside introduction of high and verifiable sustainability standards

The analyses of the scenarios and options have shown that (largely) zero emission energy carriers must be introduced in all areas within the scope of a 95 % reduction target, alongside all efforts made to hugely improve energy efficiency. These zero emission energy carriers have to cover the overwhelming majority of the remaining energy demand for 2050.

In the transport sector two different development paths can be followed. On the one hand the electrification of the transport sector can be hugely promoted in some cases (shift to rail with electric traction, electric passenger cars, etc.). On the other hand, there remain cases in which there is no foreseeable alternative to liquid fuels that is sufficiently comprehensive (some long distance passenger cars, freight transport by road, aviation, domestic maritime transport). For the time being, biofuels produced in accordance with strict sustainability requirements and using highly efficient transformation technologies, combined if necessary with CCS (see chapter 7.3.3), are the only foreseeable development path.

Selecting policy instruments for the introduction path of sustainable biofuels requires a complex approach towards, for example,

- integration in a comprehensive biomass strategy;

- integration in a consistent efficiency, demand reduction and modal shift strategy for the transport sector;
- integration in a carefully directed innovation strategy for development of highly efficient biofuels (predominantly based on the BtL path in the coming years);
- the creation of effective framework conditions and regulations for comprehensively guaranteeing the sustainability of biofuel supply; and
- development of instruments for introducing biofuels to the market.

Up to now biofuels have been put on the market in accordance with the minimum share laid down in the German Biofuel Quota Act[5] (this act also implements the target for using renewable energies in the transport sector fixed in the EU Renewable Energy Directive 2009/28/EG). The total share of biofuels (including using biomethane as a fuel substitute for natural gas) amounting to 6.25 % is to be ensured by 2014. As of 2015, there will be a shift from minimum shares to GHG reduction; the net GHG reduction (biofuels including upstream chains compared to fossil fuels) is to amount to 3 % from 2015, 4.5 % from 2017, and 7 % from 2020 onwards.

The greenhouse gas-based approach is generally – alongside the above-mentioned sustainability requirements and strategic integrations – a suitable approach for the further development of future instruments for guaranteeing the share of sustainable biofuels.

Against the background of the complex integration of this policy instrument, more detailed specification is not possible at this point. However, in the light of the model analyses for the innovation scenario and the additional option analyses of “Blueprint Germany”, it is clear that a 40 % greenhouse gas reduction target should be achieved by 2030 using sustainable biofuels. This holds both for the biofuels used to replace diesel and petrol and the biofuels used to replace mineral oil-based jet fuel.

As a crucial complementary measure, registration requirements for passenger cars and lorries have to be adjusted so that as of 2020 at the latest all manufacturers of the respective vehicles guarantee clearance for biofuel use only. This also holds for the manufacturers of engines and turbines for use in aircrafts by 2030.

9.7.8 Introducing a 120 km/h speed limit for German motorways

When the speed of a vehicle increases, a disproportional increase in fuel consumption occurs. This is above all due to an exponential increase in drag, alongside linear increases of rolling resistance. Consequently, the introduction of a speed limit would substantially reduce fuel consumption, especially in the case of high speeds, and thereby also emissions.

In addition, a long-term and standardised speed limit can have a positive effect on the manufacturers’ designs of passenger car. A relatively standardised international speed

[5] Biokraftstoffquotengesetz (BioKraftQuG).

limit enables optimisation of models towards lower performance cars which are highly efficient. Moreover, 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.

A standardised speed limit of 120 km/h should be introduced to German motorways. Furthermore, the speed limit can be supported by technical measures such as the installation of "speed limiters" or a restriction of the performance of new vehicles.

Further positive side effects of this measure are higher transport safety, less noise and air pollution, and a more effective utilisation of the infrastructure through better load distribution on the motorways.

9.8 Specific measures for the electricity sector

9.8.1 A moratorium on investments in new coal-fired power plants in Germany

The electricity production sector is the sector with the highest absolute emissions in Germany and is therefore of particular strategic relevance to emission reduction. This is even more so the case when it is taken into account that the electricity sector has a very durable capital stock. Therefore early and carefully timed measures are especially important.

Structures established in Germany under the conditions of the area monopolies and state sanctioning as well as under well-targeted interventions of energy policy (e.g. the national power generation laws which pursued in the past huge promotion of coal-based electricity production) can lead to at least part of, for example, the incentive systems introduced with emissions trading being counteracted.[6]

In the light of the severe consequences arising from an emission- and capital-intensive capital stock and above all geared to the very long term and will entail, with some probability, substantial pressure to change the emission reduction path or targets in the EU Emissions Trading Scheme, a halt on investments in new coal-fired power plants should be implemented.

There are various options for facilitating a halt on investments on new coal-fired power plants, ranging from a voluntary agreement to minimum standards for plant efficiency or CO_2 emissions. The construction of new coal-fired power plants should only be possible again when the CCS technology to be fitted in newly constructed power plants is commercially available, there are enough carbon storage sites that are sufficiently safe

[6] As long as, for example, the wholesale prices in the German electricity market are – for the historical reasons mentioned – determined by older coal-fired power plants (as price-setting marginal power plants), the risk for new coal-fired power plants of increasing or volatile prices of emission allowances is low. An increase in CO_2 prices caused by higher emissions or other framework data or the risk of volatile CO_2 prices also leads to higher cost risks for new power plants in such a market situation (when considered in isolation). However, the ostensibly higher cost risks are more than compensated by the pricing of emissions allowances in the case of power plants which set the market price (with lower efficiency and therefore higher CO_2 costs) and the resulting electricity price effects arising from additional electricity revenue.

in the long term, and the corresponding carbon infrastructures are in place (see chapter 9.9). The construction of new coal-fired power plants that only intends to incorporate retrofitting with CCS at a later date should be ruled out.

9.8.2 Further development of German RESA and framework conditions for renewable energies

To achieve the 95 % emission reduction target a large part of electricity production must be met using renewable energies up to 2050. The emission reduction target of 95 % cannot be achieved without a huge increase in electricity production based on renewable energies (also when certain shares of electricity production are still to be or must be covered by CCS power plants).

The huge increase of electricity production from renewable energies requires a number of flanking measures, which are currently implemented by, above all, the German Renewable Energy Sources Act (hereafter RESA) [7]. The key functions of the German RESA include, firstly, the priority feed-in of electricity production based on renewable energies; secondly, ensuring high investment security through guaranteed prices; and thirdly, the creation of innovation incentives by means of a corresponding degression of feed-in tariffs.

Alongside these three basic functions, a further goal should be pursued through this instrument, at least in the medium term: the more efficient use of biomass. At least as long as biomass is to be used in electricity production – which in light of the abovementioned prioritisation can only be pursued for a limited period of time – electricity production from biomass should only be promoted through the German RESA for electricity production in **combined heat and power** plants with a high degree of electrical efficiency. Thereby it would be possible to promote both the direct use of biomass and the (financial) use of biomethane fed into the gas networks.

In an electricity system with a very high share of fluctuating renewable energies (wind, photovoltaics), additional functions will continue to become more important in the flanking of renewable energies in electricity production:

- Electricity production plants based on renewable energies have to achieve a higher degree of **dispatchability**. Against this background the German RESA should be further developed so that innovations based on dispatchability and higher capacity factors for wind and solar power are incentivised at an early stage (wind power plants can, for example, achieve higher capacity factors through a greater tower height and a better ratio of disc area to installed capacity). For technologies which do not make an innovative contribution to the steering of an electricity system with a high share of fluctuating renewable energies (e.g. for wind power plants with a low capacity factor in northern Germany), the degression of feed-in tariffs should be more strongly developed.

- **The storage capacities** of the overall system will gain substantially in importance. Storage functions can be made available as indirect storage by means

[7] Erneuerbare-Energien-Gesetz (EEG).

of large-scale network integration that have been significantly strengthened or by direct storage technologies.

The design of the electricity market is of key importance to the future market integration of renewable energies. Up to now the market price for electricity has been determined on an electricity exchange according to supply and demand for each hour of the day. Currently each European country has its own electricity market. Many renewable electricity production technologies have very low variable costs (e.g. wind power and photovoltaics). In future this will tend to lead to prices always being low when the supply of, for example, wind electricity is large and the prices will be high when there is no or a low feed-in of wind electricity.

In order to decrease the fluctuating feed-in and avoid high volatilities on electricity markets, it will be necessary to bring about a huge increase in transfer capacities in border crossing points and guarantee a standardised price signal in a market area that is as large as possible (ideally for Europe as a whole). This enables the cost-effective integration of the large water reservoirs in Scandinavia and the Alps to ensure electricity demand is covered at all hours. In order to provide reserve energy for renewable energies, the creation of a German control zone is urgently needed. In the medium term the connection of the German control zone with neighbouring countries which have a complementary production profile (such as Austria and Switzerland) should be assessed.

In a perfect market substantial incentives would arise in this situation for storage operators to charge storages when electricity prices are low and discharge them when they are high, followed by marketing of the available electricity volume. The storage demand would then increase electricity prices and enable the operators of wind power plants to realise the contribution margins to finance the capital costs. However, a functioning and very liquid storage market is needed for this market-based mechanism. Along with the long-term transition to electricity production based on renewable energies in the competition market, flanking measures could be needed within the scope of infrastructural development.

In addition, flexibility potentials in demand have to be tapped. Large-scale consumers of electricity can play a crucial role in this context. In order to prepare electricity-intensive industry for this new task, the exceptions for these industry sub-sectors should be coupled in the German RESA, the German CHP Act, in eco-tax regulation, and in future in emissions trading regulation so that they have to make a contribution to the integration of renewable energies based on flexible load management.

For the medium term a comprehensive monitoring program should be started, based on which the real market functions and possibly other framework conditions (planning law, etc.) – e.g. with a view to increasing the (necessary) storage capacities and possible recuperation of investment via electricity exchanges – can be systematically assessed. Alternatives, such as the creation of markets for power plant and storage capacities through state regulation, should be prepared in appropriate analyses and developed in order to enable short-term implementation if necessary.

9.9 Measures related to innovation and infrastructure

9.9.1 Revision and expansion of the German biomass strategy

Biomass use constitutes an important and indispensable part of achieving ambitious climate protection targets. At the same time biomass is a limited resource for energy use and is – given the whole spectrum of ecological issues (from greenhouse gas effects to biodiversity) associated with its use – a highly sensitive issue.

Against this background the integrated development of biomass use is a key task of energy and climate policy in the future. The framework needs to be defined in a newly structured biomass strategy for Germany, which partly faces new challenges in the context of a 95 % reduction target:

- In which areas are there no alternatives to the use of biomass in the longer term? Where should the focuses of development lie (biofuels for freight transport and aviation, the feed-in of biomethane for industrial uses)? What is the relation between uses necessary in the long term and uses that are more efficient in the short term (electricity sector, micro-CHP)? How can the effects of long-term necessities that are counterproductive in the short and medium term be avoided?

- How can priority rules (e.g. with regard to prioritising waste and recycling management over energy use) be operationalised if necessary, taking into account the status of technological development?

- What milestones have to be set for key technological innovations involving biomass?

- What technical specifications have to be developed and implemented for biomass products and for what time horizons?

- What relation can and should be pursued – also taking into account sustainability requirements for biomass – between domestic biomass supply, biomass supply in Europe (Central and Eastern Europe) and global biomass markets?

- In what way can high sustainability standards be developed and implemented for biomass supply?

- How can key criteria for biomass-related instruments (e.g. reduction of greenhouse gases as a lead variable for the introduction of biofuels in transport) be operationalised?

- In elaborating a German biomass strategy, the interactions with other technological and structural developments must be taken into account (e.g. micro CHP).

Alongside the elements of the biomass strategy geared to the national analysis or situation, the German biomass strategy should be expanded to include international aspects. Key starting points are:

- compulsory development and implementation of sustainability and social standards in multilateral or bilateral regulations;
- detailed assessment of the possibility of early specifications of sustainability requirements and gathering practical experience with them and boundaries of intervention within the scope of investor agreements;
- interactions between biomass exports and domestic supply of energy and food; and
- impact on land use and area conversion.

A biomass strategy that is geared to new ends also provides an opportunity for developing the necessary innovation potential and dynamics within different and complex areas of biomass policy.

9.9.2 Innovation program for second-generation biofuels in Germany

In sub-sectors of the transport sector (freight transport, aviation), the use of biofuels is essential in order to achieve long-term climate protection targets.

At the same time, the balances of biofuels predominantly used today are in no way sufficient in emission terms and with regard to other ecological parameters to cover a significant segment of fuel supply in a sufficiently sustainable way.

In this context it is very important for large quantities of second-generation biofuels, which can draw upon a more extensive raw material basis for biomass, to be made available as quickly as possible.

The consistent promotion of technology and the early scaling of processes to industrial standards are essential. An innovation program for second-generation biofuels should be designed so that the total demand for biofuels can be covered by second-generation biofuels in 2020.

9.9.3 Innovation and market introduction program for electric vehicles in Germany

In the long term a huge increase in electric mobility is a crucial requirement for achieving huge emission reductions in passenger cars without using substantial quantities of biomass.

Electric mobility will only be able to make a successful contribution to emission reduction overall when, firstly, the technological development of the individual components and the technical system is sufficiently quick; and secondly when the introduction of electric mobility also leads to engine downsizing.

An innovation and market introduction program for electric vehicles should be created in which, for example, the incentive premium rates also depend on vehicle efficiency.

9.9.4 Innovation program for development and spreading of distribution networks with sophisticated load steering options

The incorporation of decentralised energy production options, such as large-scale optimisation of consumption and load, require a new, improved level of network optimisation for transfer and distribution networks. There will be no alternative to intelligent load management, particularly when there are significant shares of electric mobility. By dint of cost-effective information and communication technology it is becoming increasingly easy to pass on the price signal of electricity exchange to customers as an incentive signal, thereby developing new business models and system services.

Up to 2020 all distribution networks should be organised in such a way that uninterrupted connection to information processing systems can be realised. An important intermediate step is to upgrade all points of electricity use with smart meters and establish standardised information points by 2012. It should be possible within the framework of network regulation to recognise the costs of upgrading networks as investments.

9.9.5 Swiftest possible implementation of the German CCS pilot and demo projects

Extensive decarbonisation of industrialised countries like Germany requires emission reductions in all sectors. Carbon Capture and Storage (CCS) is a necessary building block for an ambitious climate policy of this kind.

