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BLUEPRINT GERMANY

A strategy for a climate safe 2050

Preface

Putting the target first

Climate change is one of the greatest challenges which we face and which must be tackled in order to sustain a living planet. To limit global warming to less than two degrees compared to pre-industrial times, global greenhouse gas emissions must be reduced by 80 percent compared to 1990 levels. Industrial nations must even reduce their greenhouse gases by 95 percent by the year 2050. Without such reductions in greenhouse gas emissions, humanity will rapidly head to a global warming of up to seven degrees. The consequences would be disastrous.

A change of course is not yet in sight. Year after year, global emissions continue to rise rather than decline. We can no longer afford to discuss ambitious reduction targets as a mere utopia. Never before has this utopia been transformed into a thorough policy programme which is based on concrete measures and instruments up to the year 2030. The study presented by WWF Germany is the first to address this issue. We are breaking new ground and are putting the target first. This is the only way to protect our stability, security, prosperity and jobs.

'Blueprint Germany', which has been prepared by Prognos, Öko-Institut and Dr. Ziesing on behalf of WWF, shows that the transformation from a high-carbon to a low-carbon economy is possible and affordable. By committing to this transformation path, Germany could become a model for other countries.

'Blueprint Germany' does not claim to show the only way. It does, however, identify one way which, together with intensified innovation efforts, can lead to reaching the target on a sustainable basis. There is no better time than now for setting the right course for the future – not least of all because most greenhouse gas reduction potentials are linked to very long-term investment and infrastructure decisions. Furthermore, ambitious climate policy must cover all sectors with immediate effect. Any short-sighted policy geared towards seemingly low-cost reduction options is misleading. Although power generation, the building sector, road transport and industry are central fields of action, agriculture and issues of land use will also have to be addressed in order to achieve the ambitious minus-95-percent target.

WWF Germany wants this study to trigger a discussion about the future. The study provides many new and interesting answers as well as raising many new questions, which have to be tackled now. For WWF Germany, this analysis represents only the beginning of a systematic approach to these questions and towards presenting answers in the near future. This is why WWF Germany will not only monitor, but will also actively drive this necessary transformation process.

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Introduction

In order to keep global climate warming below 2°C compared to pre-industrial levels, anthropogenic emissions of greenhouse gases will have to be cut drastically world-wide by 2050. The only way to achieve an international coordinated path is if industrialised nations reduce their emissions to such an extent that this will leave emerging countries some "leeway in the greenhouse gas account" to develop their economies and wealth further.

For Germany, this 2050 target means a reduction of greenhouse gases by approx. 95% compared to 1990 emission levels. In other words, less than one tonne of greenhouse gases per capita may be emitted by 2050. Latest scientific findings state that from 2005 to 2050 a global budget of around 800 billion tonnes of CO_2 emissions or respectively 1,230 billion tonnes of CO_2 equivalents for all greenhouse gas emissions is available in order to keep the increase of global temperature to below 2°C compared to pre-industrial levels.

How can and must a highly industrialised and technology-based society be transformed in order to reach this goal? Which technical measures and political instruments are required if economic growth, safety and comfort are to be warranted in the future? Will we have to make sacrifices or can we replace quantity by quality?

Since 1990, targets have been pursued in energy and climate policy and the related instruments implemented. A brief look at the as-is situation clearly shows that there is still a very long way to go before we reach the 95% target (refer to Fig. K-1)

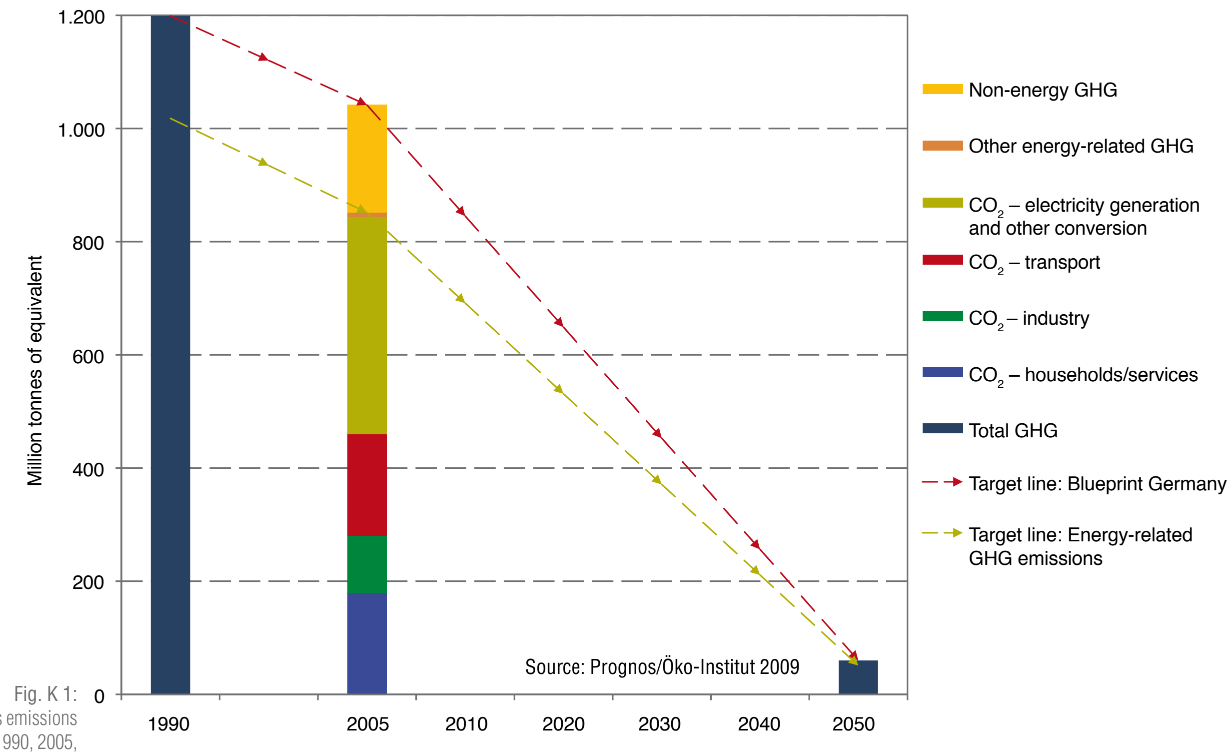

Fig. K 1: Greenhouse gas emissions by sectors, 1990, 2005, and the target up to 2050, in million t of CO_2 equivalent

All sectors will have to make a huge contribution in order to reach this very ambitious goal. It becomes clear that a huge boost in efficiency to reduce energy demand and the exhaustion of renewable energy potentials will be needed.

WWF commissioned a working group including Prognos / Öko-Institut / Dr Ziesing to perform a quantitative analysis of this issue for Germany. In addition to the question "what can and must happen on the technological level and how does the corresponding policy look like?", it is also important to assess how far these solutions are from the currently discussed political path.

This is why two quantitative scenarios have been developed: one scenario with an ambitious continuation of today's energy and climate protection policy (reference scenario) as well as an innovation scenario that investigates the transformation to a low-carbon society geared towards a 95% reduction. The continuation of today's energy and climate protection policy clearly fails to reach the target by 2050 (refer to Fig. K - 2). The reference scenario is used as the basis when calculating the costs and identifying the instruments of the innovation scenario. The comparison of emission trends in the reference scenario and in the innovation scenario shows that considerable greenhouse gases reductions are feasible up to 2050 in all sectors. Despite this, the emission reduction target of 95% against 1990 cannot be achieved with the measures considered in these scenarios. The remaining reduction gap would have to be filled with measures that are beyond the general framework specified in the scenarios.

With a selection of corresponding measures (refer to section "Component Analysis"), it is possible to describe a version of a "Blueprint Germany" in which emissions levels in 2050 are 95% below 1990.

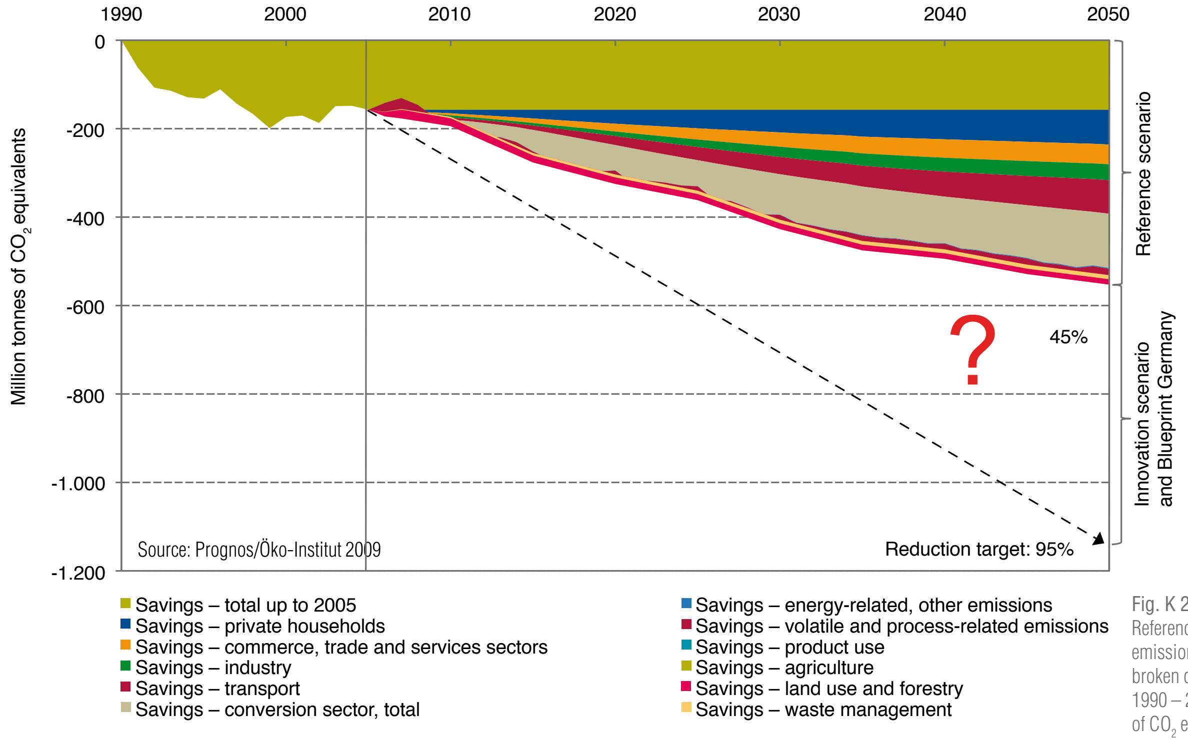

Fig. K 2: Reference scenario: emission reductions broken down into sectors, 1990 – 2050, in million t of CO_2 equivalent

Three strategy segments are distinguished for the development of long-term strategies necessary to implement the climate protection measures required in the "Blueprint Germany" version:

- **strategic goals**, which serve as the basis for evaluating the target achievement up to 2050 as well as progress in the different sectors, both in general and with sufficient sectoral differentiation;
- **implementation strategies** with which interaction between the different scopes of action up to 2050 will be addressed;
- **instrumentation strategies** which contain the long-term guidelines for the political implementation instruments.

The following section describes emission trends and the structure of greenhouse gas emissions. The main contributions of the different sectors to reduce emissions are then broken down and strategic goals are subsequently identified.
Based on this, the most important assumptions and results of the innovation scenario as well as the implementation strategies are presented sector by sector. In addition, a set of instruments is developed for the period up to 2030 that leads to the reduction in greenhouse gas emissions required in this period.