Up to now discussion of CCS has focused on electricity production, in particular that of coal-fired power plants. However, the implementation of CCS in industry is more advantageous because its energy demand is generally lower and there are other emission reduction and efficiency options available in the energy industry. In addition CCS can, combined with biomass incineration, serve as a net sink. Finally, the upgrading of natural gas-fired power plants to include use of CCS technology may prove necessary in the future.

In terms of carbon capture the clear focus of state-supported German CCS pilot and demo projects should therefore now be geared towards industry processes. In the time up to 2020 pilot plants should be built for the production of cement, lime, crude iron, hydrogen, biofuels, biomethane, and electricity. There are sufficient means for this purpose on a European level as a result of an EU emission trading regulation and the European stimulus package.

Furthermore, the testing of carbon storage sites needs to begin in the near future. In order to conduct a practical test of the density of different formations, several pilot storage sites should each be filled with 100,000 t CO_2 per annum. CO_2 that is already readily available – e.g. through bioethanol production – should be used for this purpose.

In order to achieve these goals, the support programs planned for CCS should be designed and used on a European level so that support is based on tonnes of stored CO_2. Means should be made available for each carbon capture technology. In order to set incentives for quick storage testing, promotion should – e.g. in the German RESA – be structured degressively.

9.9.6 Development of a German CCS development plan and a legal framework for CCS

In order to be able to guarantee effective management of limited CO_2 storage capacities, the contribution of CCS to climate protection expected in the future has to be specified for the whole spectrum of carbon sources relevant to CCS (electricity industry, industry processes, biomass industry).

Alongside assessment of the availability of geological formations suited to carbon storage, closer determination of the contribution to emission reduction that can be achieved by this measure is a key task for a German CCS development plan.

The necessary work involved should be coupled with an extensive information campaign for all CCS technologies. Information, the highest possible safety standards, fair treatment of competition for use in the widest sense and for both over- and underground sites (e.g. geothermal use or the building of gas or compressed air storage) and equal treatment of regional interests are crucial. Systematisation and assessment of carbon storage potentials is a necessary first step to this end.

Development of a concrete vision for the necessary expansion of infrastructure – analogous to corresponding work undertaken for high voltage electricity networks – is necessary to integrate and further develop the above-mentioned processes.

Thus, the first infrastructure projects for carbon transport should be organised in such a way that they can cope with a greater CO_2 volume than that used in the first demo projects. The risk in terms of CO_2 volume and the timing of making use of transport services could be sufficiently compensated by (partly) public ownership, a refinancing model based on charges for network use and deficiency guarantees as a flanking measure.

As a next step a regulatory framework has to be created for CCS which enables and promotes the necessary implementation of demo projects for all relevant technologies. In the light of demo projects and the existing need for consolidation of necessary knowledge and the current gaps in terms of institutions and instruments, this regulatory framework is not allowed to be designed in a prohibitive way. However, it has to accommodate the particularly high growth of knowledge and experience in the demo period.

The regulatory framework has – in view of the complexity of the respective technologies – to be designed so that reliable experiences can be gathered with the regulatory framework, institutions, and procedures in the demo period; and corresponding (market) developments (insurance products, expert assessment/certification, etc.) can be triggered. Only in this way can the protection of the environment and health be guaranteed in the long term in the case of extensive commercial use of CCS technology. And only in this way can emerging economic burdens be fairly allocated without it resulting in unacceptable delays for climate policy.

This regulatory framework must solve use conflicts that arise both in the short term (the demo project period) and in the long term (the period of commercial use). For the limited number of demo projects, possible solutions based on specific cases are sufficient; in the longer term comprehensive regulations will be needed.

In the long term the regulatory system should provide ecological incentives for future carbon networks to facilitate transportation of captured carbon over distances that are as short as possible.

9.9.7 Development of a re-organisation program for energy infrastructure in Germany

All strategies for achieving long-term reduction targets require huge re-organisation of different parts of infrastructure.

Integration of this re-organisation and the development of a necessary regulatory framework should be bundled in a German re-organisation program for energy infrastructure. Key elements of this program are:

- development of options for the necessary re-organisation and expansion of transport and distribution networks for electricity, gas, CO_2 (in the context of CCS technology) and rail transport; identification of interactions, uncertainties and robust development options, including specific aspects like the use of biomethane and long-term expansion of network integration with a view to long-term storage demand;

- elaboration of infrastructure roadmaps which appreciate the interactions of the individual elements of climate and energy strategy with the different components of the infrastructure; and

- identification of areas of infrastructure which require a special role within the public authorities as public goods or as basic public services.

In parallel and based on the infrastructure program, requirements should be created within the framework of regulation which, firstly, recognises necessary investments in the infrastructures – even if they have to occur under uncertainty and involve long lead times – as costs under infrastructure regulation. Secondly, the regulatory bodies have to be given the task and competences to realise projects identified as essential within the scope of re-organisation planning on time and bindingly and to facilitate relevant interventions, if necessary.

Against this background the spectrum of tasks and competencies of regulatory bodies for infrastructure – in both German and European frameworks – should be expanded so that they focus on the planning and implementation of reorganisation of infrastructure necessitated by climate policy, which has a long run-up period, and, if necessary, involves uncertainties that are not unsubstantial.

9.10 Measures related to industry processes

9.10.1 Compulsory introduction of CCS for the process-related emissions in steel, cement and lime industries in Germany

In contrast to energy-related emissions, process-related CO_2 emissions do not arise from the combustion of fossil energy carriers, but rather through the physicochemical characteristics of the materials used. For a (too) long time process-related emissions have been classified as unavoidable.

However, there are a number of options, on the basis of which process-related CO_2 emissions can be reduced:

- A basic option for decreasing process emissions is the substitution of materials used with high process emissions (e.g. the addition of fly ash or slag sand in cement production to reduce the share of clinker; with regard to steel, an increase in the recycling share reduces emissions).

- The very emission-intensive production of hydrogen as a raw material for many chemical products can be transferred to production based on renewable energies.

- The remaining CO_2 emissions can be stored in geological formations using CCS technology.

Therefore, the use of CCS should be made compulsory from 2030 onwards at the latest for process-related CO_2 emissions of cement, lime, iron and steel industries in Germany if the EU Emissions Trading Scheme has not facilitated extensive use of this technology by that time.

9.10.2 Package of measures for fluorinated greenhouse gases

In the past, fluorinated greenhouse gases were one of the few sources with increasing emissions. They are used as fuel as well as cooling and fire-extinguishing agents. Fluorinated gases have a particularly high greenhouse gas potential. This potential varies greatly between the specific gases, amounting to a factor of 100 to 15,000 above the greenhouse gas effect of CO_2. Up to now the measures for this very heterogeneous source of emissions have generally consisted of voluntary commitments and moderate regulation. The EU f-gas regulation (EG 842/2006) aims at a reduction of the leakages from cooling systems by means of higher requirements for the performance and maintenance of such systems.

The package of measures for reducing fluorinated GHG includes tasks for regulation, such as prohibition of the use of f-gases as cooling agents from 2015 onwards and taxing the use of f-gases (with the specific tax rate depending on the greenhouse potential of each individual gas).

The leakages of hydrochlorofluorocarbons (HCFCs) from air conditioning systems are particularly high in all vehicle types because of their design. However, it is possible to replace them with natural cooling agents. The use of HCFCs in mobile cooling systems and PU foam products (polyurethane foam) in XPS hard foams and aerosols (pump and technical aerosols) should be forbidden.

Regulatory prohibition has to be supported by putting a price on the use of f-gases. The price signal should be guaranteed either by introducing a tax for use of these very harmful greenhouse gases or by integrating them in the EU Emissions Trading Scheme (on the level of producers, importers or emitters). Due to the high greenhouse gas potential, the effect of a price signal is particularly strong and will engender technical innovations. As a result the development and use of substitutes for these f-gases will become profitable.

9.11 Waste management measures

9.11.1 Promoting waste avoidance in Germany

The promotion of waste avoidance and recycling and the efficient use of materials for energy-intensive products should be significantly expanded and intensified within the scope of existing regulations.

9.11.2 Special measures for promoting use for energy production in Germany

The use of organic residues for energy production has a particularly high priority in a long-term emission reduction strategy. In particular special emphasis should be placed on the fermentation of biomass, given that biomass is a limited resource and that demand for biomethane is to significantly increase in the future.

Thus, the treatment and use of organic waste with processes other than fermentation should only then be permitted by regulation when the use of waste to produce biomethane is not technically possible.

9.12 Agricultural measures

9.12.1 Development of a package of climate and health measures for decreasing animal husbandry in Germany

Approx. half of the greenhouse gas emissions arising from agriculture result from animal husbandry; cattle kept for milk and beef production are the most significant emitters. Further significant CH_4 and N_2O emissions stem from pig and poultry husbandry for meat and egg production.

The energy and protein intake of the German population from animal products is too high (as a result they are subject to high health risks). Meat consumption in Germany currently amounts to approx. 60 kg per person per year; from a health perspective, the optimal quantity to consume is estimated at approx. 20 kg per person per year. The consumption of animal products could successively fall to approx. 20 kg by 2050 without limitations and, where appropriate, with the side effect of reducing health risks.

The lower volume of animal products consumed can lead to a significant decrease of livestock in Germany while it is still possible to guarantee the full self-sufficiency of the domestic population. As a result agricultural greenhouse gas emissions will strongly decrease. This can be achieved by a package of health and climate measures, including:

- information campaigns in which the general public and the gastronomical sector are educated about the impact of overconsumption of animal fats and proteins as well as the related health risks; at the same time perspectives of a healthy eating program should be provided;
- motivational campaigns to encourage public cafeterias in pre-schools and day care centres for children, schools and universities, authorities and ministries to provide meals not predominantly based on animals products;
- volume- and/or price-related instruments which lead to reduced meat consumption via price signals; and
- regulatory limits on the permitted number of livestock per area and/or tax incentive measures which make livestock reduction attractive to the agricultural sector.

However, alongside the above-mentioned measures, innovation efforts for the production of high-quality foods from plant raw materials (which resemble or correspond to the protein levels of animal-based products) are an additional element of an integrated package for reducing agriculture greenhouse gas emissions based on demand.

9.12.2 Integration of conversion processes for farmland which becomes available for use in the package of area conversion measures

A decrease in livestock means that parts of farmland which were previously used for feed grain production can be used for other purposes. In the course of these transformation processes, financial incentive measures should encourage the agricultural sector to promote the:

- increase of organic farming;
- increase of sustainable energy plant production (biomass);
- increase of sustainable, domestic protein feed production;
- use of land as flood areas as part of flood control measures; and
- integration of ecological priority areas in farmland (nature conservation).

By means of increasing organic farming and energy plant production, the greenhouse gas emissions stemming from agriculture can be further reduced.

In ecological operations, animals are almost always given “in-house” feedstuffs, as a result of which energy consumption decreases. Furthermore organic farming is particularly environmentally friendly, protects the soil and drinking water, and avoids residues from chemical and synthetic pesticides getting into food.

By using parts of the newly available areas to increase sustainable energy plant production, the potential of biomass to be used for energy purposes as solid, liquid or gaseous fuel can be substantially increased. As a result, fossil energy carriers can be increasingly replaced in transport, and electricity/or heat production.

Using cropland as a flood area as part of flood control measures and nature conservation leads to lower N_2O emissions because no manure is needed at all.

9.12.3 Regulating gas-tight storage of liquid manure and support measures for increasing use of liquid manure for energy purposes and crop residues in biogas plants

In animal husbandry, CH_4 and N_2O emissions arise from animal excrement (as liquid manure, slurry and solid manure) in stables and hutches, during storage and up to use, for example, as fertiliser on agricultural soil. Up to now the approval procedures for building sites for storing liquid and solid manure have chiefly concentrated on soil and water conservation by assessing how leakproof the plants are. In the case of liquid manure held in outside storage, it is sometimes possible to eliminate CH_4 and N_2O emissions at low cost. Placing a gas-tight cover over liquid manure should be made compulsory in agricultural operations by regulation. If re-construction measures are required for this purpose, the farmers should be able to draw upon support measures. Gas-tight covers have to be developed for solid manure storage. However, at least in larger animal husbandry operations which store solid manure, drivable concrete slabs are conceivable as a simple solution to gas-tight covers; existing storage areas can also be retro-fitted with these. To this end, model projects for testing suitable covers should be initiated by the state.

Another particularly effective measure for reducing CH_4 emissions from industrial manure is the fermentation of liquid and solid manure in biogas plants. This is already promoted within the German RESA through a special bonus. The most effective measure is the use of biogas in block heat power plants for the simultaneous production of heat and electricity. If there are too few heat customers in the immediate surroundings of biogas plants, the possibility of developing a district heat network should be assessed. In the case of larger biogas plants, promotion via the German RESA should be replaced by promotion of conditioning biogas to the quality of natural gas (biomethane) and feeding it into the natural gas network.

The fermentation residues which arise in biogas plants as “waste products” should be used as high-quality industrial fertilisers on the fields. Due to the fermentation process, the residues contain ammonium, which is more stable than nitrate and therefore decomposes more slowly. This results in lower N_2O emissions. However, fermentation residues continue to emit methane, which is why the storage of fermentation residues also has to be included in the compulsory use and, if necessary, promotion of gas-tight covers.

9.12.4 Increasing share of organic farming on German cropland to 25 % by 2030 at the latest

Organic farming can make an important contribution to the reduction of greenhouse gas emissions since their emissions are lower than those of conventional farming. In accordance with the 2008 Progress Report on the national sustainability strategy of the German government, the share of land available within total farmland for organic farming should be increased step-by-step from 5.1 % in 2007 to 20 % in 2020 and 25 % in 2030. This results in a proportional decrease in production, use of synthetic fertilisers and associated emissions. Humus management, which is obligatory in organic farming, leads to an increase in the humus content of the soil, with the result that carbon absorption increases.

The transition to organic farming is to be provided for in appropriate support programs with higher incentives.

9.12.5 Developing a package of measures for fertiliser management

With the goal of focusing Common Agricultural Policy of the EU (CAP) on climate-friendly agriculture in the long term, instruments and measures are to be developed which both allocate subsidies to climate protection efforts and integrate agriculture in legal regulations on climate protection.

The level of N_2O emissions stemming from cropland greatly depends on the quantity of fertiliser used. To increase nitrogen efficiency, support instruments for improved fertiliser management need to be elaborated. To reduce the quantity of fertiliser used, limiting the application share and use of application technologies should be promoted, which enables the quantity of fertiliser used per unit of land ("precision farming", injection procedures, the CULTAN injection technique) to be regulated. In addition, the use of slow-acting fertilisers also needs to be taken into account. The obligation to use appropriate fertilisers laid down in the German Ordinance on Fertilisation (e.g. the prohibition of fertiliser production in winter, § 4 (5)) should involve sanctions in all future forms of EU agricultural promotion.