Total greenhouse gas emissions

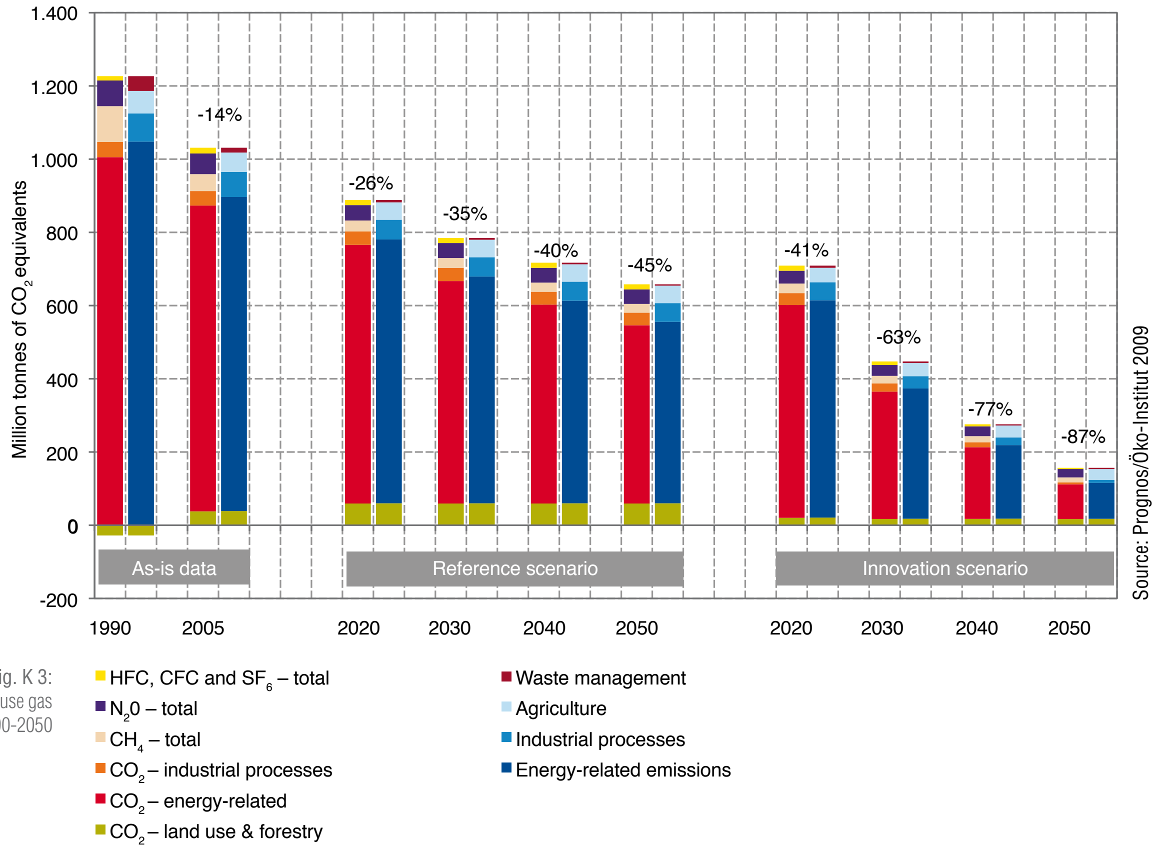

Fig. K 3:
Total greenhouse gas emissions 1990-2050

Overall, very different trends are shown **for total greenhouse gas emissions** in the two scenarios:

- In the **reference scenario**, greenhouse gas emissions decline by around 36% in the 2005-2050 period. Compared to 1990, this corresponds to a reduction of around 45%. In 2050, percapita GHG and CO_2 emissions amount to approx. 9 and 8 tonnes respectively. GHG and CO_2 emissions accumulated since 2005 (in terms of a carbon budget) amount to approx. 38 and 34 billion tonnes respectively.

- In the **innovation scenario**, emissions are reduced by around 85% in the 2005-2050 period. This corresponds to a reduction of 87% compared to 1990. In 2050, per-capita GHG and CO_2 emissions amount to approx. 2.2 and 1.6 tonnes respectively; accumulated GHG and CO_2 emissions amount to approx. 26 and 22 billion tonnes respectively.

- In the **Blueprint Germany**, 2050 emissions are around 94% lower than in 2005; this corresponds to a reduction of 95% compared to 1990. Total greenhouse gas and CO_2 emissions per capita in 2050 amount to 0.9 and 0.3 tonnes respectively, although these values take into account remaining greenhouse gas emissions and the creation of additional CO_2 sinks through CCS in the area of biomass (-0.4 tonnes of CO_2 per capita). For the 2005-2050 period, accumulated GHG and CO_2 emissions total approx. 24 and 21 billion tonnes.

Emission trends are characterised by the following developments:

Relevant polluter sectors:

- **Energy-related emissions** are and continue to be of paramount importance for the level of greenhouse gas emissions in Germany. Accounting for around 82% of total greenhouse gas emissions in 2005, this share falls to around 75% by 2050 in the reference scenario and to almost 62% in the innovation scenario. These developments also underpin the special role played by the energy sector in an ambitious climate protection strategy.

- The contribution made by **process-related emissions** (in this case without the iron and steel industry) rises in the reference scenario between 2005 and 2050 from 7% to almost 8%. This contribution falls to around 5% in the innovation scenario. This suggests that a considerable potential for reductions is also possible in the medium term in the area of process-related emissions.

- The increasing contributions from **agriculture** and **land use and forestry** over the period are an indication that the options for reducing emissions in these sectors are subject to much stronger limitations than in other sectors. In the reference scenario, for instance, the share of greenhouse gases from agriculture rises between 2005 and 2050 from 5% to 7%, and to more than 19% in the innovation scenario. Net contributions to emissions by the LULUCF sectors increase in the 2005-2050 period from 4% to around 9% in the reference scenario and to around 11% in the innovation scenario.

- **Waste management** has a less important role to play since its contribution to total greenhouse gas emissions is below 1% in the reference scenario and below 2% in the innovation scenario.

Relevant greenhouse gases:

- **Carbon dioxide** is the dominant greenhouse gas in both scenarios. In the reference scenario, the decline in the share of CO_2 in total greenhouse gas emissions is very weak, i.e. from 89% to 88%. In the innovation scenario, the share falls from 89% to 75% between 2005 and 2050.

- The importance of **nitrous oxide** increases considerably. In the reference scenario, the share remains stable in the range of 5% to 6%; in the innovation scenario, N2O accounts for almost 16% of total greenhouse gas emissions in 2050.

- The share of **methane** emissions declines from 4.5% to 3.6% in the reference scenario between 2005 and 2050. This share rises in the innovation scenario to around 8.5% in 2050.

- The emission trends of **fluorinated greenhouse gases**, which account for a share of 1.5% to 2% in the reference scenario and 1% in the innovation scenario, are of lesser importance.

Component analysis and target achievement for the development of greenhouse gas emissions

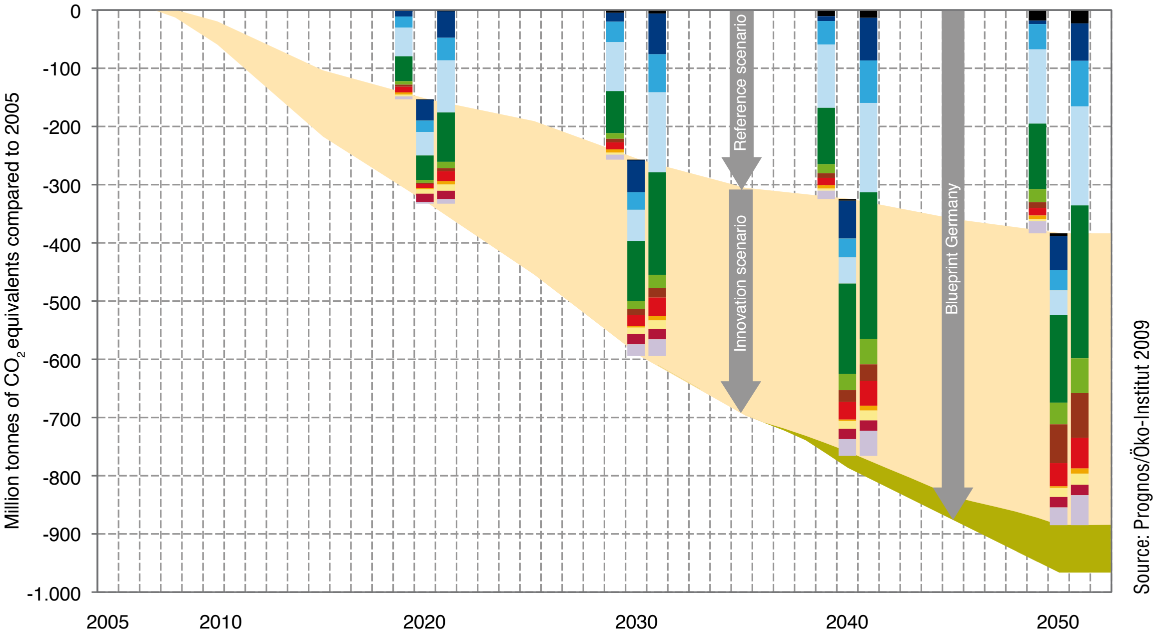

Fig. K 4: Sectoral contribution to GHG emissions trends

On the whole, a 45% reduction in emissions (based on 1990) is achieved by 2050 in the **reference scenario**. The reduction amounts to 51% without land use, land use change and forestry (LULUCF).

In the **innovation scenario**, a reduction of 87% (89% without LULUCF) is achieved by 2050. By the year 2040, emission trends in the innovation scenario roughly correspond to the trend which would have to be pursued to achieve the 95% reduction target.

In order to reach the emissions level of the **Blueprint Germany**, additional emission reduction measures have to be identified in order to fill the remaining gap of approx. 97 million tonnes of CO_2 equivalent.

A component analysis has been used to systematically compare the **contributory effect** of the different sectors or sources to emissions reductions in both scenarios. For the 2005-2050 period this results in:

In the **reference scenario,**

- the biggest reductions in emissions are achieved by various measures in the area of energy efficiency. By 2050, these measures will be responsible for around 46% of the total reductions in emissions whilst the most decisive contributions are made primarily by improved efficiency in the building sector and in industry;
- the use of renewable energy accounts for a 29% share in emission reductions;
- measures in the field of industrial process emissions make a considerable contribution with a share of around 3% o f emissions reduction whilst the cost-efficient reduction of N_2O emissions in the chemicals industry, in particular, has an outstanding role to play.

In the **innovation scenario**,

- once again improved energy efficiency accounts for a contribution of 27% of additional emission reductions. The hugely increased efficiency of electricity applications is here decisive, since it accounts for around half of the total additional reduction in the field of energy efficiency;
- additional emission reductions are largely made through the huge increase in the use of renewable energy which cover a share of 37% of total additional emission reductions. Around 7 percentage points result from the indirect effects of transport electrification (which, in the innovation scenario, can also be interpreted as a contribution by renewable energy);
- emission reductions resulting from substitution in the field of fossil fuels are considerable and account for a share of 13% of additional emission reductions;
- measures in the field of carbon sinks contribute around 4% to additional emission reductions.