A reduction of surplus nitrogen should be achieved by increasing the cost of nitrogen use – a charge should be introduced for this purpose. The charging of surplus nitrogen can be levied on the operation level and should limit the total balance surplus to 80 kg of nitrogen (N) per hectare and year up to 2010. Reducing the total balance surplus, which currently amounts to 110 kg N per ha and year, is also the target of the 2008 national sustainability strategy of the German government. In a second step, surplus nitrogen should be limited to 40 kg N per ha and year up to 2020. The revenue from the charge should be used to promote improved fertilisation management, the training of farmers, and research.

9.13 Land-use measures

9.13.1 Promotion of forestry measures which aim at sustainable forest management and maintaining/increasing the forest sink

Due to the decision to incorporate forest management in the Kyoto Protocol as an additional measure for achieving greenhouse gas emission reduction targets, it is possible to generate so-called forest sink credits. The co-operation of forestry in this potential benefit is linked to the promotion of wooded areas and their sink capacity.

In the same way support instruments for sustainable forest management should be developed which aim to preserve the carbon stock of existing wooded areas. Existing sinks can be increased by means of climate-friendly re-organisation of the forestry sector (diversification and stabilisation of wooded areas, production of indigenous forest species), afforestation which takes into account the promotion of natural forest communities and forest management measures linked to market conditions and nature conservation targets. Furthermore building materials, the production and supply of which entail significant greenhouse gas emissions, should be substituted as far as possible with sustainably produced wood for energy production; finally, the potential of sustainably produced wood for energy production should be tapped as extensively as possible.

9.13.2 Limiting conversion of unsealed areas within regulation

In accordance with the target of the German government, area use – i.e. the conversion of undeveloped areas in residential, transport and industry areas – should be reduced from approx. 110 ha/day today to 30 ha/day by 2020. Reduction of the deforestation rate – based on the wooded share of areas subject to conversion – should be provided for in administrative regulation.

9.13.3 Developing of a package of measures for area conversion

To reduce areas containing organic soil which are used agriculturally and decrease the drainage of organic grassland, a bundle of instruments and support measures should be elaborated, on the basis of which support funds are made available for climate protection efforts. This includes renaturation of such areas with subsequent wetland conversion.

In addition, incentives for alternative uses should be developed. Paludicultures (fens) as site-appropriate land use can enable the transfer of EU agricultural support measures by producing energy biomass via reed cultivation on fens.

9.13.4 Tightening regulations on land conservation as a requirement for subsidy payments within the scope of a new EU agricultural policy

With the goal of focusing EU agricultural policy on climate-friendly land use in the long term, grassland should be more strongly safeguarded in legal regulations. In this way, the compulsory maintenance of permanent grassland could be a requirement for receiving EU agricultural funds. Sanctions for failure to safeguard the current grassland share should be increased for the subsidy applications for "areas" in accordance with 1782/2003 (EG) within the framework of cross compliance.

The ploughing of grassland can be further decreased through the target of the German biodiversity strategy. The area share of ecologically valuable habitats, such as high value grassland, should be increased by at least 10 % up to 2015 compared to 2005.

10 Conclusions and outlook

By continuing current energy and climate policy (even ambitiously), use of customary technologies, and current energy and resource consumption patterns, a reduction target of 95 % for total greenhouse gas emissions by 2050 (compared to 1990) cannot remotely be achieved. Continuation of the ambitious energy and climate policy as assumed in the reference scenario would mean that approx. a 45 % reduction of greenhouse gas emissions can be expected at best in the period from 1990 to 2050.

An emission reduction path that is consistent with international efforts and which limits the increase of the average global temperature to below 2°C compared to pre-industrial levels requires many crossroad decisions to be taken at an early stage. The assessments of the innovation scenario and the further analyses elucidate the following challenges for necessary changes up to 2050:

- Substantial efforts to bring about a huge increase in energy efficiency should be made straight away. Without an increase in energy efficiency amounting to at least 2.6 % per annum, it is extremely unlikely that the emission reduction target will be reached.
- In all sectors, the remaining energy demand should be met using renewable energies; the use of CCS is essential for the main share of remaining emissions from fossil fuels and industry processes.
- A large share of the necessary changes involves plants and infrastructures with a long operational life, long lead times or lengthy transformation processes. Policy strategies and measures have to be continually assessed in terms of their consistency with necessary long-term developments.
- Alongside measures for energy-related greenhouse gas emissions, substantial reductions of non-energy related emissions are also essential. Increased emission reductions in industry processes, agriculture and land use are crucial.
- Emission reductions in the medium and long term in particular require comprehensive innovations which should be developed in a well-directed manner and introduced to the market quickly and at an early stage.

Even when there is no alternative to reduction efforts for the whole spectrum of greenhouse gas emissions, achievement of the 95 % reduction target up to 2050 will, with high probability, be impossible if the following crossroad decisions are not successfully implemented in Germany:

- significant reduction and stabilisation of electricity demand to 35 % below current levels, also in the case of a huge introduction of electric drives in the transport sector;
- increase of electricity production from renewable energies to 95 % (when CCS power plants are used, the increase should be to more than 50 %);

- rehabilitation of existing buildings so that the room heating demand is (practically) zero and early introduction of a zero energy standard for new buildings;

- substantial modal shift which requires, for example, a doubling of freight transport capacities to rail and a huge increase of public passenger transport;

- an efficiency improvement of passenger cars amounting to 60 % on average and an efficiency improvement of freight transport by road of more than 30 %;

- a huge shift of passenger cars to electric drives with the remaining fuel demand in passenger car, freight and aviation transport being met using sustainably produced biofuels;

- reduction of process-related CO_2 emissions from the iron and steel industry and cement production based on huge savings in materials or substitution and the use of CCS in industry;

- meeting the remaining process heat demand in industry by using sustainably produced biomethane;

- huge emission reductions in agriculture and land use.

The key innovations which will play a crucial role in the implementation of the long-term emission reduction path include in particular:

- battery technologies for electrical vehicles;

- efficient cooling production for air conditioning purposes;

- high performance thermal insulation and high performance windows, reactive window coatings;

- technologies which increase daylight use and corresponding architectural models;

- development of all new key technologies, placing specific focus on their contribution to increasing energy efficiency (bio-, nano-, ICT- and micro-system technologies);

- substitution of products which require energy-intensive production with tailored alternatives which have similar characteristics;

- consistent downscaling of processes (decentralised production) and regulation;

- substitution of conventional thermal processes with innovative biotechnological processes;

- highly efficient processes for biofuel production based on very varied waste material and biomass;

- more effective carbon capture technologies and the solving of storage-based safety questions;

- third generation photovoltaics (based on polymers, colouring agents, etc.) in order to reduce dependency on strategic raw materials; and

- fundamental research on geothermics: safety, exploration and predictions of underground sites.

Alongside a multitude of technical innovations, changes in all production and consumption patterns as well as huge structural change are unavoidable. Furthermore, necessary changes can only then be realised upon successful development of a consistent, systemic perspective of the necessary transformations:

- Manifold changes of energy supply and demand require a huge new and re-organisation of electricity, gas and CO_2 infrastructures as well as systematic approaches geared to the long term for system and market integration of climate-friendly technologies, particularly in terms of fluctuating feed-in of electricity based on renewable energies.

- Huge emission reductions necessitate new strategic assessment of the approach to limited resources for a number of important climate protection options. Biomass use must address – alongside the issue of quantities available nationally, internationally and in Europe, and the need to use the resource as efficiently as possible – the question of the cases where there is no other alternative in the long term but to use biomass. Limited carbon storage reservoirs make priorities of use necessary for CCS, along with corresponding management of storage resources.

- Necessary strategies for the sustainable production of biomass must include the development and implementation of high sustainability standards (which involve substantial preparation).

The extra costs of huge emission reduction based on the strategies pursued in the innovation scenario seem practicable in terms of investment, amounting to a maximum of 0.6 % of the German GDP. However, the burdens are distributed disproportionately (e.g. high, non-amortisable investments in buildings). Effective instruments for the allocation and distribution of extra costs must be created.

What is needed are extensively more ambitious, better coordinated and more complex instruments and instrument packages than those discussed up to now in energy and climate policy, integration of these instruments in targets and policy strategies geared to the long term and broad social consensus on strategic goals and balanced burden sharing. In particular, this broad social consensus must incorporate extensive tapping of renewable energy potentials and/or carbon storage options, and the necessity of changed mobility and consumption patterns.

Beyond emission reduction potentials that can be tapped technically and economically and the policy instruments needed to implement them, it will also be necessary in the end to garner supportive acceptance from the German population for necessary restructuring processes. For this purpose, a comprehensive social discussion process is essential. Developing and accompanying this process with other social groups is a long-term and strategic task.

Alongside policy frameworks the realisation of the whole spectrum of emission reductions requires a plethora of new stakeholders. Energy and climate policy geared to ambitious climate protection targets needs to pursue a great diversity of stakeholders as well as high competition intensity as a separate goal; it must also prevent development of market structures which act as barriers to innovations.

The strategic goals and necessary development of technologies, infrastructures and business models require integration in an international context, on the basis of which one-sided burdens of industry subject to global competition and leakage effects can be avoided. This should include fair (ambitious) commitments of all industrialised and current newly industrialising countries, technology transfer and international offsetting mechanisms. Above all, internationally coordinated and work-sharing cooperative technology development is advantageous for time-saving and cost efficiency reasons.

The re-organisation of the economy, above all gearing the energy industry to completely new goals, is a complex challenge, but in no way an unsolvable one. Careful analysis, clear strategies, a diverse range of new stakeholders, and a multifaceted exploratory process are necessary. Ambitious and comprehensive targets have to be set and clear decisions must be made. Policies and measures have to be designed so that they are simultaneously innovative, consistent and flexible in a new way.

Notwithstanding the importance and necessity of European and international integration of many implementation measures for an emission reduction path like the one developed in “Blueprint Germany”, Germany is called upon to develop a sound national strategy which aims to meet a 95 % emission reduction target in the long term. Such a strategy is necessary to assess the consistency of all policy measures. The strategies and measures developed within the scope of this report can create a reliable basis for national policy development that is strongly geared to innovation, climate protection and to Germany assuming a leading role.

The overarching strategic vision could be summarised as “the 6i strategy”:

- innovations of all kinds,
- infrastructures of the future,
- industrial creativity,
- integrated strategies,
- intelligent regulation, and
- international cooperation.

The target of extensive decarbonisation in a highly developed industrialised country, made necessary by severe increases in global warming, is not only an appropriate vision for the long term. First analyses on the detailed implementation of this target are already engendering fresh insights and in some cases surprising clarity – which also have not unsubstantial effects for action taken by policy and companies in the shorter term.

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Annex B Prefixes and energy unit conversion factors

Prefixes

Name (symbol)	Factor	Name (symbol)	Factor:
Nano (n)	10^{-9}	Mega (M)	10^{6}
Micro (μ)	10^{-6}	Giga (G)	10^{9}
Milli (m)	10^{-3}	Tera (T)	10^{12}
Kilo (k)	10^{3}	Peta (P)	10^{15}

Energy units (conversion factors):

From: \ to:	J	TJ	kWh
J	1	1×10^{-12}	0.2778×10^{-6}
TJ	1×10^{12}	1	0.2778×10^{6}
kWh	3.6×10^{6}	3.6×10^{-6}	1
GWh	3.6×10^{12}	3.6	1×10^{6}

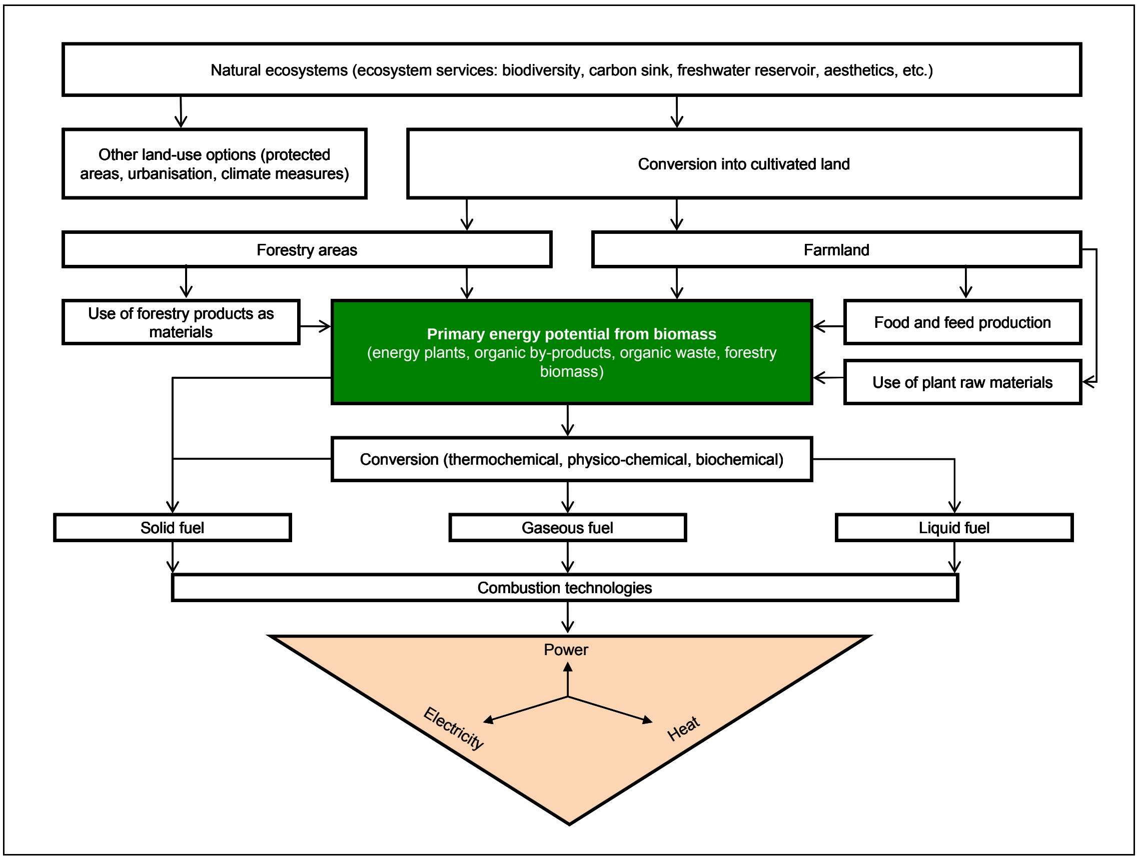
Annex C Biomass

C.1 Sustainable biomass potentials

C.1.1 Introduction

Recently there has been controversy about the production of biomass for use as bio-energy carriers. Those in favour cite climate and environmental protection, guarantee-ing energy and supply, and rural development as arguments in support of such produc-tion. As renewable energy carriers, biomass is categorised as climate-neutral. Biomass is a storable energy carrier and converted into different forms for use by means of dif-ferent processes. In this way the possibilities of use as bioenergy are manifold, both in terms of supply and use. Each conversion stage involves different emissions, (external) costs and/or efficiency. The following figure provides an overview of the bioenergy sys-tem, serving at the same time as a basis for the remainder of this excursus.

Figure C- 1: Overview of the bioenergy system



Source: Prognos 2009 based on WBGU 2009; Kranzl et. al. 2008

The following considerations are based on the results of the WBGU expert report enti-tled “Sustainable bioenergy and land use” (WGBU, 2009), unless stated otherwise. The supply side is systematised above the dotted line. The crucial question here is what primary energy potential can be made available in a sustainable way, taking into con-sideration competition for use. The area potential available for sustainable bioenergy production is decisive in this context; in the determination of this potential competition for use of the limited areas for other purposes is taken into account – competition which always arises in the case of each land use change.

The possible kinds of energy use and use chains are presented in the diagram below the dotted line.

In the case of limited production potentials, the question of the optimal use of biomass has two different aspects:

4. "Efficiency": How can the determined primary energy potential be used to achieve the highest possible reduction of greenhouse gas emissions, i.e. what technical use chain is to be selected? Each use chain comprises several sub-processes, beginning with energy plant production, making biogenic residues available, to final energy supply. Within each sub-process one of several options can be chosen, which leads to a multitude of different use chains with different efficiencies, costs, greenhouse gas emissions and interactions with the eco-system.

5. "Effectiveness": Are there cases in this context where there is no alternative but to use biomass to achieve an emission reduction target in fulfilment of a service (e.g. industry production or transport services)?

C.1.2 Primary energy potential of bioenergy

C.1.2.1 Competition for land use

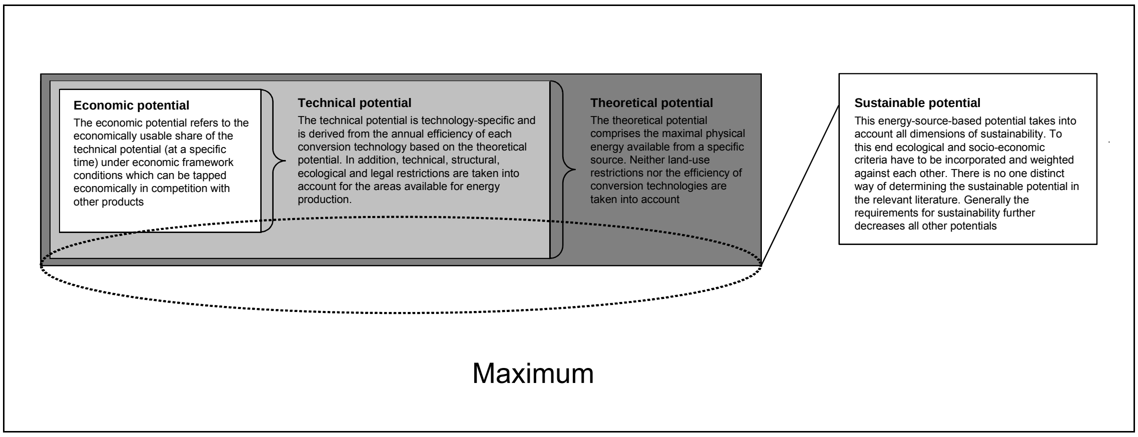
The potential available for biomass production is limited, but not fixed to absolute levels: The ice-free areas needed for biomass are given by nature and the efficiency factor of photosynthesis is subject to a natural limit. Thus the biomass potential which can be renewed in the biosphere is finite. However, bioenergy production is only one of many possible uses for these areas and is therefore to be assessed in the context of competing needs and requirements.

Natural land-cover consists of wooded areas and grassland which have important functions in the eco-system, not least of all biodiversity, which provides a multitude of "services" for the eco-system (e.g. coastal protection, water balance, pollination, genetic blueprints). In its function as a carbon sink, wooded areas and grassland draw CO_2 from the atmosphere and store it in organic elements and in the soil. When humans make use of these capacities it constitutes one kind of anthropogenic land use. Land use change is when humans change the natural environment for the purpose of a different kind of land use. In terms of areas cover, the most significant intervention on this first (anthropogenic) level is the conversion of cultivated land for the production of forestry and agricultural products. Such conversion is in direct competition with other land use options such as the designation of areas as nature conservation areas to preserve the natural environment or the use of areas for other climate protection measures (e.g. solar or wind power plants could be installed in the areas, which can potentially supply final energy more efficiently than biomass transformation). Another option is to use the area as urban living space, but this – in spite of strong increases in global population – is not very significant, covering only 5% of the land area. Overall, human intervention has led to over three quarters of land-use changes in ice-free areas.

In the case of forestry use of cultivated land, bioenergy production and the material use of biomass are in competition for land-use. Currently the share of direct wood used as firewood is approx. 40%. Almost all of this stems from the high share of traditional biomass use in developing countries. For the direct use of areas subject to forest management for bioenergy purposes, chiefly the use of logging residues, uncultivated growth and single trees not suited to industrial use is considered. In industrialised countries the most important use of forest biomass is the material use (wood pulp products, furniture, building materials); however this kind of use can also contribute to the primary energy potential for bioenergy via diverse accruals (sawmill by-products, black liquor, cascade use) (Kranzl et. al., 2008). In addition, it should be taken into account that material use can also be a climate protection option since – alongside carbon storage – the use of, for example, emission-intensive materials can be avoided (e.g. concrete production).

A large share of land use changes from uncultivated to cultivated land originates in agricultural activities. Globally, approx. 50 million km^2 is currently used agriculturally, 69% of which is used as pasture land and 31% as cropland. There is direct competition between energy plant production and the two alternatives of food & feed production and material use of plant raw materials (synthetic materials, cosmetics, textiles, etc.). This is because not only areas are withdrawn from use, but also the same plant raw materials can be re-used many times. In addition to direct competition, there are also a number of indirect effects. Since the same agricultural raw materials and capital resources are generally used, energy plant production would, under conditions that otherwise stay the same, lead to a price increase of food through indirect effects. This impact is made stronger by the fact that increasing wealth in parts of the world is leading to a change in eating habits from plant-based foods to food rich in fat and protein. This change in eating behaviour requires substantially more area to supply the same energy volume (compared to carbohydrates), which leads in turn to an effective reduction of areas available for food production, thereby driving the price. It should also be taken into account that both food production and use of plant raw materials contribute to the primary energy potential via by-products and waste products (e.g. liquid manure, crop residues, and organic waste).

Figure C- 2: Bioenergy potentials



Source: Prognos 2009 based on WBGU 2009

However, which areas are available for direct production of bioenergy depends on which criteria are used to determine the potential. In most studies, the technical potential is shown. The WGBU determines the sustainable technical potential in its report.

The sustainability requirements are derived from the above-mentioned competition for use. Due to the available areas being limited, it is necessary to lay down priorities of use. In terms of sustainability, priority is placed on those land uses which yield capacities that cannot be substituted or are essential (e.g. biodiversity, sufficient food production). Proceeding in this way, the available primary energy potential for bioenergy has to be successively reduced in each conversion step.

To implement these sustainability requirements, the WBGU developed a plan for boundaries of action. These boundaries are defined by limits of damage, the transgression of which would have ecological or socio-economic consequences that cannot be tolerated. Table 4.3-28 provides an overview of the action boundaries developed by WGBU. However, compliance with these boundaries is a necessary, but not sufficient criterion for sustainability since several requirements are difficult to quantify or cannot be implemented globally. These aspects have to be taken into account case by case when elaborating national sustainability requirements. Alongside questions of food competition, for example, this includes the possible prioritisation of biomass use in newly industrialising countries within the domestic energy supply or the prioritised use of residues and waste.

Table C- 1: Ecological and socio-economic boundaries of action

Guard rail	Commentary
Ecological sustainability	
Climate protection	(1) Mean global rise in temperature > 2°C from pre-industrial levels or a rate of temperature change > 0.2°C/decade >> requires concentration of greenhouse gases in atmosphere to be stabilised below 450ppm CO2eq. (2) PH level of the uppermost ocean layer should not fall by more than 0.2 units against baseline of pre-industrial levels.
Biosphere conservation	Designated as parts of a system of protected areas: (1) 10-20% of global area of terrestrial ecosystems and river ecosystems (incl. catchment areas); (2) 20-30% of area of marine ecosystems. Priorities: endangered species, special uniqueness, nature untouched by man, gene centres, species richness.
Soil protection	Maintaining the natural yield potential over a period of 300-500 years. Soil degradation attributed to (1) erosion (tolerance limit: 1-10 t/ha/year) and (2) salinisation (should not exceed the level that can be tolerated by crops in common use over a period of 300-500 years).
Socioeconomic sustainability	
Access to food	Bioenergy production removes land as well as agricultural and living resources from food production; securing the world food supply must take precedence. FAO def.: When all people, at all times, have access to sufficient food that is safe and nutritious. (1) Necessary requirement: Agricultural land available globally must be sufficient to enable all to receive food with average calorie content of at least 2700 kcal (11.3 MJ) per person/per day
Energy services	(1) Access to "clean" energy; min.: 700-1000 kWh per capita/year.
Avoiding health risks through energy use	Standard of living & health are human rights > tension between the two: (1) Proportion of regional Disability Adjusted Life Years (DALYs) attributable to urban and indoor air pollution should be reduced to below 0.5%.

Source: Prognos 2009 based on WBGU 2009

C.1.2.2 Modelling sustainable bioenergy potential

To simulate the global sustainable bioenergy potential, the global dynamic vegetation model LPJmL (Lund-Potsdam-Jena managed land) developed by the Potsdam Institute for Climate Research is used (Beringer/ Lucht, 2008). Based on process-orientated depictions of the most important biogeochemical, biophysical and biogeographical mechanisms, LPJmL is able to simulate the extensive distribution of very different types of vegetation. On this basis parameters are derived such as plant productivity and the exchange of carbon dioxide and water between plants, soil and the atmosphere. The model is capable of showing both natural and human-influenced/–used ecosystems. Natural biodiversity is represented in the model by nine plant functional types and the agricultural crops by thirteen crop functional types. For the representation of energy plant production, LPJmL was expanded to include a highly productive grass type (C4 Photosynthesis mechanism) and two quick-growing tree types (one tropical and one non-tropical). The model is supported by 15 climate scenarios and 3 emission scenarios, all of which were calculated for the fourth IPCC report. Alongside the expected revenue, the availability of land for systematic bioenergy production is decisive.

Taking into account the fact that approx. 50 EJ per annum can be produced from waste and residues, the global sustainable technical potential based on the model calculations amounts to between 80 and 170 EJ per annum. The share of the total potential from energy plants that can be tapped within Europe is estimated at between 3.4 and 14 EJ per annum, depending on the scenario.

For Germany no potentials can be shown using the model since it was developed for global rather than national application. In order to be able to make an estimate, statements made by the German Advisory Council on the Environment[8] in its special expert report "Biomass-based climate protection" (SRU, 2007) are used. The Advisory Council analysed four studies in total, which consider different scenarios in terms of the assumed increase of biomass production. In the following only the environmentally based scenarios are taken into account, which pay particular attention to environmental and nature conservation terms of reference, because they come closest to determining the sustainable technical potentials. Furthermore special attention is paid to the results of studies conducted by Öko-Institut (Fritsche et. al., 2004) and the German Aerospace Center[9] (Nitsch et. al., 2004) since, in the view of the SRU, the other reports either fail to adequately consider current nature conservation regulations or the assumptions are not sufficiently differentiated on the country level (SRU, 2007, p.37). In Table C- 2Table C- 2: Potentials based on residues and areas in Germany

the potentials from residues and areas that are available for energy plant production are presented.[10] The residue potentials for 2000 are approximately the same; in the DLR report they sharply escalate after this date to a higher level. The reason for this is that the use of landscape conservation materials is only added to the potential from 2010 onwards in the DLR report.

Table C- 2: Potentials based on residues and areas in Germany

Study/year	2000	2010	2020	2030	2040	2050
Potential from residues (PJ/yr)						
Öko-Institut	520	525	536	545		
German Aerospace Center (DLR)	543	677	696	705	715	724
Area potential, excluding grassland (mln ha)						
Öko-Institut		0.61	1.82	2.94		
German Aerospace Center (DLR)		0.15	1.1	2.0	3.1	4.2

Prognos 2009, data sources: Öko-Institut et. al. 2004; Nitsch et. al. 2004

In order to derive a primary energy potential from the area potential, assumptions have to be made on the plant types used and the revenue that can be realised per area. Kollas et al. provide a possible order of magnitude to estimate the primary energy potential from the cultivation of short-rotation plantations in Germany. Using model 4C, plant growth for the 2041-2060 time period is simulated on the basis of 21 climate scenarios.

8 Sachverständigenrat für Umweltfragen (SRU).
9 Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR).
10 For the exact derivation of each potential, see the relevant reports.

Depending on the scenario, this results in 5.77 – 7.25 tonnes of dry matter per hectare. The primary energy potential that can be tapped is calculated for different areas of land that are available. If 4 million ha are used, which corresponds approximately with the potential determined for 2050 in the DLR report, 415 - 522 PJ/a can be realised on average in the 2041-2060 period. If the potential from residues is added to this amount, the maximum sustainable technical potential from bioenergy that can be tapped in Germany in 2050 amounts to approx. 1200 PJ/a.