In the **innovation scenario**, the increase in energy efficiency and the increase in the use of renewable energy (both in the order of 35% by 2050) contribute to an almost equal extent (regarded as the aggregate contributions of the reference and the innovation scenarios) to the total reduction of emissions. Furthermore, significant contributions are also made, for instance, by the fuel switch in the case of fossil fuels (9%) as well as emission reductions in industrial processes (6%), and in the field of soils and forests (2%). Measures in all other areas (agriculture, etc.) add up to a share of 12% of total emission reductions.

Around half of total additional emission reductions in the innovation scenario and around two thirds of energy-related emission reductions up to the year 2050 are due to measures designed towards **particularly long-life capital stock** (buildings, power stations, infrastructures, etc.). In their case it is particularly important to introduce the necessary climate protection measures on time. Similarly, around half of the emission reductions of the innovation scenario which will come into effect by 2050 are related to measures which will require considerable **innovation** (technology, costs, system integration) over the coming years.

Moreover, in the **"Blueprint Germany"**:

- the significant base of industrial CO_2 emissions that remains can be cut by around another 16 million tonnes of CO_2 through the use of CCS in relevant industrial processes (pig iron production, cement production);
- the remaining process heat demand and natural gas and heating oil applications in the commerce, trade and services sectors can be replaced by the use of biomethane; this would result in an additional reduction of approx 25 million tonnes of CO_2 emissions, but – in view of availability limits – would require the integration of a higher-level biomass strategy or corresponding complementary measures in the transport sector;
- the wide replacement of conventional fuels with biofuels in aviation could additionally reduce emissions by approx. 22 million tonnes of CO_2; the corresponding additional fuel quantities would have to be supplied by more extensive approaches in passenger transport (avoidance/shift as well as increase in electrification by around 20% in each case), in road freight transport (avoidance/shift of around 20%) or by biomass imports;
- an additional carbon sink of up to 32 million tonnes of CO_2 equivalents can be achieved by storing carbon dioxide from biofuel production in geological formations.

These additional measures make the path for the "Blueprint Germany" possible and the reduction target of 95% can be achieved. If the reduction in emissions is put into relation with the emissions level without LULUCF, this results in a 96% reduction in emissions including the additional measures.

Targets and strategic approaches

to achieve the climate protection goals of the Blueprint Germany

The analysis of the innovation scenario and the additional potentials required in the “Blueprint Germany” provide the following **strategic framework** to achieve the targets:

- a reduction of total **greenhouse gas emissions** by 40% by 2020, 60% by 2030, 80% by 2040 and 95% by 2050 (based on 1990);
- an improvement of **overall economic energy productivity** by 2.6% p.a.;
- an increase in the share of **renewable energy sources** in overall primary energy to 20% by 2020, 35% by 2030, 55% by 2040 and by more than 70% by 2050.

In order to control targets and to monitor the progress achieved, it makes sense to put safeguards in place for the different sectors. The respective sector-specific targets will be identified in the individual sector chapters.

Between the individual options for greenhouse gas reductions and in the context of ambitious climate protection strategies, a series of system connections and interactions have to be considered which must also be taken into consideration in the strategic shaping of the respective climate protection and energy policies:

- In **all sectors**, significant effort must be made to reduce emissions. However, considering the scale of the contributory effects required, measures in the electricity sector (demand and generation), in the building sector (new and existing buildings), in motorised private transport, road freight transport, in air transport, in industry (including process emissions), in agriculture and in the field of land use and forestry are particularly important.

- It will not be possible to achieve the emission reduction targets by 2050 without significant advances in **energy efficiency**, nor without a huge increase in the share of **renewable energy**.

- A very high share of the additional emission reductions required (around 60%) is related to **long-life capital stock** (buildings, power stations, infrastructures, etc.). Delays in implementing measures will mean that the target will not be reached or that the costs of climate protection policy will rise very steeply. This is why measures are urgently required over the course of time in the field of electricity demand (efficiency on the one hand and electrification on the other), electricity generation, buildings (new and existing buildings), infrastructures (electricity, gas, heat, CO_2, transport) as well as in the transport shift.

- A very high share of the additional emission reductions required (also around 60%) is expected, especially after 2030, to come from emission reduction options where significant **innovation** still has to be achieved in terms of technology, costs and system integration/infrastructure. This applies especially to electricity generation based on renewable energy, electricity storage and infrastructure, the generation of sustainable biofuels and the provision of sustainably generated biomethane, energy efficiency in industry, energy efficiency in conventional and electric vehicles as well as CCS technology.

- Advances for a range of central emission reduction options are inevitably **linked to complementary options**; without systematically designed strategy approaches the reductions aimed at could fail:

  - Electrification of motorised individual traffic is inevitably linked, on the one hand, to the development of additional options for electricity generation based on renewable energies (or CCS) and, on the other, on the creation of intelligent electricity grids.

  - The massive use of biofuels in road and air transport requires the availability of biofuels which meet high sustainability standards.

  - The use of decentralised efficiency technologies which initially run on natural gas (e.g. decentralised cogeneration), as well as the switch of industrial process heat generation to renewable energies require in the medium to long term the availability of considerable quantities of biomethane that is fed into the gas grids.

- The introduction of new electricity generation options as well as the creation of capacities for modal shift require a long-term approach in the respective **infrastructure development** (transport and distribution network, CO_2 infrastructure for CCS, rail network).

- Limits to potential must be considered for at least two central emission reduction options, i.e. the use of biomass and the introduction of CCS, and a suitably active approach must be pursued for **strategic resource management**:

  - If for the transformation switch of the energy system in to biomass is to be primarily restricted to the – limited – domestic or European potential, sustainability requirements will have to be met. The use of biofuels is justifiable only on condition that these are sustainably cultivated in both social and ecological terms and according to legally binding regulations and standards. Adherence to minimum standards for sustainability must be assessed and guaranteed through certification systems. Internationally coordinated, binding regulations and minimum standards that warrant the sustainability of agricultural resources are vital if the use of biofuels is to be expanded. When these preconditions are fulfilled, priorities for use must be established and monitored. In addition to usage priorities also the generation of biomass is of utmost importance in the framework of an all-encompassing biomass strategy. The conversion of waste and residues should be prioritised over the cultivation of energy plants.

- Regarding biomass, priority must be given to applications that lack sufficient alternatives. This applies, on the one hand, to the remaining fuel use in road transport (after extensive electrification of motorised individual transport) and to air transport. Process heat applications (especially in industry) should be seen as the next priority, only then to be followed by electricity generation from biomass. Regarding the use of biomass to generate electricity, stricter efficiency requirements apply: generating electricity from biomass without using cogeneration is not compatible with a long-term climate protection and energy strategy.

- The storage available for CCS is a limited resource (also in terms of competition to use the underground) for which use priorities and management approaches must be developed. Priority is given here to process-related CO_2 emissions and the use of storage for carbon dioxide from biomass conversion processes (production of biofuel, generation of electricity from biomass). This prioritisation should also be considered when addressing the question as to which contribution is to be assigned to CCS in electricity generation in the climate protection and energy strategy.

• The climate-friendly conversion of the energy and transport system requires considerably improved efficiency in the use of energy-intensive **materials and products**.

With a view to the **political implementation tools** which will and must change in terms of direction and design, the following strategic approaches are of higher and more long-term importance:

• Securing a sufficiently **diverse range of players** and **competitive markets** forms a key precondition for the development of robust and efficiently designed climate protection paths. An insufficiently diverse range of players increases the risk of lock-in effects and could hinder or delay the innovation processes required.

• In all areas, the political implementation measures must also promte a continuous and targeted **innovation process** in order to bring climate protection options to market maturity as quickly as possible. Support measures for early market introduction processes have an important role to play here.

• The significant **pricing** of greenhouse gas emissions forms the necessary basis for an ambitious and successful climate policy.

• If climate protection options with a significant solution potential are not compatible with the applicable **market structures** (such as fluctuating supplies of large electricity quantities from renewable energy sources), then the market structures must be gradually adjusted.

• Regulatory approaches make sense and are necessary for very **homogenous technologies** and/or climate protection options as far as special support measures are needed.

• As far as market developments in the field of long-life capital stocks could lead to **lock-in situations** that in the long term prevent the achievement of ambitious climate protection targets, suitable regulatory measures should be adopted.

• The creation of a robust and sustainable **energy efficiency market** is vital for the broad and significant increase in energy efficiency.

• The development of **infrastructures** for the energy and transport systems must be planned and pushed ahead with a long forerun and hence with considerable uncertainties. This will lead to a special (new) field of government responsibility.

Finally, a careful analysis of the long-term implementation strategies and the short to medium-term political instruments must take into account the consistency of short-term, medium-term and long-term solution contributions. Not all approaches which will no longer be relevant in the long-term target structures are automatically problematic in the short to medium term (e.g. the distribution of fossil energy generation with a biogas potential that is limited in the long term). What is central here are the medium-term switch strategies and the precondition that no contra productive structures are created in the short to medium term. At the same time, the solutions required in the long term can lead to problematic structures (e.g. biofuels with insufficient sustainability standards). Targeted policy and innovation approaches with clearly defined time horizons are vital in these areas.

Framework data

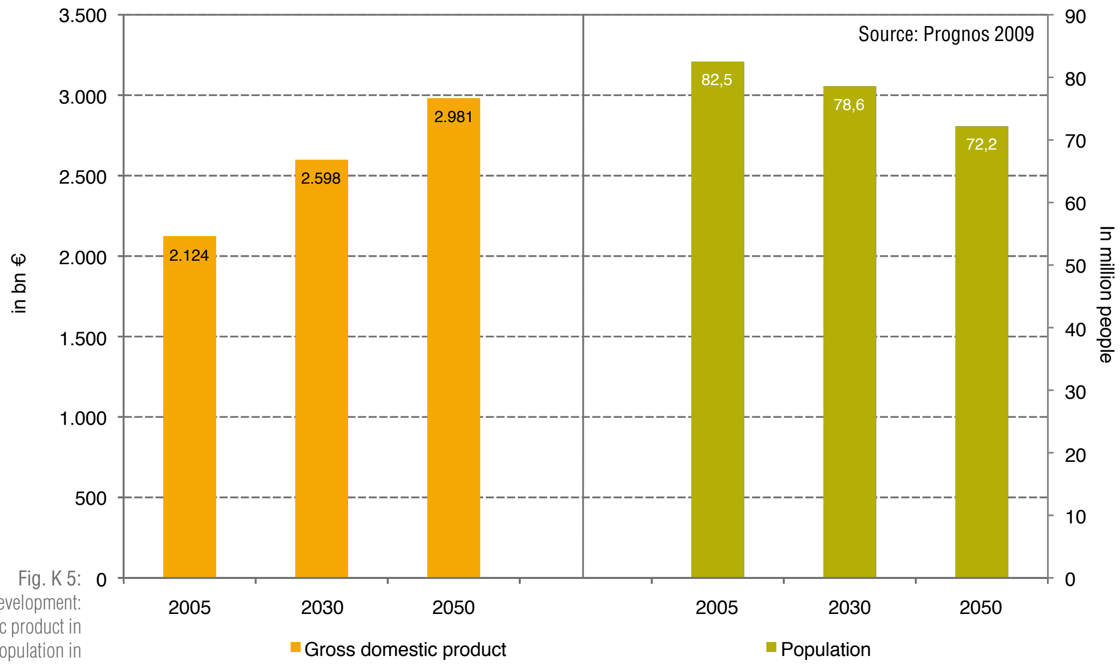

Fig. K 5: Framework development: gross domestic product in billion€ and population in millions, 2005 to 2050

The framework data describes the assumptions regarding a few macroeconomic variables underlying the scenarios.

Despite average net immigration figures of approx. 150,000 persons p.a. for the period from 2005 to 2050, **population figures** will decline by 12.5% over that period, which represents about 10 million people.