C.2 Final energy from bioenergy

C.2.1 Conversion processes

The primary energy to be drawn from biomass is converted into fuel by means of a conversion process in most cases. This is used in order to produce heat in the combustion process, which can be converted to the desired form of final energy. On each step of the process, there are a number of possible approaches which involve different costs, efficiencies, and greenhouse gas emissions. In the conversion of biomass to fuel, thermochemical, physicochemical and biochemical processes can be distinguished. The thermochemical processes include charring, i.e. the conversion to charcoal to increase energy content, gasification, which produces biogenic gas under high process temperatures, and pyrolysis (liquefaction), which produces pyrolysis oil with a high energy density through thermal decomposition of solid biomass. Physicochemical processes involve the many processes through which energy oils can be produced through compression or extraction with the help of a solvent. These processes are already used in the production of cooking oil. Furthermore, with esterification it is also possible to convert the oils into biodiesel with losses of 5-10%. Biochemical conversions take place with the help of micro-organisms. During fermentation, the anaerobic breakdown of organic substances produces biogas; in the case of aerobic breakdown heat is produced through oxidation; and in alcohol fermentation, ethanol is produced from organic substances with the help of yeast. No conversion is necessary in the case of the co-combustion of biomass in power plants since biomass is already a fuel in these cases.

For final energy production there are also a number of procedures, which can be used in either a centralised or decentralised manner. In these cases, energy is released in the oxidation of a fuel – usually carbon, which is also a basic part of all biomass products, but it is also possible to use hydrogen (which can, for example, be produced from biogas) in fuel cells. Generally it is the case that under conditions which otherwise remain the same, the greater the plant size (conversion, combustion), the higher the efficiency that can be achieved, which accordingly has an impact on the costs and the contribution to emission reduction.

C.2.2 Assessment of use chains for bioenergy

Many use chains for the production of final energy (electricity, heat, power) can be derived from the above processes, which are in competition for the limited primary energy potential of bioenergy. Since the individual process steps are dependent on each other, the total process chain needs to be taken into account if the assessment is to be reliable and useful. To this end, ecological, economic, technical and geographical criteria can be applied. Which of these are crucial to the choice of use chains depends on the focus of the assessment.

The WBGU commissioned experts from the German Biomass Research Centre (Müller-Langer et. al., 2008) and Öko- Institut (Fritsche and Wiegmann, 2008) to assess potential use chains. Overall 66 use chains were specified, for which there is already a market or which the WBGU considers to be particularly worthy of consideration from an ecological or technical perspective. Measured against comparatively strict sustainability criteria, additional paths were excluded from the analysis when at least one of the following conditions applied:

1. When the country of origin of the biomass is not Germany or another EU country. This is currently a necessary, but not sufficient requirement for being able to guarantee compliance with strict sustainability standards.

2. When the greenhouse gas balance of a path is negative, i.e. more greenhouse gases are emitted than saved (this is particularly the case in some paths due to the incorporation of indirect land-use changes).

3. When the path’s costs for greenhouse gas reduction amount to over 420 €/t CO_2e.

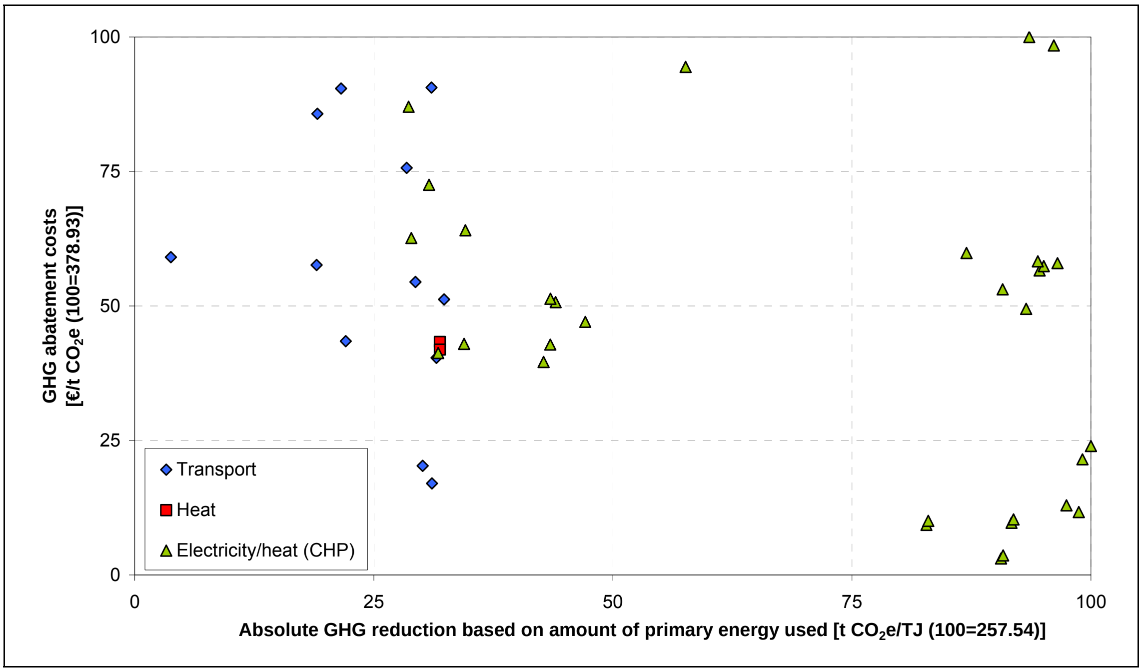
This is the case for the current CO_2 reduction costs of photovoltaics in Germany, which was selected in this context as a “backstop” technology because it is regarded at present as a very expensive option, although it is assumed that the costs of the option will significantly decrease in the future on the basis of “technological learning”. A similar effect can also be expected for innovative bioenergy technology paths which currently still involve high costs. This rule can lead to the exclusion of climate-efficient paths, but bioenergy should be understood as only one of many climate protection measures which are competing for limited funds.

The assessment of available paths is conducted on the basis of their position in a four-field matrix which uses the following dimensions: “Absolute greenhouse gas reduction based on the volume of gross energy used” on the x-axis and “Greenhouse gas reduction costs” on the y-axis. The x-axis parameter is chosen because it enables useful comparison of paths incorporating both energy plant production and waste utilisation. In addition it is also taken into account that electrical and mechanical energy involve a higher quality of final energy than heat energy, with the result that a comparison between sectors is possible and helpful.

The axes were standardised so that “100” in each case represents the highest level shown by a parameter within the given data. In terms of emission reduction this amounts to 257.54 t CO_2e/TJ and of emission reduction costs 378.93 €/t CO_2e. All other amounts should be seen in percentage relation to these amounts. Based on the figure the most effective paths in terms of greenhouse gas reduction and the related costs can be identified. In order to attain the highest benefit of bioenergy use in future, the paths should be chosen according to how bioenergy (with its related characteristics) can lead to the highest benefit in a transformed energy system that is as close to zero emissions as possible. Given that this can be applied universally, this can above all involve paths for which there is no other climate-friendly substitute.

Paths which fall within the upper left rectangle should not be pursued further since they are inferior to other paths both in terms of costs and climate protection. Paths which fall within the lower right rectangle should be pursued further. When there are several alternatives, further criteria should be assessed which facilitate synergies in a transformed energy system. For paths which fall in the lower left and upper right rectangles, it should be assessed whether their use cannot be substituted in each specific case. For paths which fall in the upper right rectangle, it should particularly be assessed whether the comparative cost disadvantage is based of the capital costs and, if so, on what part of the learning curve is the technology to be found. Estimates can then be made for the future, on which basis it may be possible to derive recommendations for support measures. For paths falling within the lower left rectangle, the lower contribution to climate protection can be accepted if, as a result, uses for which substitutes are difficult to find are performed with the intention of optimising the system.

Figure C- 3: Depiction of use chains according to associated greenhouse gas reduction potentials and greenhouse gas reduction costs



Prognos 2009, Data sources: Fritsche/Wiegmann 2008; Müller-Langer et. al. 2008

C.3 Conclusion and requirements of a biomass strategy

There is a conflict between the different demands for biomass use (food, material use, raw materials for energy use) and the limited potential of sustainably produced biomass. This conflict can only be resolved by development of strategy which interweaves the guaranteeing of biomass and food supply. To this end, the operationalisation of sustainability criteria is necessary for areas, products and production method. These criteria should include competition for area use for food production, the maintaining or improvement of biodiversity capacities as a requirement of land use changes, and issues related to the effects of indirect land use effects.

This is above all a challenge for imports of biomass. In the long run it should be ensured that effective internationally recognised proof systems are developed for biomass trading.

In order to use biofuels, greenhouse gases have to be reduced overall, taking into account the whole process chain (including indirect land-use effects).

Annex D Electricity storage

D.1 Background

The introduction of large volumes of fluctuating renewable energies to the electricity system requires an approach to regulatory and network issues, which is significantly different to previous ones.

The power fed into the network is independent of the demand load curve. Currently it is still manageable, given the small share (approx. 10 %) of fluctuating production, with the help of temporary storage, peak and reserve energy power plants. Nevertheless, there are larger volumes of wind electricity from coastal regions in the transport sector which are already causing stability problems in the network, above all in low load periods.

When there are significantly larger volumes of renewable energies in electricity production (as is the case in the innovation scenario without CCS), this problem becomes more significant. As a result, new ways will have to be found to provide for equalisation and network stability.

There are basically three ways in which electricity demand and electricity production can be equalised:

- steering of electricity production
- steering of electricity demand
- temporary storage of electrical energy

All three options are being tested and developed further. Within the scope of steering options enabled by electronic measurement and control technology, and automated communication with final energy applications (appliances which use final energy), the coupled real time steering of the network and consumption is regarded as having a certain potential for solving the problem. Model projects on these issues are currently being carried out ("e-energy"). However, it is to be expected that the problem cannot be solved by means of regulatory mechanisms alone. The approximate calculations of the scenarios show that the difference between the load curve and electricity fed into the network can, at times, amount to significantly more than 20 GW. Thus, storage will also have to take on an important role in the context of load management.

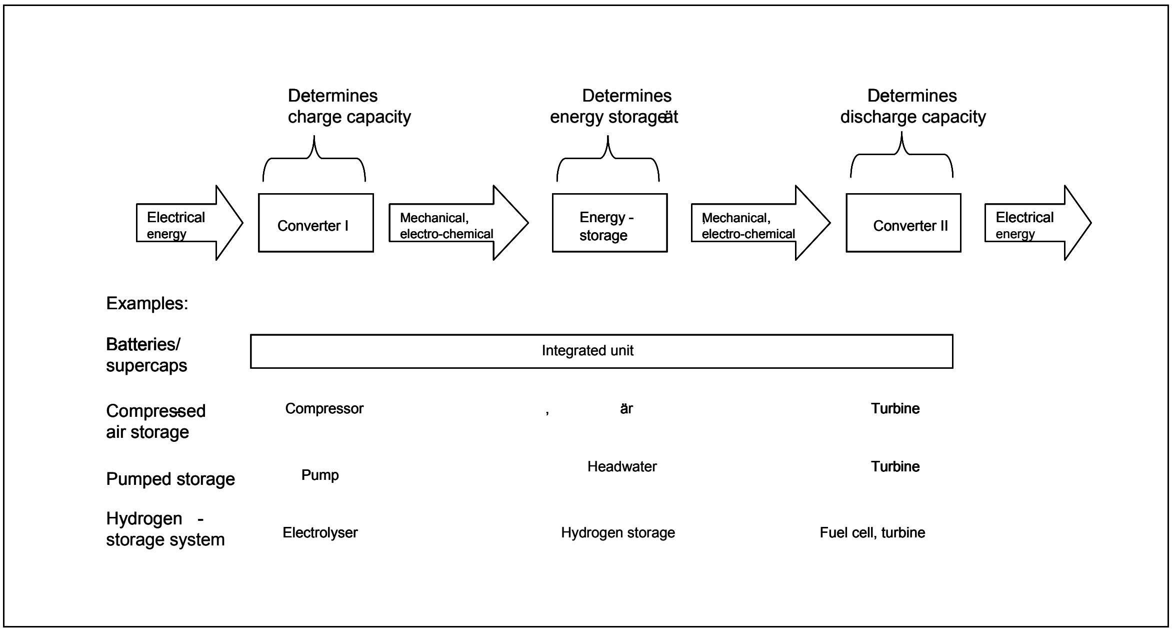
Storage can be used in very varied time scales, load characteristics and for a wide range of purposes. The following four different objectives are the key purposes:

- uninterrupted electricity supply
- load leveling
- primary energy management

- maintaining voltage quality.

Technically electricity storage generally follows the functional principle of "electricity transformer (input) – storage medium – electricity transformer (output)". Each element has a limited load capacity, storage capacities and discharge capacity. Some characteristics of storage types are shown in the following diagram:

Figure D- 1: Storage types and characteristics



Source: ISEA 2008

There is a multitude of familiar technical options for electricity storage, the particular technical codes of which differ, in some cases greatly, in terms of their characteristics. From today's perspective there is no technology which is suitable for all applications as a universal form of energy storage.

Many technologies are still in the development stage. Currently, it is not possible to foresee which technologies will be applied for which purposes. Therefore no reliable statements can be made on possible cost degression. Generally, the peak and reserve energy production from gas turbine power plants (with CO_2 compensation) can be used as a benchmark for the target costs.

D.2 Technical options

Compressed air storage

In compressed air storage (CAES – Compressed Air Energy Storage and AA-CAES – Advanced Adiabatic Compressed Air Energy Storage), excess electricity is used to store the surrounding air with the help of compressors using pressures of 50 - 70 bar. If necessary, the compressed air can be expanded by means of a gas turbine, which in turn drives a downstream generator to produce electricity. In such a process, an efficiency of approx. 50% can be achieved. Current research aims to increase efficiency to more than 70% by storing the heat arising in air compression in thermal high energy storage and using it to heat the air when released. Compressed air storage could be an attractive option for decentralised, near-offshore storage of wind energy since most salt formations that are feasible for storage are located on the northern coast of Germany where wind availability is at its highest. For technical realisation of AA-CAES there are challenges both in the further development of compressors which have to withstand temperatures of around 650°C and pressures of 100 - 200 bar and research on materials which temporarily store heat.

Pumped storage

Pumped storage power plants use the difference in altitude between a storage reservoir (backwater) and a lower-level reservoir (underwater) in order to remove power from the network or feed it into the network, according to demand, by using high pumps or turbine operation. The storable energy depends on the differences in altitude and reservoir volume and is typically sufficient to power a turbine for eight hours at full capacity. Since pumped storage power plants reach their nominal capacity relatively quickly (approx. after a minute) and are technically sophisticated, they are – with a total installed capacity of 6, 610 MW – by far the most important technology for supplying reserve energy in Germany. The potential at available sites has been tapped to the greatest possible extent in Germany. The capacity could still be increased by retrofitting old plants. It may be possible to find new sites by developing underground plants (e.g. former opencast mining) or by using salt water sites (although there are still a number of open questions here).