Ageing will continue: The group of people over the age of 65 grows by 6.2 million while the number of people under the age of 65 will fall in total by 16.5 million. In 2050, there are 12.5 million fewer people of working age (20 to 65 years old) than in 2005.

The average **household size** declines from 2.10 to 1.86 persons. One and two-person households increase by 3.2 million while the number of larger households declines significantly.

The average **living space** per capita moderately increases further, on the whole by 253 million m^2. New built homes are primarily one and two-family homes. Until 2030, the addition of living space in new buildings surpasses the number of age-related withdrawals. After this, the trend reverses and living space then declines in total by an average of 6.6 million m^2 annually.

Gross domestic product (GDP) in 2050 is around one third above the level of 2005. Following the crisis-related decline in 2009, the previously attained growth path is scarcely reached.

With a declining population, average **increases in GDP** between 2020 and 2040 are moderate. GDP growth per capita will be higher, totalling between 0.6% p.a. for the period 2025 to 2030 and 1.4% p.a. for the period 2045 to 2050.

Unemployment will substantially decrease until 2050. Due to demographic change, the workforce will decrease faster than employment opportunities.

The **services sector** is becoming increasingly important for economic growth. Between 2005 and 2050, gross value added increases by around 46%. In the period from 2005 to 2050, **industry** grows by almost 20%. Energy-intensive industries, which in 2005 accounted for approx. 14% of overall industry production, will reduce their output by 2050 by more than 20%. However other industrial sectors will grow by around 44% in that period. This confirms the continuation of structural change that has been taking place since the 1980s.

In face of the challenges ahead, industry will secure its international competitiveness through technical progress, innovative and knowledge-based products as well as through internationally coordinated collaboration in technology.

Passenger transport is and remains strongly marked by motorised individual mobility. Due to the decline in population, absolute passenger transport performance declines by 10% between 2005 and 2050. Due to economic development and the ongoing increase in international trade, **freight transport performance** increases by 86% between 2005 and 2050. Rail accounts for a considerable share of this growth since freight transport by rail increases by 191% while freight and inland navigation increase by only 67% respectively 47%. The share of rail transport in freight rises from almost 17% in 2005 to 26.5% in 2050.

Air transport performance rises by 7% in the period under review by, hence much slower than road freight.

The sustainable **biomass potential** (without competing with food production or generating a reduction in the ecological quality of previously high-quality land) is very limited in Germany and is estimated at approx. 1,200 PJ of primary energy. This rules out the idea of completely replacing fossil fuels with bio-fuels. Instead, strategic approaches will be needed to use biomass products in areas where there are no alternatives.

Technology development

Current technology developments on the demand side will continue in the areas of energy and material efficiency. The reference scenario however shows that the climate protection targets cannot be reached with these technologies when applied in existing structures even if upgraded in an ambitious manner. In order to reach the targets, **systematic changes** will also be needed in the development of products, materials and production processes. Key technologies, above all (nano-technology, biotechnology and microsystem technology), must be developed with energy and material efficiency in mind. These new technologies can pose risks. Before being put to use, each individual technology must hence be examined in terms of its sustainability. On the other hand, efficiency developments beyond the scope of the reference scenario are inconceivable without such qualitatively new technology developments and approaches.

The **key new fields of technology** in which innovation is needed and is assumed as implemented in the innovation scenario, are, for example (only an illustration rather than a complete listing):

- **New materials**: energy efficient materials, tailored according to specific properties, which avoid the use of metals for static functions (e.g. for load-bearing skeletal structures in buildings or resistant skins for vehicles).
- **High-performance thermal insulation** which can be easily and extensively used in existing buildings; specific, reactive window coatings which enable considerable savings in room heating in winter and reductions in radiation exposure in summer.
- **New building materials** based on plastic and composite materials.
- **Biological production processes** in the chemicals sector, e.g. using specialised bacteria or enzymes to synthesize substances; use of catalytic processes to reduce excitation energy.
- **Microprocesses** for producing special products “on the chip” (e.g. pharmaceuticals).
- **Optoelectronics** to boost the bandwidth, speed and performance density of electronic applications; reduction of waste heat with increasingly more powerful IT applications.
- **Miniaturisation** of displays (visors instead of monitors).
- Optimised and efficient **battery systems** and **power storage**.
- Highly efficient production of **biofuels** of the second (and third) generation.
- **Process optimisation** and **optimisation of building management** through control and instrumentation equipment.
- **Grid optimisation** and **demand side management** to balance out peak loads, to reduce power storage use and losses, and to integrate fluctuating renewable energy into the power system.
- **Photovoltaics** of the third generation (on an organic basis).
- High performance **transport infrastructures** thanks to information and communication technology.
- Carbon capture and long-term storage in secure geological formations **(CCS)**.

Private households sector

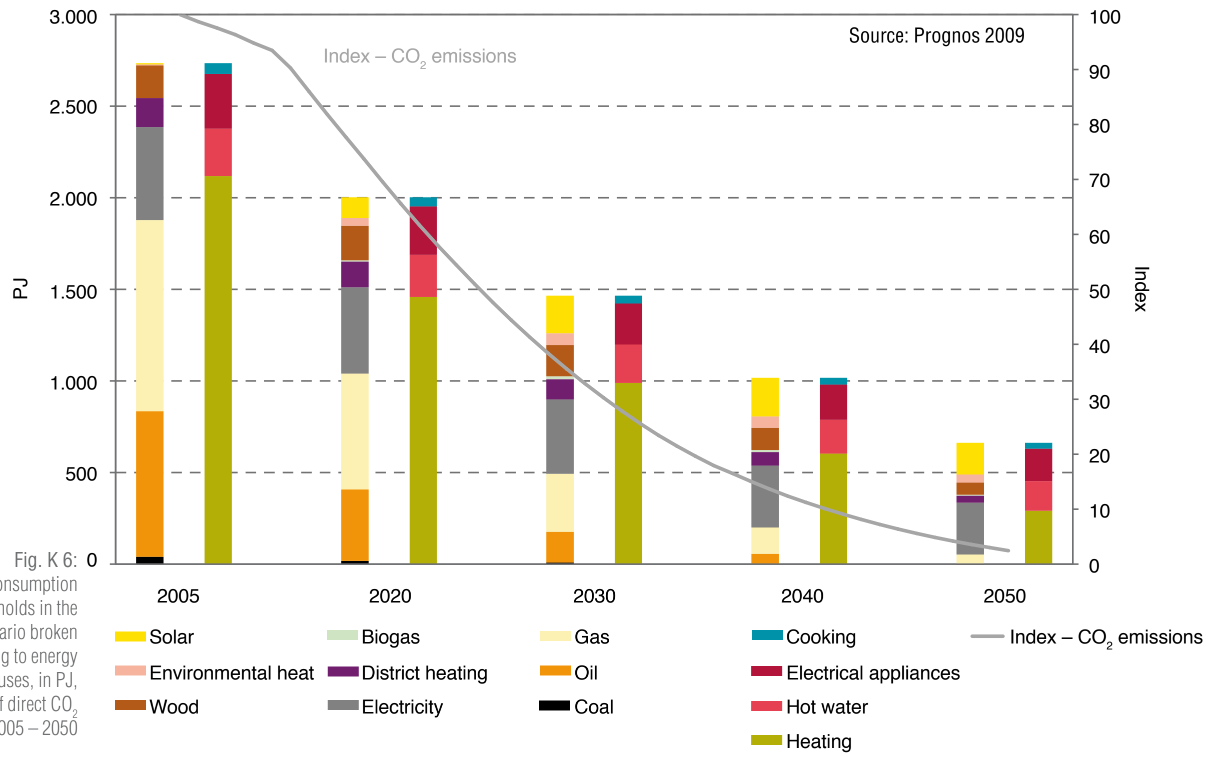

Fig. K 6: Final energy consumption by private households in the innovation scenario broken down according to energy sources and uses, in PJ, index of direct CO_2 emissions, 2005 – 2050

In the private household sector, direct **CO_2 emissions** fall by 98% from 212 million tonnes to 3 million tonnes between 2005 and 2050.

- The key to reducing emissions in this sector is to reduce space heating demand. **Space heating** is the one application where efficiency measures can lead to the by-far greatest share of savings in final energy, both in absolute and relative terms. Specific space heating demand in buildings will be reduced to almost zero both in new buildings and in existing buildings thanks to building measures (thermal insulation of the building shell and of windows). From 2025 / 2030 onwards, suitable materials will be available for standard application. The rate of refurbishment of existing buildings will double after 2012 from almost 1% to approx. 2% p.a.,, the energy-related standard of refurbishment from 2025 onwards corresponds to an ambitious new building standard. Specific space heating demand in new buildings is reduced successively in steps by approx. 50% until it reaches almost zero after 2030.
- Thanks to the use of further-enhanced, water-saving fittings, hot water consumption per capita falls by more than 10% with growing comfort. By 2050, energy demand for the generation of **hot water** will be reduced by 37% compared to 2005.
- The efficiency improvements of **household appliances** will be strongly developed so that by 2050 average specific energy consumption will have fallen by 70% to 80%. Magnetic refrigerators will be standard, as will be waterless washing machines, thus making tumble dryers superfluous. Despite the convergence of (electronic) media, other electric applications lead to an increase in the number of appliances in households. Specific energy consumption by electronic devices and appliances will fall by 70 to 80% primarily due to new display technologies; in total, electricity demand for electric appliances will fall by 40%.

In order to achieve the required reductions, the following **strategic safeguards** must be put in place:

- In the **building sector**
  - an average annual final energy consumption standard of 20 kWh per m^2 should be achieved for space heating in new buildings starting around 2015, and decreasing to around 10 kWh per m^2 after 2020 with the goal of zero-energy or plus-energy houses after 2025
  - specific final energy consumption in existing buildings should be cut by more than half from 2005 to 2030 and by around 90% by 2050;
  - the share of renewable energy or (directly) emission-free energy sources (district and local heating) in overall energy for the remaining space heating and hot water generation should be increased to around 40% by 2030 and to at least 75% by the year 2050.

- The following **implementation instruments** can be derived from this for the time horizon until 2030:

  Building-specific instruments to boost energy efficiency
  - Stricter new building standards with a maximum, annual final energy consumption value for space heating of 20 kWh per m^2 starting 2015, of 10 kWh per m^2 starting 2020 and the zero-energy or plus-energy house standard from 2025 onwards;
  - Continuation and improvement of subsidy programmes for building refurbishment to secure refurbishment rates of more than 2% p.a. and long-term refurbishment efficiency of 90%.

- **Energy efficiency programmes specifically for electricity**
  - Consistently strict consumption limits for all electric appliances according to the top-runner principle (consumption values of the best appliances as minimum standards to be achieved by the next generation of appliances within five years);
  - Ban on night storage heating after a transition period of five years (accompanied by subsidy programmes).