Fly wheels

Fly wheels store electrical energy in the form of kinetic energy. During loading the fly wheel is set in motion by an electric motor, which works as a generator during discharge. Fly wheels are particularly suited to temporary high capacity storage since they can produce or absorb a lot of energy in a short space of time and the self-discharge is relatively high. The storable energy depends on the torque of inertia of the rotating body and the rotation speed. With a view to electricity production based on renewable sources, a number of additional consumption (sub-)sectors in which fly wheels could be used are currently under discussion. For use in electric vehicles the development of lighter fly wheels from composite materials will be decisive. To equalise load fluctuations, the storage time has to be increased. Superconducting magnet energy storage, which is currently being developed, could contribute to this end.

Double layer capacitators

Double layer capacitators – also called supercaps (EDLC – electrochemical double layer capacitors) – combine very high capacity and cycle material strength with a comparatively high energy storage capacity, thereby filling the gap between conventional capacitators and batteries. The higher energy storage capacity compared to conventional capacitators is achieved by use of highly porous electrode material with a very effective surface. The costs are still very high, some amounting to € 10, 000 per kW. However, it is expected that significant cost reduction can be achieved through mass production. To support renewable electricity supply, use in several consumption (sub-) sectors is conceivable. In vehicles in which capacitators have to be re-charged at every stop, they can be used to cover peak electricity demand; using them exclusively in electric vehicles is also being tested. Moreover, EDLCs are suited to equalising fluctuations in capacity, temporary storage of photovoltaic electricity, and steering the wind turbine rotators independently of the network.

Electrochemical storage systems

Electrochemical storage systems can be differentiated according to whether energy storage takes place within the system or occurs externally. Conventional examples of systems with internal storage are batteries which can either be operated at room temperature (lead-acid, NiCd/ NiMH, li-ion) or at high temperature (NaNiCL, NaS). In the case of systems with external storage, energy conversion and storage occur independently of each other. Since the energy content can be flexibly increased by expanding the tank size, these systems are particularly suited to large-scale use. Redox-flow batteries are the most well-known of this group. If the energy storage medium can be transported, the charging and discharging processes can also be separated from one another, as is the case with hydrogen storage with an electrolyser and fuel cells.

Lead-acid batteries

The technology of lead-acid batteries, in which the electrodes are formed from porous active mass with high inner surfaces, has been established for over 100 years now. Since this technology is technically sophisticated and therefore also reliable and inexpensive, it tops the league in terms of globally installed battery capacity – in spite of having a comparatively low energy density. It is used in many (sub-)sectors to solve local problems related to energy supply, such as stabilising line taps and maintaining frequency and voltage stability.

Lithium-ion batteries

Lithium-ion batteries are generally used in mobile applications. The crucial advantage compared to other batteries is to be found in the higher energy density achieved (up to 240 Wh/kg). In terms of the choice of electrolytes and electrode materials, there are diverse combinations for lithium-ion batteries, many of which are still being researched. Thus it is assumed that there are large potentials for optimisation of lithium-ion batteries in the respective applications (e.g. electric mobility) and for cost reduction in the future.

High temperature batteries

In contrast to other battery types, the electrodes (active mass) in high temperature batteries are liquid and the electrolytes are solid. So that the active mass becomes reactive, it has to be in liquid form. This is the case with operating temperatures of 300 - 350°C, which should be kept as stable as possible since a too sudden fall in temperature renders the battery useless. The temperature can be maintained under corresponding isolation by using the reaction heat of the battery itself. For this purpose cycles without standby and idle times are needed, which is why high temperature batteries tend to not be suited for use in uninterrupted electricity supply.

Redox-flow batteries

Redox-flow batteries are the most well-known of the group of battery systems with external storage which house the energy-storing electrolytes. If necessary, the electrolytes can flow into the cell for the charging and discharging processes; hence the word "flow" in their name. With such a system the stored energy volume is independent of the cell size, with the result that the energy content is determined by the tank size and the battery capacity by the charging/discharging unit. Since the tank size can be expanded simply, and the electrolytes delivered by tank lorry, such systems are suited for use in large stationary systems with network connection and for operation in an isolated network far away from the main network.

Hydrogen

A hydrogen cycle can be explained as an electricity-to-electricity process using the temporary storage of hydrogen. Such a cycle has similar characteristics to those of a battery. From a climate and efficiency perspective hydrogen is best produced from CO_2-free and excess electricity. Through an electrolysis process hydrogen is created at the negative electrode and oxygen is created at the positive electrode. Since the electrolysers have a very flexible capacity, hydrogen production is also an option for load equalisation in the case of strongly fluctuating electricity production whereby excess electricity is used for hydrogen production and the electrolysers are immediately shut down when short-term increases in demand occur. In order to bridge the time between production and use of the hydrogen and to transport it, if necessary, to a different location, the hydrogen must be stored. Currently compressed gas storage, liquid gas storage and metal hydride storage are considered for this purpose. In compressed gas storage, the storage occurs under high pressure (200 - 700 bar) – similar to natural gas. The storage density of hydrogen can be substantially increased when it is cooled down to -253°C, which makes possible its transport by ship over long distances. However, approx. a third of the energy content has to be used for the cooling process. In the use of sponge-like, porous metal hydrides, the hydrogen molecules bind themselves in such a way to the metal atoms that the same storage densities can be achieved using pressures of 10 - 20 bar which are much easier to manage (as in compressed air storage). The disadvantage is the (comparatively) very high weight of the respective metal compounds.

Table D- 1: Technical codes of storage systems

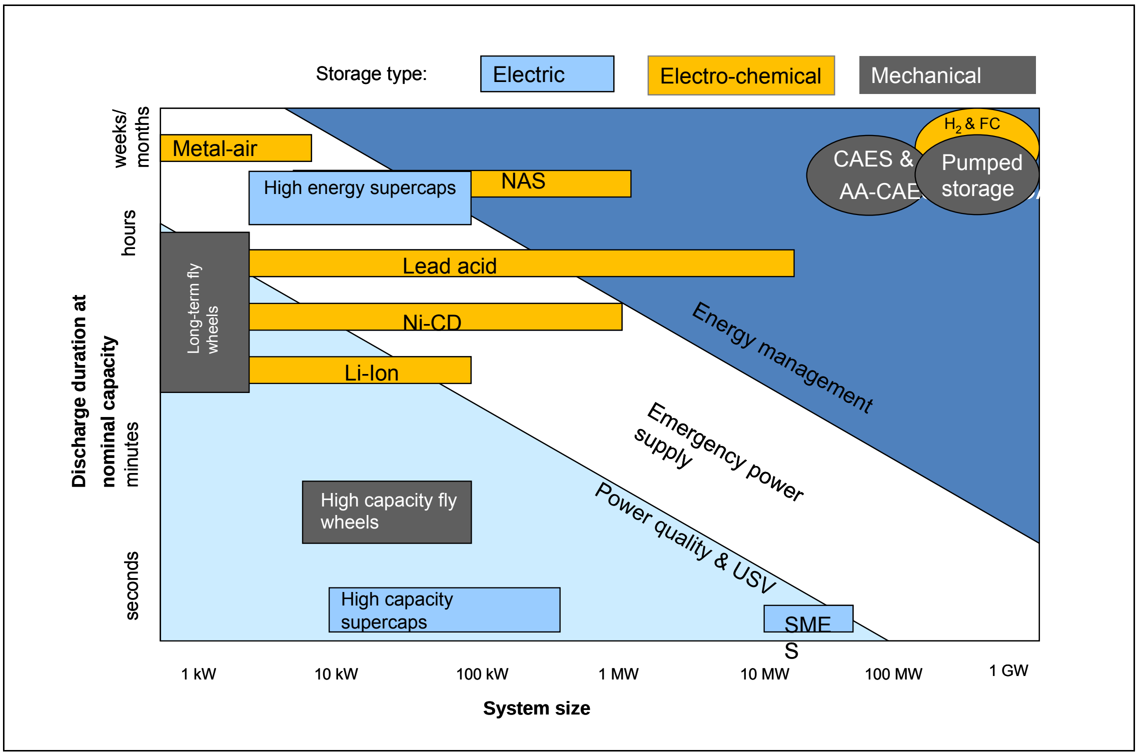
Physical storage type			Storage technology	Use	Efficiency (%)	Capacity	Electricity storage capacity	Energy density	Discharge duration	Self-charging rate	Number of cycles	Costs (€/kWh)
Mechnical	Potential		Pumped storage	Peak load, tertiary control, black start capability	65 - 85	2.3 MW - 1060 MW (in DE)	up to 8,480 MWh (in DE)	0.35 - 1.12 kWh/m^3	4 - 10 hours	0 - 0.5 %/day	unlimited	100 - 500
Mechnical	Potential		Compressed air storage	Peak load, tertiary control, black start capability	45 - 55; adiabatic: 60 - 75	110 MW - 290 MW; adiabatic - GW (planned)		0,5 - 0,8 kWh/m^3 (bei 60 bar)	2 - 24 hours	0 - 10 %/day	unlimited	40 - 100
Mechnical	Kinetic		Fly-wheel	Capacity reserve, uninterrupted electricity supply	80 - 95	5 kW - 3 MW		84 - 333 kWh/m^3	seconds / minutes	3- 20 %/h	several millions	1000 - 5000
Electric			Capacitators	Capacity reserve, uninterruptible electricity supply	90 - 95	< 150 kW		bis zu 10 kWh/m^3	a few seconds	0,1 - 0,4 %/h	> 1,000,000	10,000 - 20,000
Electric			Coils	Capacity reserve, uninterruptible electricity supply	90 - 95	10 kW - 100 MW		ca. 10 kWh/m^3	seconds / minutes	10 - 12 %/day	1,000,000	30,000 - 200,000
Electro-chemical	internal storage	low tempe-rature battery	Lead acid	Uninterruptible electricity supply, guaranteeing power quality, reserve storage	80 - 90	70 MW (max. installed capacity up to now)		25 -40 Wh/kg	between 1 hour and several days	5 %/month	50 - 2000, rarely up to 7000	25 - 250
Electro-chemical	internal storage	low tempe-rature battery	Ni-Cd/ Ni-MH									
Electro-chemical	internal storage	low tempe-rature battery	Li-Ion	Electromobility	just under 100	1 kW - several MW		95 - 240 Wh/kg	between 1 hour and several days	5%/year	500 - 3000 (80% discharge)	800 - 1,500
Electro-chemical	internal storage	high temp. battery	NaNiCl/NaS							low		
Electro-chemical	external storage		Electrolyser / hydrogen	Long-term storage, network regulation, isolated networks	20 - 40	kW / GW		33,000 Wh/kg 2,300 Wh/l		0-1%/ day		not yet precisely quantifiable
Electro-chemical	external storage		Redox flow	Long-term storage, voltage regulation	66 - 81	30 kW - 3 MW	to 5 MWh (realised); to 120 MWh (planned)	15 - 70 Wh/kg	1.5 s - 10 hours	none	10,000	100 - 1,000

Prognos 2009, Data sources: Renewable Energies Agency 2008, authors' own research

D.3 Different uses of electricity storage

The requirements of the adaptability of the power plant mix arising from fluctuating feed-in can be characterised on the basis of capacity demand and availability. The areas in the background represent the tasks of energy management, emergency electricity supply and maintaining the quality of network voltage in the capacity-time diagram; the individual fields represent the characteristics of the storage types in this system of coordinates.

Figure D- 2: Storage types, characteristics and areas in which they can be used



Source: ISEA 2008

The whole spectrum of necessary capacities and energies are covered by well-known storage technologies. The additional challenges faced as a result of increased use of renewable energies are chiefly to be found in load equalisation from minutes to days. In the case of stationary storage, pumped storage power plants, compressed air storage and large batteries such as redox-flow systems or high temperature batteries in particular are options to be considered. Increasingly decentralised electricity production and storage are an alternative option in this context.

One possible way of using local plants efficiently is the large virtual power plant, which conducts the centralised steering of plants. For this, the plants have to be linked to the control centre with very modern communication technology. First of all, the captive demand is covered by the electricity production. The feed-in of electricity to the network is coordinated via the control centre. The use of decentralised storage systems can also be effective for network connection. The logic behind this is to optimise the drawing of electricity based on production plant operators. Energy storage always makes sense economically when the difference between the costs of energy purchase and the payments for feed-in is greater than the storage costs. If the stored content is also connected to the network via the control centre, centrally managed large-scale storage can be realised.

Another perspective for connecting decentralised electricity storage with the network can be found in the development of plug-in hybrid vehicles. These vehicles are fitted with bi-directional storage and a power supply unit so that they can be charged via the electricity network for mobile use. Since most vehicles have longer stationary than use times, they can in principle be used as steerable load through network connection. For this purpose they require a (spatially) very dense load infrastructure –there have to be network connections at all places where vehicles can be parked. The coordination of charging and discharging storage in the case of excess and low load places corresponding demands on the measurement and communication infrastructure. With an average capacity of 25 kW per vehicle and more than 40 million registered vehicles in Germany, the theoretical potential of virtual vehicle storage is very large, even if only a small share of vehicles is connected to the network. However, the question still needs to be solved as to whether the demands of such additional capacity on the network as a result of such vehicles is or can be made compatible with the demand for high mobility (at any time) with which passenger cars are associated.

D.4 Conclusion

Generally it seems that the new challenges can be solved technically and from the perspective of regulatory logic by means of integrating increasing volumes (capacity) of fluctuating renewable energies in network regulation. The necessary storage technologies, which are regarded as having a key role in this new system, are technically available and operable in principle, but the majority of them are still in the development stage. Reliability, operating life, handling, integration in the network, and in particular profitability have to be improved before wide-scale storage use is within sight. At the moment it is not yet possible to estimate which specific technologies or solutions are the “best candidates” for these tasks. Furthermore, well-directed development work which includes targets and milestones has to be carried out to facilitate the electrification of passenger cars on the one hand, and to fulfil diverse equalisation tasks in the strongly fluctuating electricity system on the other hand. A corresponding research and innovation program is, in terms of the goals of “Blueprint Germany”, a high priority.

Annex E Methodology and results of the decomposition analysis

The objective of the decomposition analysis is to quantitively assess the contributions of different areas to emission reductions within the different sectors or sources.

The areas of intervention are, for example, energy efficiency, renewable energies, use of district and local heat, electrification, etc. In terms of the sectors, different sub-sectors are distinguished for energy consumption (e.g. passenger cars, freight transport, aviation or existing buildings and new buildings) and for transformation (e.g. electricity production) in the energy system on the one hand; and the remaining sources of greenhouse gas emissions (waste management, agriculture, etc.) on the other hand.