Services sector

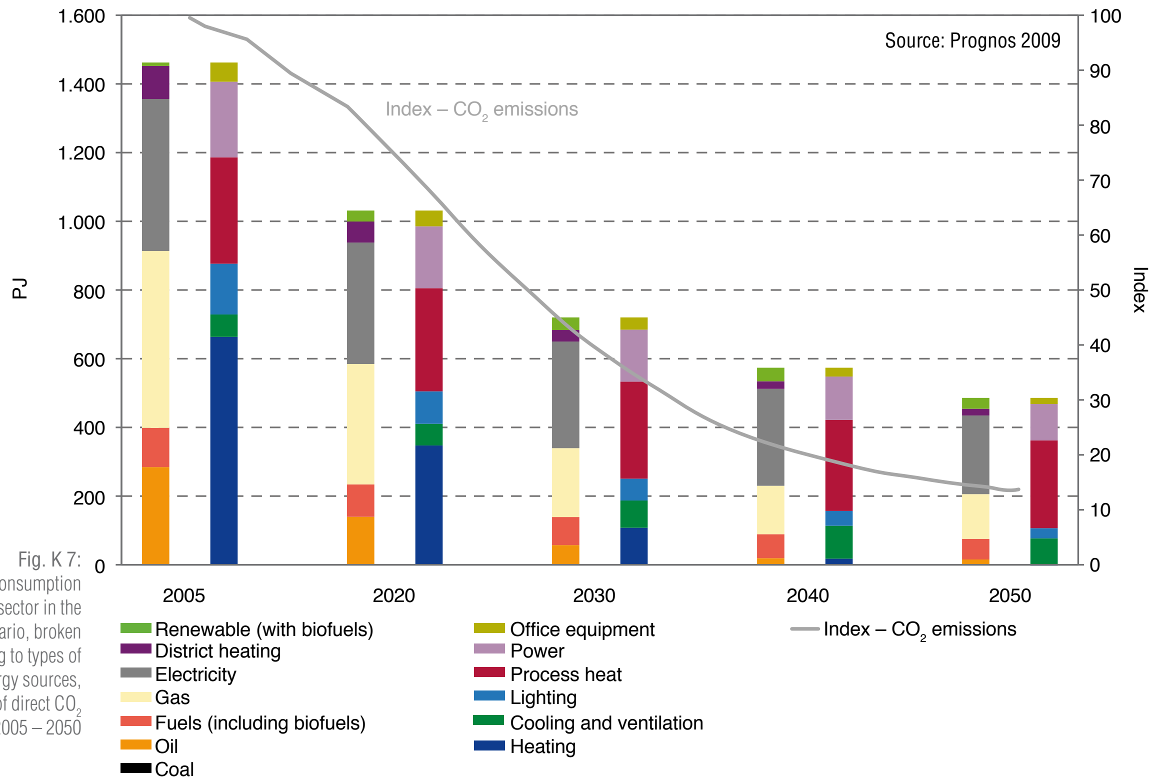

Fig. K 7: Final energy consumption by the services sector in the innovation scenario, broken down according to types of use and energy sources, in PJ, index of direct CO_2 emissions, 2005 – 2050

Between 2005 and 2050, direct energy-related **CO_2 emissions** in the services sector fall by 85% from 58 million tonnes to 8 million tonnes.

- The greatest part of this reduction is achieved in space heating. Specific **space heating** demand in services buildings falls to almost zero by 2050 both in the case of new buildings and existing buildings. Since buildings in the commercial sector are more likely to be torn down rather than refurbished, the turnover of buildings is higher than for private households.
- Due to **cooling demand** as a result of global warming, final energy demand for air conditioning increases. This will be kept in check by the highly efficient production of cold (e.g. with heat pumps and the use of renewable energy sources and waste heat).
- When it comes to providing **process heat** and **power**, the possibilities for saving energy are physically limited. Shifts in technology, both in the case of process design and in the organisation of services, will help to achieve a 17% decline in process heat demand despite an almost 50% increase in value added. Sterilisation with UV light, water-free washing machines, etc. are some examples of savings.
- When it comes to **power applications**, the most efficient cross-section technologies will be used for electric motors, pumps and compressed air. Moreover, material-efficient processes and altered materials (e.g. in vehicle construction) will be used in a targeted manner and will reduce specific demand for mechanical energy for each value added unit by up to 80%. This reduces energy demand for power applications by almost 52%.
- **Total final energy demand** in the services sector in 2050 is 66% below the 2005 level. Almost half of the remaining demand will be covered by electricity. Especially when it comes to providing process heat, gas will remain an important energy source, accounting for 26% of the total mix. Renewable energy sources (Geothermal heat, solar heat, as well as biofuels to a very small extent) will cover the demand that remains.

The **targets** and **instruments** resulting for the 2030 time horizon for buildings match those of the household sector. This is supplemented by high efficiency requirements for cooling equipment (from approx. 2030 on, these will run only combined heat and power, heat pumps or with renewable energies). In the case of highly standardised devices, the instruments applicable to the private household sector must also be applied.

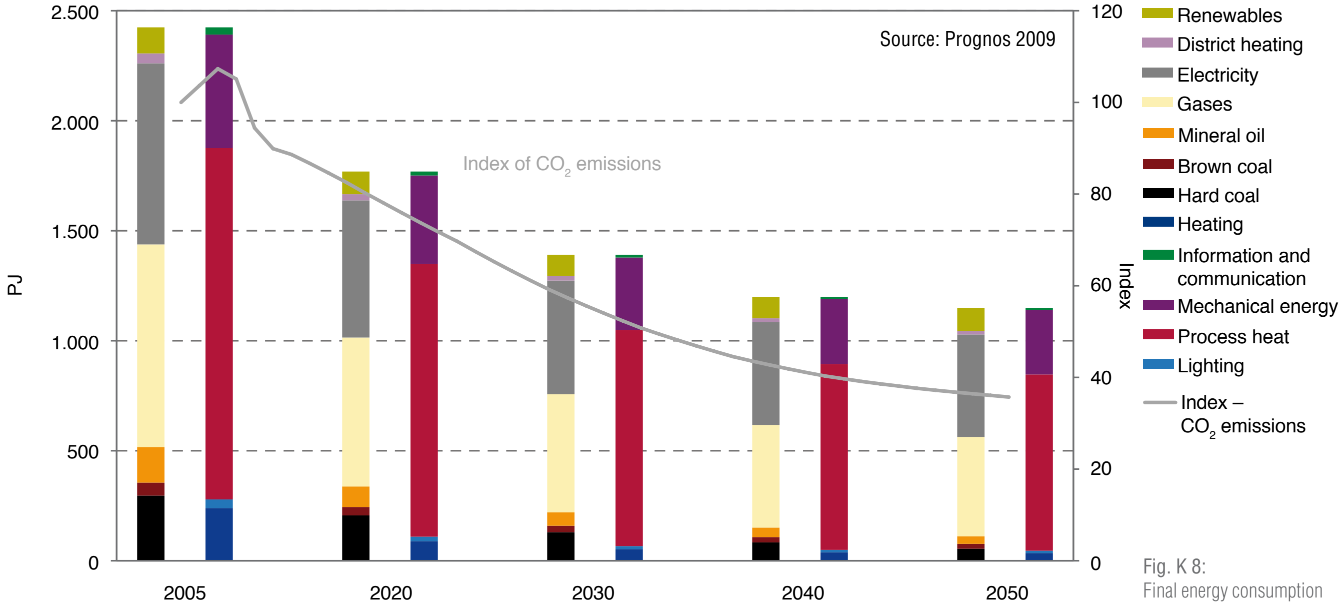

Fig. K 8: Final energy consumption by the industrial sector in the innovation scenario, broken down according to types of use and energy sources, in PJ, index of direct CO_2 emissions, 2005 – 2050

Direct **CO_2 emissions** by the industrial sector decline in the innovation scenario from 101 to 36 million tonnes between 2005 and 2050; this corresponds to a reduction of 64%.

- The main contribution to this reduction results from the reduction of **process heat demand**. In 2005, process heat had a 66% share in final energy consumption and was the main form of energy use in industry. Through persistent shifts in technology and processes, specific process heat consumption falls by approx. 68% by 2050. New production methods and shifts from energy-intensive (e.g. metal production) to less energy-intensive industrial sectors reduce absolute process heat demand by 50% despite an almost 20% increase in production.
- **Power applications** are the second highest form of energy use in industry, accounting for 21% in 2005. Highly efficient cross-section technologies and specially developed optimisation of materials, products and processes reduce final energy use here. All in all, energy demand for these applications falls by 43% between 2005 and 2050.
- Specific **space heating demand** in industrial buildings falls very steeply by the year 2050.
- In the industrial sector, the reduction of emissions is subject to **physical limits** when it comes to the specific consumption by processes using heat and power. This is why energy savings are limited to 53% in the industrial sector between 2005 and 2050.
- The **energy mix** in industry is dominated by electricity (41%) and gas (39%).

In order to achieve the innovation scenario and also the reductions called for in the "**Blueprint Germany**", the following **strategic safeguards** must be put in place:

- **Energy productivity** should be roughly doubled from 2005 to 2030 and tripled by 2050.
- The share of **renewable energy** and emission-free energy sources (district and local heating, electricity) in total final energy demand should rise to around 60% by 2030 and to 90% by 2050.
- By 2050, CO_2-intensive **industrial processes** should only be operated in conjunction with CCS.
- **Process-related greenhouse gas emissions** should be reduced from today's level by more than 50% by the year 2030 and by 90% by 2050.

In addition to the political measures to create a flexible system allowing for the quantitative control of energy savings referred to in section "Key Elements of an integrated climate protection and energy programme" and the ability to deduct energy-saving measures from taxation, the following **sector-specific implementation instrument** for the 2030 time horizon is needed:

- Binding introduction of **energy management systems** in industry.

This must be supported by incentives for the development and use of efficient technology innovations. This applies especially to application-orientated research.

Transport sector

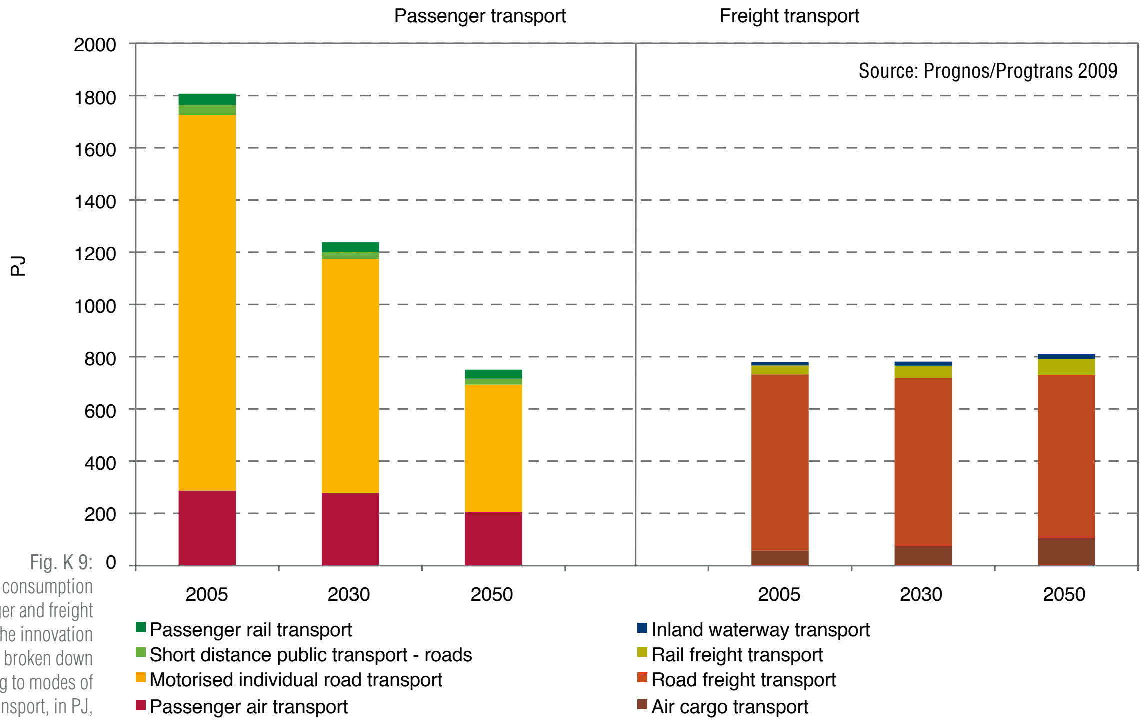

Fig. K 9: Final energy consumption by passenger and freight transport in the innovation scenario, broken down according to modes of transport, in PJ, 2005 – 2050

Direct **CO_2 emissions** of the transport sector will decline in the innovation scenario in the period from 2005 to 2050 from 180 million tonnes to 30 million tonnes, corresponding to a reduction of 83%.