The starting point for the decomposition analysis is the methodology developed by Kaya (Kaya/Yokobori 1997), on the basis of which the total energy-related CO_2 emissions can be described as follows:

$$E = P \cdot \frac{V}{P} \cdot \frac{S}{V} \cdot \frac{E}{S} = P \cdot v \cdot s \cdot e \qquad (1)$$

mit

E	*emissions*
P	*population*
V	*value added (gross domestic product)*
S	*primary energy use*
v	*specific value added per capita*
s	*economy-wide energy intensity*
e	*emissions intensity of energy use*

This basic analytical approach is expanded in three directions for the sectoral decomposition analysis.

- Firstly, the approach is specified for individual sectors or sub-sectors;
- Secondly, the number of explanatory variables is increased so that important areas for action can be identified and classified; and
- Thirdly, the decomposition analysis is designed so that it can also be used to compare the scenarios.

Such a description of the emission level of a sector or sub-sector can be formulated in a decomposition analysis using different explanatory factors, as follows:

$$E_i^s = A^s \cdot \frac{A_i^s}{A^s} \cdot \frac{ES_i^{tot}}{A_i^s} \cdot \frac{ES_i^{fos}}{ES_i^{tot}} \cdot \frac{E_i^{fos}}{ES_i^{fos}} = A^s \cdot a_i^s \cdot ep_i^{tot} \cdot es_i^{fos} \cdot e_i^{fos} \qquad (2)$$

with

E_i^s	*emissions from sub-sector i in sector s*
A^s	*driving force parameter (activity) for sector s*
A_i^s	*driving force parameter (activity) for sub-sector i in sector s*
ES_i^{tot}	*total energy use in sub-sector i*
ES_i^{fos}	*total fossil energy use in sub-sector i*
E_i^{fos}	*total emissions from fossil energy use in sub-sector i*
a_i^s	*share of sub-sector i in total activity of sector s*
ep_i^{tot}	*energy productivity of sub-sektor i*
es_i^{fos}	*fossil fuel share in total energy use in sub-sector i*
e_i^{fos}	*emissions intensity of fossil fuel use in sub-sector i*

In this way, both intersectoral shifts in activity and the different components which have intrasectoral effects can be described. However, the following derivations only refer to intrasectoral contributions to emission reduction.

Further, the contribution to emission reduction of the fossil fuel share within the total energy use of a specific subsector can also be indirectly specified via the shares of non-fossil energy carriers (including the secondary energy carriers of electricity, district/local heat and hydrogen, as classified by convention).

$$es_i^{fos} = E_i^{tot} \cdot \left(1 - \frac{ES_i^{ren}}{ES_i^{tot}} - \frac{ES_i^{nuc}}{ES_i^{tot}} - \frac{ES_i^{el}}{ES_i^{tot}} - \frac{ES_i^{he}}{ES_i^{tot}} - \frac{ES_i^{hy}}{ES_i^{tot}}\right)$$
$$= E_i^{tot} \cdot \left(1 - es_i^{ren} - es_i^{nuc} - es_i^{el} - es_i^{he} - es_i^{hy}\right) \qquad (3)$$

with

E_i^{tot}	*total emissions from fossil fuel use in sub-sector i*
ES_i^{ren}	*renewable energy use in sub-sector i*
ES_i^{nuc}	*nuclear energy use in sub-sector i*
ES_i^{el}	*electricity use in sub-sector i*
ES_i^{he}	*district heat use in sub-sector i*
ES_i^{hy}	*hydrogen use in sub-sector i*
es_i^{ren}	*renewable share in total energy use in sub-sector i*
es_i^{nuc}	*nuclear share in total energy use in sub-sector i*
es_i^{el}	*electricity share in total energy use in sub-sector i*
es_i^{he}	*district heat share in total energy use in sub-sector i*
es_i^{hy}	*hydrogen share in total energy use in sub-sector i*

For each component shown in equation (2), a trend factor can be determined for the different modelling years of the periods under analysis:

$$d_t^c = \frac{c_t}{c_0} \tag{4}$$

with

d_t^c	*driving force parameter (activity) for component c at time step t*	(4)
c_t	*value of component c at time step t*	
c_o	*value of component c at base year*	

For all components shown in equation (2), the contributions to emission development can be isolated for each component based on the emissions of the reference year:

$$\Delta E_t^c = E_0^{fos} \cdot \left(d_t^c - 1\right) \tag{5}$$

with

ΔE_t^c	*isolated emissions contribution of component c*	(5)
E_0^{fos}	*total emissions from fossil fuel use at base year*	
d_t^c	*value of driving force parameter (activity) for component c at time step t*	

Since overlappings between the different components also need to be taken into account, the isolated contributions of the different components to emission development are proportionally adjusted so that the actual emission contributions are as follows:

$$\Delta E_t'^c = \left(E_t^{fos} - E_0^{fos}\right) \cdot \frac{\Delta E_t^c}{\sum_i \Delta E_t^i} \tag{6}$$

with

$\Delta E_t'^c$	*effective emissions contribution of component c*	(6)
E_0^{fos}	*total emissions from fossil fuel use at base year*	
E_t^{fos}	*total emissions from fossil fuel use at time step t*	
ΔE_t^i	*isolated emissions contribution of component i*	

To enable comparison of the different components in spite of the adjustment step for different scenarios, the adjustment calculation described in equation (6) is carried out separately for both the activity factors (see equation (2)) and the other so-called intervention components. Compared to the reference scenario, the contributions of the activity components to changes in emission levels are determined as follows:

$$\Delta E''^{c}_{s} = \Delta E'^{c}_{ref} \cdot \frac{A^{s}_{i_s}}{A^{s}_{i_{ref}}} \qquad (7)$$

mit

$\Delta E''^{c}_{s}$	*adjusted effective emissions contribution of activity component c in scenario s*
$\Delta E'^{c}_{ref}$	*effektive emissions contribution of activity component c in the reference scenario*
$A^{s}_{i_s}$	*driving force parameter (activity) for sub-sector i in sector s in scenario s*
$A^{s}_{i_{ref}}$	*driving force parameter (activity) for sub-sector i in sector s in in the reference scenario*

Accordingly the contributions of the intervention components are determined as follows:

$$\Delta E''^{c}_{s_t} = \left(E^{i}_{0} + \sum_{a} \Delta E''^{a}_{s_t} - E^{i}_{s_t} \right) \cdot \frac{\Delta E'^{c}_{s_t}}{\sum_{j} \Delta E'^{j}_{s_t}} \qquad (8)$$

with

$\Delta E''^{c}_{s_t}$	*adjusted effective emissions contribution of intervention component c in scenario s at time step t*
E^{i}_{0}	*emissions level of sub-sector i in scenario s at base year*
$E^{i}_{s_t}$	*emissions level of sub-sector i in scenario s at time step t*
$\Delta E''^{a}_{s_t}$	*adjusted effektive emissions contribution of activity component a in scenario s at time step t*
$\Delta E'^{c}_{s_t}$	*effektive emissions contribution of intervention component c in scenario s at time step t*
$\Delta E'^{j}_{s_t}$	*effektive emissions contribution of intervention component i in scenario s at time step t*

Now that the components shown in the equations (2) can be assessed in accordance with the equations (4) - (8) in terms of their actual contributions to emission development in each scenario, the components shown in equation (3) are differentiated according to the following approach (all shares of energy carriers covered in equation (3) are considered here as non-fossil energy carriers):

$$\Delta E''^{c}_{s_t} = \Delta E''^{foss}_{s_t} \cdot \frac{es^{c}_{s_t} - es^{c}_{0}}{es^{fos}_{0} - es^{fos}_{s_t}} \qquad (9)$$

with

$\Delta E''^{c}_{s_t}$ *adjusted effective emissions contribution of intervention component c in scenario s at time step t*

$\Delta E''^{foss}_{s_t}$ *adjusted effective emissions contribution of intervention component 'fossil fuel share' in scenario s at time step t*

es^{c}_{0} *share of (non-fossil) energy carrier c in total energy use in base year*

$es^{c}_{s_t}$ *share of (non-fossil) energy carrier k in total energy use in scenario s at time step t*

es^{fos}_{0} *fossil fuels share in total energy use at base year*

$es^{fos}_{s_t}$ *fossil fuels share in total energy use in scenario s at time step t*

The basic assumption of the approach for the decomposition analysis described here is that the different components are, to a large extent at least, independent of each other. This is a sufficiently robust assumption in most (sub-)sectors and most components. However, for two areas this basic assumption leads to significant model artefacts.

- The first artefact concerns electricity production. The energy-related statistical conventions for the primary energy assessment of electricity production in nuclear power plants and wind, hydrogen, solar and geothermal power plants and for the assessment of electricity imports lead to substantial distortions of energy use levels. An increase in electricity production of wind, hydrogen and solar power plants or an increase in electricity imports (assessed according to convention as having 100 % efficiency in each case) leads in the calculations to a huge decrease in energy use within electricity production, with the result that the contribution of renewable energies is underestimated and that of energy efficiency is overestimated. The opposite effect occurs with the share of electricity production in nuclear power plants (assessed according to convention as having 33 % efficiency) and with geothermal power plants (assessed according to convention as having 10 % efficiency).

- The second artefact concerns electric mobility. Here the contribution of electrification is underestimated since the estimated energy use in transport in terms of final energy substantially decreases in the case of an increased share of electric vehicles; accordingly, the estimation for the energy efficiency component is (too) high.

In order to avoid the emergence of these artefacts through energy-related statistical conventions or in the final energy estimations, extra conventions were applied for the above two areas.

For electricity production, the following convention is applied to determine the energy productivity component:

$$ep_{el}^{tot} = \frac{ES_{el}^{fos}}{A_{el}^{fos}} \qquad (10)$$

with

ep_{el}^{tot}	*energy productivity of the power generation sector*	(10)
ES_{el}^{fos}	*total fossil fuel use in power generation*	
A_{el}^{fos}	*total power generation from fossil fuels*	

In this way, the contributions of energy productivity are determined solely on the basis of changes in the fossil fuel part of the power plant mix.

For the assessment of the energy productivity and electrification components in the context of passenger cars, the following adjustments are made:

$$\Delta E_t''^{ep} = \Delta E_t'^{ep} \cdot \frac{\left(ES_t^{tot} - ES_t^{el}\right) - \left(ES_0^{tot} - ES_0^{el}\right)}{\left(A_t^{tot} - A_t^{el}\right) - \left(A_0^{tot} - A_0^{el}\right)} \cdot \frac{\left(A_t^{tot} - A_0^{tot}\right)}{\left(ES_t^{tot} - ES_0^{tot}\right)}$$

$$\Delta E_t''^{el} = \Delta E_t'^{el} + \left(\Delta E_t'^{ep} - \Delta E_t''^{ep}\right) \qquad (11)$$

with

$\Delta E_t''^{ep}$	*adjusted emissions contribution of energy efficiency component at time step t*	
$\Delta E_t'^{ep}$	*effektive emissions contribution of energy efficiency component at time step t*	
ES_t^{tot}	*total energy use at time step t*	
ES_0^{tot}	*total energy use at base year*	
ES_t^{el}	*electricity use at time step t*	(11)
ES_0^{el}	*electricity use at base year*	
A_t^{tot}	*total mileage at time step t*	
A_0^{tot}	*total mileage at base year*	
A_t^{el}	*mileage from electric drives at time step t*	
A_0^{el}	*mileage from electric drives at base year*	
$\Delta E_t''^{el}$	*adjusted emissions contribution of electrification component at time step t*	
$\Delta E_t'^{el}$	*effektive emissions contribution of electrification component at time step t*	

The contributions arising in electric mobility (in passenger cars) due to the inherently higher energy efficiency are added to the electrification component.

For the sources besides energy-related emissions the contributions are not differentiated according to component. The sectoral contributions for the emission development are determined as follows:

$$\Delta E_t^s = \left(E_t^s - E_0^s\right)$$

mit

ΔE_t^s	*effective emissions contribution of sector s at time step t*	(12)
E_t^s	*emissions from sector s at time step t*	
E_0^s	*emissions from sector s at base year*	

The decomposition analysis for the contributions of different sectors or sources was carried out for the following areas:

1. Residential sector
   a. Existing buildings
   b. New buildings
   c. Hot water
   d. Cooking
2. Service sector
   a. Room heating
   b. Process heat
   c. Non-electrical drives
3. Transport
   a. Passenger cars
   b. Public passenger transport
   c. Freight transport by road
   d. Freight transport by rail
   e. Domestic maritime transport
   f. Aviation
4. Industry
5. Electricity production
6. Other transformation sectors
7. Fugitive emissions of the energy sector

8. Process-related emissions in industry and emissions from product use
    a. CO_2 emissions
    b. Methane emissions
    c. Laughing gas emissions
    d. F-gas emissions
9. Agriculture
10. Waste management
11. Land use and forestry

For the sectors or sources covered in 1 - 5, the following components were analysed:

I. Demand
    a. socio-economic activities (living space, value added, transport volume, etc.)
    b. electricity demand (as a driver of electricity production)

II. Energy productivity (to measure the development of energy efficiency in the different areas)

III. Share of renewable energies (in the consumption (sub-)sectors and in electricity production)

IV. Electrification (as an option of emission shift from consumption (sub-)sectors to electricity production)

V. District and local heat (as an option of emission shift from consumption (sub-)sectors to the energy transformation sector)

VI. Hydrogen (as an option of emission shift from the consumption (sub-)sectors to the energy transformation sector)

VII. Nuclear energy (as a specification for the electricity production sector)

VIII. Fossil fuel change (in the final consumption sectors and in electricity production)

Table E- 1: Results of decomposition analysis for the reference scenario, 2005 – 2020, in million t CO_2e

mln t CO_2e	Reference scenario								
	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-2.4	-19.7	-1.7	0.2	-1.7	-	-	-0.9	-
Space heating (new buildings)	7.5	-4.6	-1.7	0.2	-0.1	-	-	-1.0	-
Warm water	-0.2	-0.5	-1.3	-0.8	0.0	-	-	-0.1	-
Cooking	0.0	-0.1	0.0	-0.2	-	-	-	-0.0	-
Commercial									
Space heating	0.9	-13.9	-1.2	0.3	-0.0	-	-	-0.7	-
Process heat	2.1	-1.9	-0.8	-0.4	0.0	-	-	-0.4	-
Non-electric drives	1.4	-2.6	-	-	-	-	-	-0.0	-
Industry	21.5	-24.5	-1.3	-3.9	-0.0	-	-	-2.0	-
Transport									
Motorised private transport	1.6	-20.4	-6.8	-0.2	-	-	-	-0.5	-
Public transport	-0.0	-0.1	1.8	-0.3	-	-	-	0.2	-
Road freight transport	18.5	-17.4	-3.3	-	-	-	-	0.0	-
Rail freight transport	0.0	-0.0	0.0	-0.1	-	-	-	0.0	-
Inland navigation	0.0	0.0	-0.1	-	-	-	-	0.0	-
Aviation	7.3	-3.6	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-16.8	-9.9	-56.6	-4.3	-	-	16.1	-0.7	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-6.9
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-2.6
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-12.6
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-1.7
Waste sector	-	-	-	-	-	-	-	-	-6.7
Agriculture	-	-	-	-	-	-	-	-	-5.2
Land use (change) and forestry	-	-	-	-	-	-	-	-	21.3
Others[b]	-	-	-	-	-	-	-	-	13.4