- **Central elements** for the reductions in the transport sector are vehicle efficiency in motorised individual transport, electrification of motorised individual transport and the contribution of freight transport switching to renewable energy sources.
- **Electric vehicles** will be introduced to the passenger car fleet. Vehicles with combustion engines without a hybrid part will no longer be of any relevance after 2045. In 2050, hybrid electric vehicles account for around 36% of cars, plug-in hybrids for 28% and battery electric vehicles for 18%.
- By 2040, the average **specific energy consumption** of new passenger cars with combustion engines declines by approx. 60%. By 2050, the average fleet consumption (calculated over the entire vehicle fleet and performance) falls by 64%; specific CO_2 emissions per vehicle kilometre decline to approx. 40 g per km.
- In **freight transport**, a large part of transport growth shifts to rail transport. Electrification of the HGV fleet is not assumed; this is due to the power density which this requires and for which no battery technologies are foreseeable. Specific consumption by HGVs falls by approx. 25%.
- **Air traffic performance** (domestic principle) declines both for passenger and for freight transport. Between 2005 and 2050, energy efficiency increases by approx. 40%. This means that energy consumption by air traffic falls in total by 10%.
- Due to the more efficient vehicles and the efficiency advantage in terms of final energy of electric vehicles and rail transport, **final energy consumption** by the transport sector declines in total in the period under review by 41%.
- In 2005, final energy demand by transport will hence be mainly covered by **biofuels** (59%) of the second and third generation and by **electricity** (12%). Hydrogen and gas have a minor role to play.

By 2050, all mineral-oil based fuels in the innovation scenario will be replaced by second and third-generation biofuels. This means that the sustainable biomass potential available in Germany is almost completely exhausted. (This calls for a strategic decision concerning the targeted use of the biomass potential in the transport sector, rather than in favour of the generation of low-temperature heat).

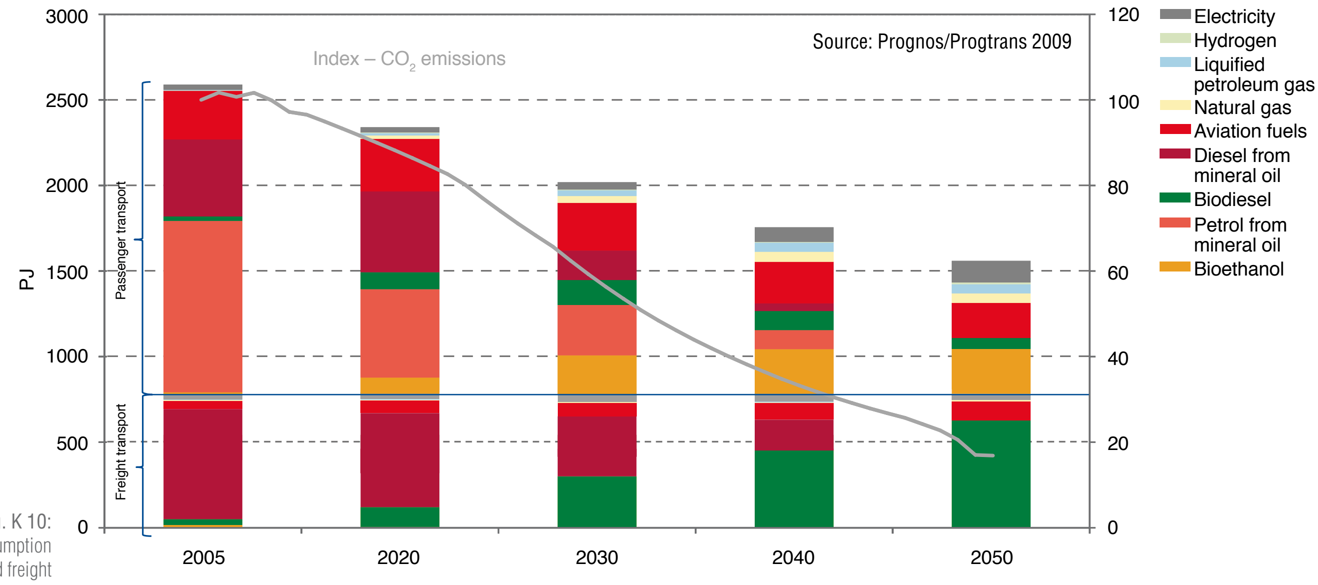

Fig. K 10: Final energy consumption by passenger and freight transport in the innovation scenario, broken down according to energy sources, in PJ, index of direct CO_2 emissions, 2005 – 2050

In order to achieve the "**Blueprint Germany**" in the transport sector, the following **strategic safeguards** must be put in place:

- In the field of **motorised individual transport**,
  - transport avoidance or transport shifting should reduce performance by 2030 by around 20% and by 2050 by around 30%;
  - specific final-energy consumption of the vehicle fleet (including the efficiency effects resulting from electric vehicles) should be reduced by more than 60% by the year 2050;
  - the aim should be to achieve a 7% share of electric drives in total performance by 2030 and around 50% by 2050;
  - the aim for the year 2050 should be to achieve almost complete coverage of final energy demand through renewable (biofuels) or emission-free (electricity, hydrogen) energy sources.
- In the field of **road freight transport**,
  - performance in 2050 should not exceed the current level by more than one third;
  - specific energy consumption by the entire vehicle fleet should be reduced from today until 2030 by 30% and by 2050 by around 50%;
  - the entire remaining fuel consumption must be converted to renewable energy sources (biofuels, hydrogen) by 2050.
- In the field of **air transport**,
  - specific energy consumption by the entire aircraft fleet should be reduced by 20% by the year 2030;
  - fuel use must be fully converted to regenerative energy (biofuels) by the year 2050.

With a view to **the political instruments** for implementation for the 2030 perspective, this means the following set of measures:

- An **investment programme** to double the capacity of Germany's rail network by 2030.
- An **investment programme** to boost by 25% the performance of public passenger transport by 2030 (and to make public passenger transport more attractive).
- Stricter **limit values for passenger cars** to be set at 70g of CO_2 per km in 2030 (without the inclusion of biofuels and without the non-inclusion of electric vehicles).
- Creation of **HGV fleet limit values** of about 30% below the current values by 2030 (including the establishment of a suitable test cycle and calculation basis);
- Increase in the **HGV road toll** to 50ct per km in 2030, granting of an efficiency bonus and expansion to include all HGV and the entire road network
- Increase in **fuel tax** to a level that results in 2030 in a price of €2.50 per litre for conventional petrol.
- Considerable increase in the share of biofuels by combining high and reliably verifiable sustainability standards for biomass and a further-developed **biofuel quota** based on a biomass strategy (the height of the quota is determined by the sustainability standards and the CO_2-emissions reduction potential) by the year 2030.
- A **speed limit** of 120kph on all motorways.

Final energy consumption

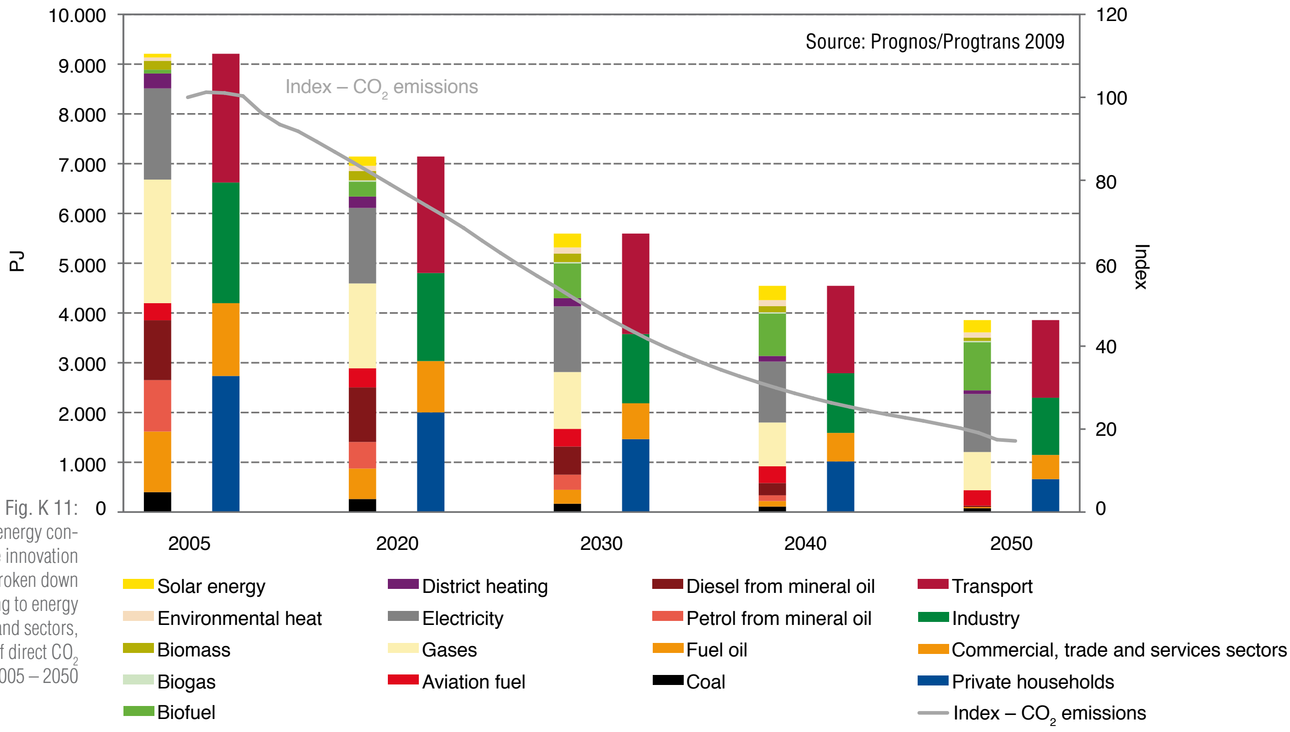

Fig. K 11: Total final energy consumption in the innovation scenario, broken down according to energy sources and sectors, in PJ, index of direct CO_2 emissions, 2005 – 2050

CO_2 emissions from the direct, energy-related combustion of fossil fuels decline in the innovation scenario between 2005 and 2050 from 459.4 million tonnes to 77.7 million tonnes, and hence by 85%.

- **Final energy demand** on the whole declines between 2005 and 2050 by almost 59%.
- All **sectors** will contribute to this with considerable **savings in consumption**. The biggest savings are made in the private households (-76%) and services (-67%) sectors because space heating (in the 2005 reference year) dominates consumption here and this can be practically fully reduced through energy efficiency measures. Savings of 53% are made in the industrial sector. Compared to the reference scenario (savings between 2005 and 2050: 21%), innovation and industry shifts will cut consumption considerably. In the transport sector, consumption in 2050 is 41% lower than the baseline.
- In 2050, **mineral oil products** will be primarily used in air transport and inland waterway transport, and to a very small degree to generate process heat in industry. These products continue to account for a share of almost 10% in the overall energy mix. In motorised passenger and freight transport, they will be systematically replaced by second and third-generation biofuels that have been produced with high efficiency.
- In 2050, **natural gas** will be primarily used to generate process heat in the industrial and services sector, to a lesser degree in innovative technologies for combined generation of heat and electricity, of heat and cold, as well as in passenger cars. In 2050, natural gas accounts for 20% of the energy mix.
- **Electricity** will be used in all sectors for additional purposes and applications, and will be introduced into the transport sector for passenger cars. Despite this expansion, the persistent implementation of efficiency technologies along with technology shifts will lead to an overall decline of 37% in electricity consumption in the period under review. The share in the final energy mix rises from 20% to 30%.
- The use of **renewable energy** (solar heat, ambient heat, biofuels) triples in the period under review. Its share in the final energy mix rises from 4.3% to 36.6%, due to the significant decrease in overall consumption.Taking the additional measures in the “Blueprint Germany” into consideration, the share of renewable energy in overall final energy consumption (in a certain bandwidth – depending on the complementary development assumed in the field of transport avoidance, additional electrification of transport or additional vehicle efficiency) reaches a level of around 30% in 2030, around 40% in 2040 and around 50% in 2050.

Electricity generation without CCS

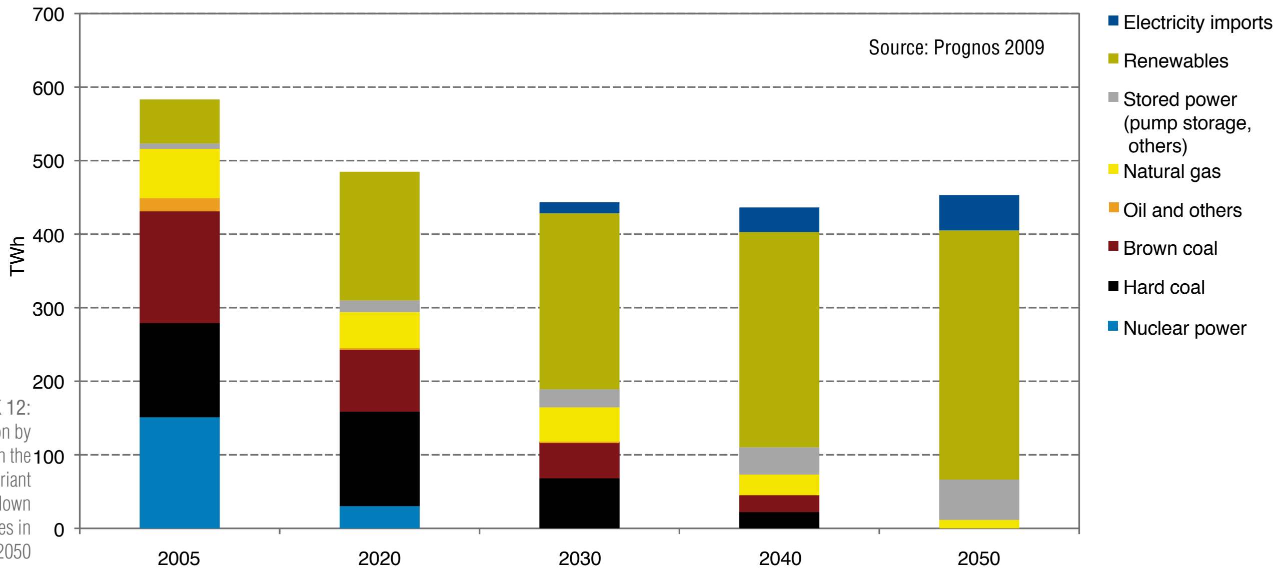

Fig. K 12:
Net electricity generation by German power stations in the innovation scenario (variant without CCS), broken down according to energy sources in TWh, 2005 – 2050

CO_2 emissions from electricity generation fall between 2005 and 2050 from 323 million tonnes to 14 million tonnes and hence by 96%.

The general **decline in electricity demand** (refer to section "Final energy consumption") is a pre-condition for the growing decarbonisation of electricity generation.

Renewable energy has a very high share of net electricity generation. A high share of the **renewable energy** (237 TWh) is supplied by variable wind and Photovoltaics, making considerable intermediate storage and balancing capacities necessary. This requires a number of gas power stations and the extensive increase in storage volumes. The infrastructure-related preconditions for this are the provision of grid capacities to integrate and transport power supplied by offshore wind power plants (38 GW) as well as grids with realtime response capability to manage decentralised feed-in (29 GW of photovoltaics, 34 GW of wind, onshore) as well as the integration and management of storage capacities.

In 2050, the **import balance** (electricity from renewable energy) totals 48 TWh max. and is hence below the quantity assessed as possible in the 2008 Environment Ministry's pilot study. Generally speaking, imports are not ruled out in any of the scenarios.

Electricity generation with CCS

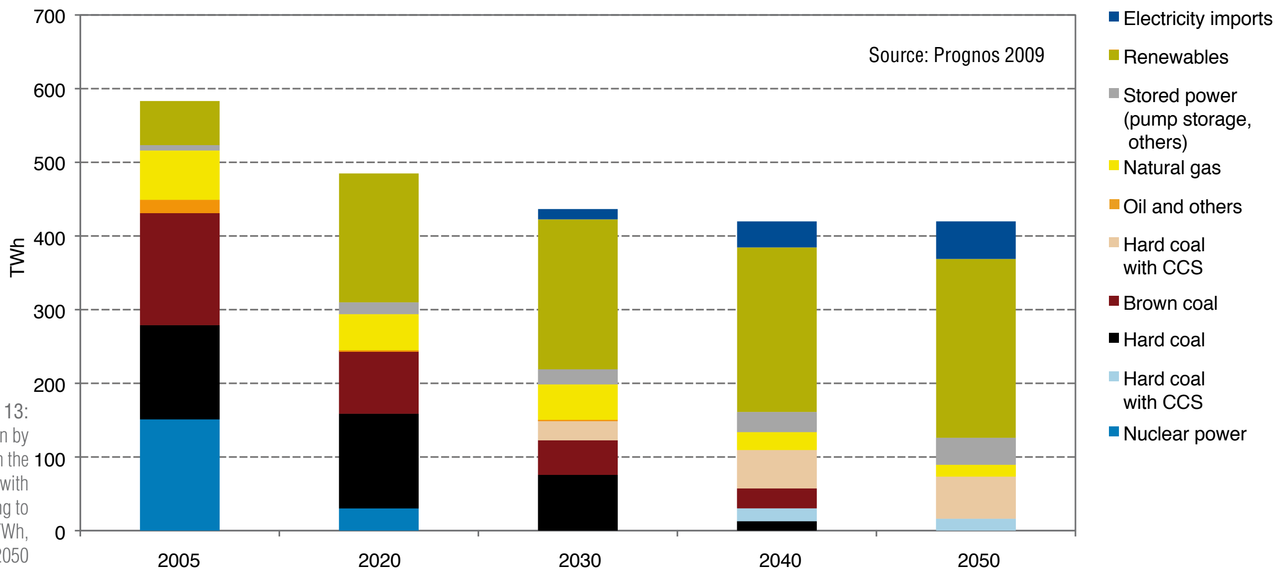

Fig. K 13:
Net electricity generation by German power stations in the innovation scenario (variant with CCS), broken down according to energy sources, in PJ, in TWh, 2005 – 2050

In the variant "with CCS", **CO_2 emissions** fall from 323 to 23 million tonnes and hence by 93%.

This variant assumes the large-scale availability and **implementation of CCS technology**. At the same time, it is estimated that the expansion of renewable energy is not fast enough. In this case, new fossil fuel power stations equipped with CCS technology could be erected.

In the variant with CCS, it is assumed that starting in 2025, this technology will be the standard, first of all, in new lignite power stations, and starting in 2035, in new hard coal power stations also, and that **CO_2 storage** is sustainable and safe. No more new coal-fired power stations without CCS technology will be built after 2025. The old coal-fired power stations without CCS will leave the mix by 2046 for reasons of age or economy.

In 2050, there are no more **coal-fired power stations** without CCS in the mix, but there are still 3 GW of hard-coal capacity and 10 GW of lignite capacity with CCS technology.

There are still 17 GW of **gas power station capacity** available to produce peak load energy.

The volume of electricity from **renewable sources** is lower than in the variant without CCS and in 2050 totals 243 TWh, accounting for around 66% of the total net electricity volume generated. Conventional baseload power plants also exist. That's the reason why storage demand is lower than in the variant without CCS, but still has to increase five-fold compared to 2005. The requirements for the expansion and conversion of infrastructural preconditions (transmission grids, smart grids) match those of the variant without CCS and are in line with the somewhat slower increase in renewable energy.

In order to achieve the **"Blueprint Germany"** in the electricity sector, the following **strategic safeguards** must be put in place:

- By 2030, **electricity demand** (including new application areas, such as electrification of transport) should be reduced by around 25% until 2030 and subsequently further reduced by 10 percentage points until 2050.
- The share of **renewable energy** in electricity should reach a level of 60% by 2030 and of 95% by 2050.
- The remaining fossil **electricity generation** capacities should only be permitted to operate from 2040 onwards if they are equipped with **CCS**.
- In order to balance out the huge increase in contributions by variable power generation, existing **storage capacity** (up to now primarily pumped-storage power stations) should be increased by 2030 by a factor of 3.5 and by a factor of 8 by the year 2050.

In order to reach these targets, the following **set of instruments** is proposed:

- Introduction of a **moratorium** for **coal-fired power stations without CCS**.
- **Further development of the renewable energy feed-in law** (maintaining priority dispatch, innovation-orientated cost degression, promotion of the generation of electricity from biomass only with cogeneration);
- Creation of **additional market incentives** (market model) to provide **power** and **balancing capacity** for the different (big and small) consumer groups.
- Development of a long-term **electricity storage expansion programme** that can in the medium and long term supplement the interconnectivity of the German electricity system with neighbouring nations and regions which is also necessary.