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 2: Results of decomposition analysis for the reference scenario, 2005 – 2030, in million t CO_2e

	Reference scenario								
mln t CO_2e	**Driving force**	**Energy productivity**	**Renewable energies**	**Electri-fication**	**Heat**	**Hydrogen**	**Nuclear**	**Foss. CO_2 intensity**	**Others**
Residential									
Space heating (existing stock)	-5.0	-29.8	-4.0	0.8	-2.7	-	-	-1.2	-
Space heating (new buildings)	12.8	-7.6	-3.2	0.3	-0.2	-	-	-1.6	-
Warm water	-0.3	-0.3	-2.6	-0.7	0.0	-	-	-0.1	-
Cooking	0.0	-0.2	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-1.7	-22.2	-2.5	0.2	-0.0	-	-	-0.7	-
Process heat	3.2	-3.2	-1.4	-0.7	0.0	-	-	-0.7	-
Non-electric drives	2.1	-4.2	-	-	-	-	-	-0.0	-
Industry	25.3	-35.8	-2.8	-5.6	-0.1	-	-	-4.0	-
Transport									
Motorised private transport	1.0	-28.6	-11.1	-1.4	-	-	-	-0.8	-
Public transport	-0.0	-0.1	1.7	-0.3	-	-	-	0.1	-
Road freight transport	26.4	-23.5	-7.1	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.0	0.0	-0.1	-	-	-	0.0	-
Inland navigation	0.1	-0.0	-0.1	-	-	-	-	0.0	-
Aviation	8.1	-5.9	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-22.5	-14.8	-72.1	-5.0	-	-	17.4	1.7	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-8.3
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-3.5
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-12.6
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-1.7
Waste sector	-	-	-	-	-	-	-	-	-8.1
Agriculture	-	-	-	-	-	-	-	-	-5.2
Land use (change) and forestry	-	-	-	-	-	-	-	-	21.3
Others[b]	-	-	-	-	-	-	-	-	-1.4

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 3: Results of decomposition analysis for the reference scenario, 2005 – 2040, in million t CO_2e

mln t CO_2e	Reference scenario								
	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-9.3	-35.9	-5.8	1.4	-3.3	-	-	-1.5	-
Space heating (new buildings)	16.8	-9.9	-4.4	0.4	-0.3	-	-	-2.1	-
Warm water	-0.7	-0.5	-4.4	-1.2	0.4	-	-	0.3	-
Cooking	0.0	-0.3	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-3.8	-24.2	-5.8	0.2	0.0	-	-	-0.5	-
Process heat	4.4	-4.3	-1.9	-1.1	0.1	-	-	-1.1	-
Non-electric drives	2.8	-5.7	-	-	-	-	-	-0.0	-
Industry	28.8	-43.3	-4.2	-7.2	-0.1	-	-	-5.6	-
Transport									
Motorised private transport	-1.9	-30.6	-13.9	-6.9	-	-0.1	-	-1.2	-
Public transport	-0.0	-0.1	1.6	-0.2	-	-	-	0.1	-
Road freight transport	32.1	-27.7	-11.0	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.0	0.0	-0.1	-	-	-	0.0	-
Inland navigation	0.2	-0.0	-0.2	-	-	-	-	0.0	-
Aviation	7.6	-6.1	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-12.3	-33.1	-92.4	-6.0	-	-	34.3	5.2	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-9.3
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-4.4
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-12.6
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-1.7
Waste sector	-	-	-	-	-	-	-	-	-8.9
Agriculture	-	-	-	-	-	-	-	-	-5.2
Land use (change) and forestry	-	-	-	-	-	-	-	-	21.3
Others[b]	-	-	-	-	-	-	-	-	-8.3

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 4: Results of decomposition analysis for the reference scenario, 2005 – 2050, in million t CO_2e

	Reference scenario								
mln t CO_2e	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-13.9	-40.3	-7.6	2.1	-3.7	-	-	-1.7	-
Space heating (new buildings)	19.8	-11.5	-5.5	0.5	-0.5	-	-	-2.4	-
Warm water	-1.2	-0.6	-5.2	-0.3	0.5	-	-	0.0	-
Cooking	-0.0	-0.3	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-5.1	-24.9	-5.5	-0.0	0.0	-	-	-0.5	-
Process heat	6.2	-5.8	-2.1	-1.4	0.1	-	-	-1.2	-
Non-electric drives	4.0	-7.6	-	-	-	-	-	-0.0	-
Industry	35.4	-50.1	-5.5	-8.8	-0.0	-	-	-7.0	-
Transport									
Motorised private transport	-7.0	-31.0	-13.9	-15.7	-	-1.2	-	-2.0	-
Public transport	-0.0	-0.1	1.6	-0.3	-	-	-	0.1	-
Road freight transport	39.0	-31.9	-15.5	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.0	0.0	-0.1	-	-	-	-0.1	-
Inland navigation	0.2	-0.0	-0.2	-	-	-	-	0.0	-
Aviation	6.3	-5.9	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-8.8	-46.6	-107.9	-6.9	-	-	46.8	7.7	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-9.9
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-5.2
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-12.6
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-1.7
Waste sector	-	-	-	-	-	-	-	-	-9.4
Agriculture	-	-	-	-	-	-	-	-	-5.2
Land use (change) and forestry	-	-	-	-	-	-	-	-	21.3
Others[b]	-	-	-	-	-	-	-	-	-16.2

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 5: Results of decomposition analysis for the innovation scenario, 2005 – 2020, in million t CO_2e

	Innovation scenario								
mln t CO_2e	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-2.4	-31.4	-10.2	0.5	-2.2	-	-	-1.5	-
Space heating (new buildings)	7.6	-4.3	-2.5	0.2	0.1	-	-	-1.2	-
Warm water	-0.2	-0.9	-2.0	-2.2	0.2	-	-	-0.1	-
Cooking	0.0	-0.1	0.0	-0.2	-	-	-	-0.0	-
Commercial									
Space heating	0.9	-17.3	-1.3	0.3	-0.0	-	-	-0.7	-
Process heat	2.3	-2.6	-0.8	-0.3	0.0	-	-	-0.4	-
Non-electric drives	1.5	-3.0	-	-	-	-	-	-0.0	-
Industry	21.3	-44.3	-1.6	-5.1	0.6	-	-	-1.4	-
Transport									
Motorised private transport	1.6	-21.2	-15.1	-0.3	-	-0.0	-	-0.6	-
Public transport	-0.0	-0.0	1.5	-0.2	-	-	-	0.1	-
Road freight transport	18.0	-17.4	-7.4	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.0	-0.0	-0.1	-	-	-	0.0	-
Inland navigation	0.1	0.0	-0.1	-	-	-	-	0.0	-
Aviation	7.2	-4.4	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-57.2	-14.0	-65.2	-5.1	-	-	16.1	-0.8	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-7.8
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-7.0
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-12.6
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-1.7
Waste sector	-	-	-	-	-	-	-	-	-7.2
Agriculture	-	-	-	-	-	-	-	-	-13.5
Land use (change) and forestry	-	-	-	-	-	-	-	-	-17.8
Others[b]	-	-	-	-	-	-	-	-	4.4

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 6: Results of decomposition analysis for the innovation scenario, 2005 – 2030, in million t CO_2e

	Innovation scenario								
mln t CO_2e	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-5.0	-50.8	-17.0	0.9	-2.9	-	-	-2.3	-
Space heating (new buildings)	12.8	-6.3	-5.4	0.3	0.3	-	-	-2.4	-
Warm water	-0.3	-1.5	-4.3	-2.9	0.5	-	-	-0.2	-
Cooking	0.0	-0.2	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-1.7	-25.5	-3.3	0.2	-0.0	-	-	-0.8	-
Process heat	3.6	-4.2	-1.4	-0.6	0.0	-	-	-0.8	-
Non-electric drives	2.4	-4.8	-	-	-	-	-	0.0	-
Industry	24.9	-60.0	-3.7	-7.6	0.7	-	-	-4.0	-
Transport									
Motorised private transport	1.0	-32.6	-32.2	-4.3	-	-0.0	-	-1.9	-
Public transport	-0.0	-0.0	1.1	-0.1	-	-	-	0.0	-
Road freight transport	25.2	-23.1	-23.0	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.0	-0.0	-0.1	-	-	-	0.0	-
Inland navigation	0.2	-0.0	-0.5	-	-	-	-	0.0	-
Aviation	7.9	-7.2	0.0	0.0	-	0.0	-	-0.0	-
Power generation[a]	-81.6	-20.5	-114.7	-10.4	-	-	17.4	-7.1	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-9.7
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-17.1
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-14.2
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-5.8
Waste sector	-	-	-	-	-	-	-	-	-8.8
Agriculture	-	-	-	-	-	-	-	-	-17.0
Land use (change) and forestry	-	-	-	-	-	-	-	-	-21.0
Others[b]	-	-	-	-	-	-	-	-	-20.8

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 7: Results of decomposition analysis for the innovation scenario, 2005 – 2040, in million t CO_2e

	Innovation scenario								
mln t CO_2e	**Driving force**	**Energy productivity**	**Renewable energies**	**Electri-fication**	**Heat**	**Hydrogen**	**Nuclear**	**Foss. CO_2 intensity**	**Others**
Residential									
Space heating (existing stock)	-9.3	-63.4	-16.9	1.0	-2.8	-	-	-3.2	-
Space heating (new buildings)	16.8	-7.4	-7.6	0.4	0.5	-	-	-3.6	-
Warm water	-0.7	-2.1	-5.7	-2.8	0.9	-	-	0.3	-
Cooking	0.0	-0.3	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-3.8	-21.9	-10.1	0.1	-0.0	-	-	-0.0	-
Process heat	5.0	-5.7	-2.1	-0.9	0.0	-	-	-1.2	-
Non-electric drives	3.2	-6.6	-	-	-	-	-	-0.0	-
Industry	28.3	-67.2	-5.9	-9.5	0.8	-	-	-6.7	-
Transport									
Motorised private transport	-1.8	-36.9	-29.9	-16.7	-	-0.1	-	-4.0	-
Public transport	-0.0	-0.0	0.9	-0.1	-	-	-	0.0	-
Road freight transport	29.8	-27.2	-35.7	-	-	-	-	0.0	-
Rail freight transport	0.1	-0.1	-0.0	-0.2	-	-	-	0.0	-
Inland navigation	0.3	-0.0	-0.8	-	-	-	-	0.0	-
Aviation	7.4	-8.0	-0.0	-0.0	-	-0.0	-	0.0	-
Power generation[a]	-85.8	-18.3	-180.5	-20.3	-	-	34.3	-14.1	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-10.8
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-25.9
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-14.2
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-10.0
Waste sector	-	-	-	-	-	-	-	-	-9.8
Agriculture	-	-	-	-	-	-	-	-	-19.9
Land use (change) and forestry	-	-	-	-	-	-	-	-	-20.7
Others[b]	-	-	-	-	-	-	-	-	-36.8

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009

Table E- 8: Results of decomposition analysis for the innovation scenario, 2005 – 2050, in million t CO_2e

mln t CO_2e	Innovation scenario							
	Driving force	Energy productivity	Renewable energies	Electri-fication	Heat	Hydrogen	Nuclear	Foss. CO_2 intensity	Others
Residential									
Space heating (existing stock)	-13.9	-71.6	-12.8	0.9	-2.2	-	-	-4.1	-
Space heating (new buildings)	19.8	-8.1	-8.8	0.4	0.6	-	-	-4.8	-
Warm water	-1.2	-2.2	-6.5	-1.5	0.9	-	-	-0.4	-
Cooking	-0.0	-0.3	0.0	-0.3	-	-	-	-0.0	-
Commercial									
Space heating	-5.1	-20.9	-8.5	-1.2	-0.5	-	-	-0.0	-
Process heat	7.0	-7.7	-2.3	-1.0	0.1	-	-	-1.3	-
Non-electric drives	4.6	-8.7	-	-	-	-	-	-0.0	-
Industry	34.7	-71.6	-7.9	-11.0	0.8	-	-	-9.7	-
Transport									
Motorised private transport	-6.8	-37.1	-21.7	-27.9	-	-0.8	-	-6.3	-
Public transport	-0.0	-0.0	0.7	-0.1	-	-	-	0.0	-
Road freight transport	35.2	-31.3	-51.3	-	-	-	-	1.4	-
Rail freight transport	0.2	-0.0	0.0	-0.1	-	-	-	-0.1	-
Inland navigation	0.4	-0.0	-1.3	-	-	-	-	0.0	-
Aviation	6.1	-8.5	-0.0	-0.0	-	-0.0	-	0.0	-
Power generation[a]	-75.9	-25.4	-189.4	-27.4	-	-	46.8	-63.8	-
Fugitive emissions from energy sectors	-	-	-	-	-	-	-	-	-11.4
Non-energy-related emissions[b]									
Industrial processes (CO_2)	-	-	-	-	-	-	-	-	-34.0
Industrial processes (CH_4)	-	-	-	-	-	-	-	-	-0.0
Industrial processes (N_2O)	-	-	-	-	-	-	-	-	-14.2
Industrial processes (F-Gases)	-	-	-	-	-	-	-	-	-14.2
Waste sector	-	-	-	-	-	-	-	-	-10.4
Agriculture	-	-	-	-	-	-	-	-	-22.7
Land use (change) and forestry	-	-	-	-	-	-	-	-	-21.1
Others[b]	-	-	-	-	-	-	-	-	-45.9

Notes: [a] driving force for power generation is power consumption, electrification for power sector is electricity supply from storage. -
[b] other energy-related emissions are included

Source: Öko-Institut 2009