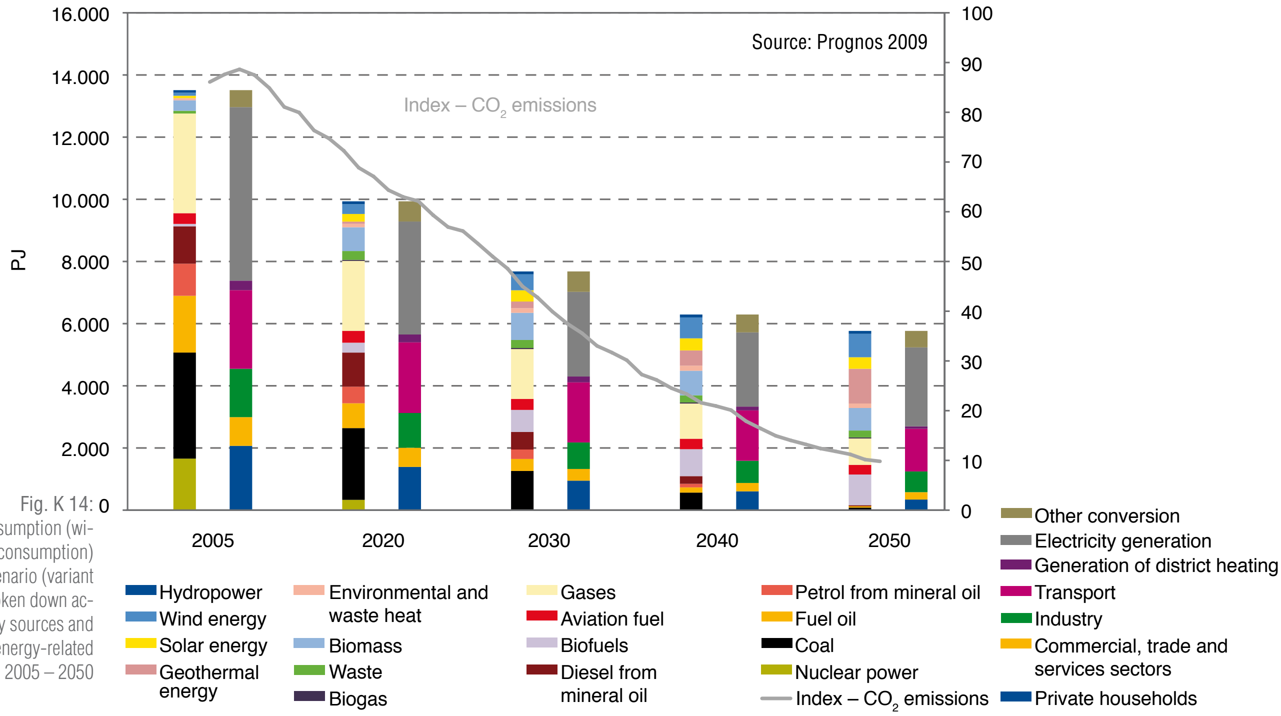

Fig. K 14: Primary energy consumption (without non-energetic consumption) in the innovation scenario (variant without CCS), broken down according to energy sources and sectors, index of energy-related CO_2 emissions, 2005 – 2050

Direct energy-related **CO_2 emissions** decline in the innovation scenario variant without CCS between 2005 and 2050 by 757 million tonnes, or 89%, respectively, and in the variant with CCS by 748 million tonnes, or 88%, respectively.

Between 2005 and 2050, **primary energy consumption** (without non-energetic consumption) falls by 57% from 13,546 PJ to 5,766 PJ. Consumption of conventional energy sources will decline by 85% whilst use of renewable energy will rise in total by a factor of almost 6. Nuclear power and coal will no longer be part of electricity generation (in the variant without CCS), coal will only be used to a lesser degree in metal production.

In the innovation scenario, **mineral oil products** will only continue to be used as aviation fuel and in residual quantities for the generation of process heat; its consumption will decrease by 91%. Natural gas and other gases are the only fossil sources of energy which will have any kind of a role to play in the mix. They will be used in the services and industrial sector to produce process heat. Gases will also be used to generate peak load energy and balancing energy and to a lesser extent to produce cogenerated electricity (accompanied by low-temperature heat).

The use of primary energy in **electricity generation** will be reduced by 49%. Renewable energy sources with their per-definition excellent efficiency will contribute considerably to this development. The around 74% decline in energy used to **generate district heating** is largely a consequence of falling demand. In the “other conversion” area, conversion declines due to the fall in the use of mineral oil products. In contrast to this, the increased production of biogas and biofuels leads to greater **use of biomass**. All in all, the use of energy sources in other conversion changes only slightly (-3%). The substitution of fossil fuels with biofuels and the (reduced) use of biomass and biogas in the generation of electricity and heat result in around 1,700 PJ of biomass being used in total for primary energy. This volume exceeds the potential that can be generated in a strictly sustainable manner in Germany. As a condition for the use of imported biomass from Europe or global markets binding regulations and legal standards for the ecological and social integrity of the biomass have to be implemented.

Taking the additional measures of the “**Blueprint Germany**” into consideration, the **share of renewable energy sources** in overall primary energy consumption reaches a level of around 43% in 2030, of around 65% in 2040 and around 85% in 2050.

Costs and savings

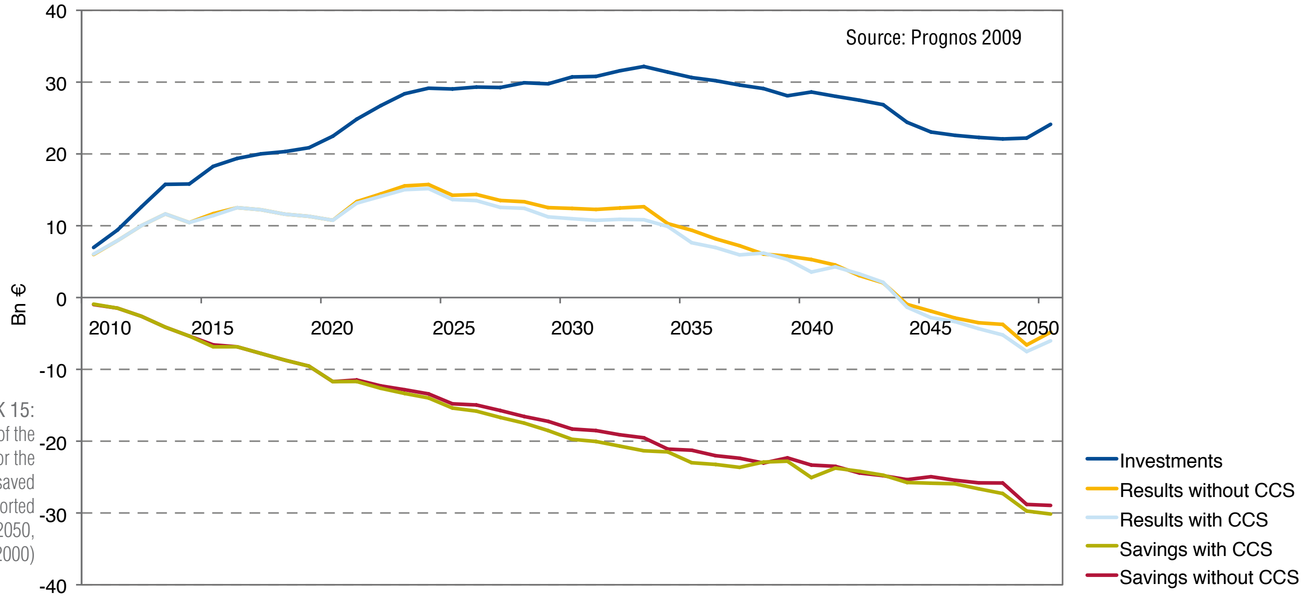

Fig. K 15: Additional cost of the innovation scenario for the national economy vs. saved expenditure for imported fossil fuels, 2010 – 2050, in billion (real, 2000)

The innovation scenario includes investments and strategic decisions which lead to **additional costs** compared to the reference scenario with its continuation of current energy policy. In contrast to this, the reduced use of fossil energy sources especially means **savings for the economy.** All in all, integrated costs which total a maximum of 0.6% of GDP are comparatively low and economically acceptable.

Additional investment and hence **additional costs** will be generated by:

- more extensive refurbishment of existing buildings and on the whole very demanding energetic building standards, especially in the private household sector;
- the introduction of electric vehicles in the field of passenger cars, including infrastructure, as well as the improvement of freight transport logistics, including handling centres;
- the changeover of processes in the industrial and services sector, as well as technology development;
- the changeover of power stations to renewable energies, the expansion of storage capacities and the introduction of CCS technology.

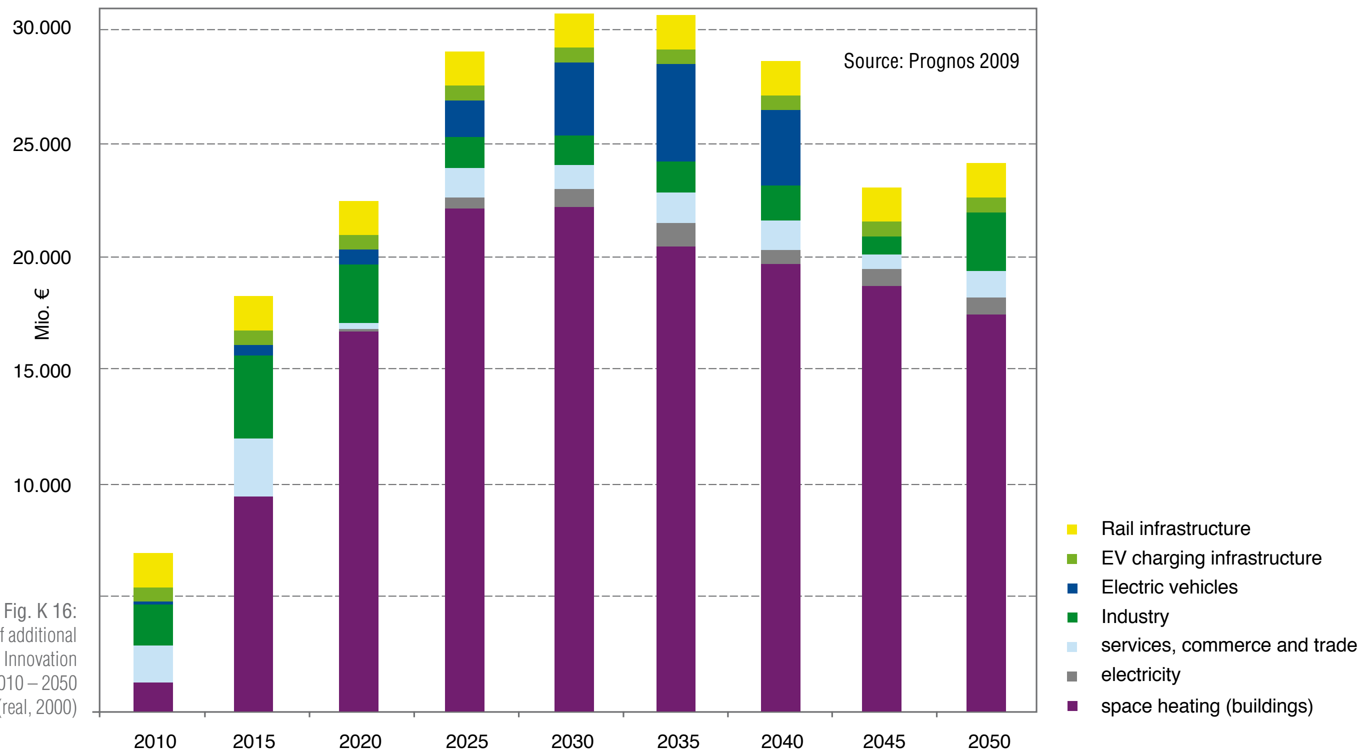

Fig. K 16: Elements of additional costs in the Innovation scenario 2010 – 2050 in Mio. € (real, 2000)

This is set off by the saved expenditure for **imported fossil fuels**, calculated at import prices.

Assuming that starting in 2010 targeted investment begins, **annual additional costs** rise from approx. € 6 billion in 2010 to a good € 32 billion max. in 2033; after this, they fall slowly to approx. € 22 billion per year.

Annual savings from the lower use of fossil fuels grow continuously due to investment in savings and rising energy prices to € 29 billion annually, and to approx. € 30 billion in the variant with CCS.

From 2044 on, savings outweigh investment. **Net savings** rise to € 6.6 billion p.a.

In 2024, this leads to **maximum net costs** for the economy of almost € 16 billion (approx. **0.6% of GDP**) after which time, this burden will decline.

Added together over the **entire period under review** (and with a discounted, long-term interest rate of 1.5%), this results in a burden of approx. **0.3% of GDP**.

Energy-related greenhouse gas emissions

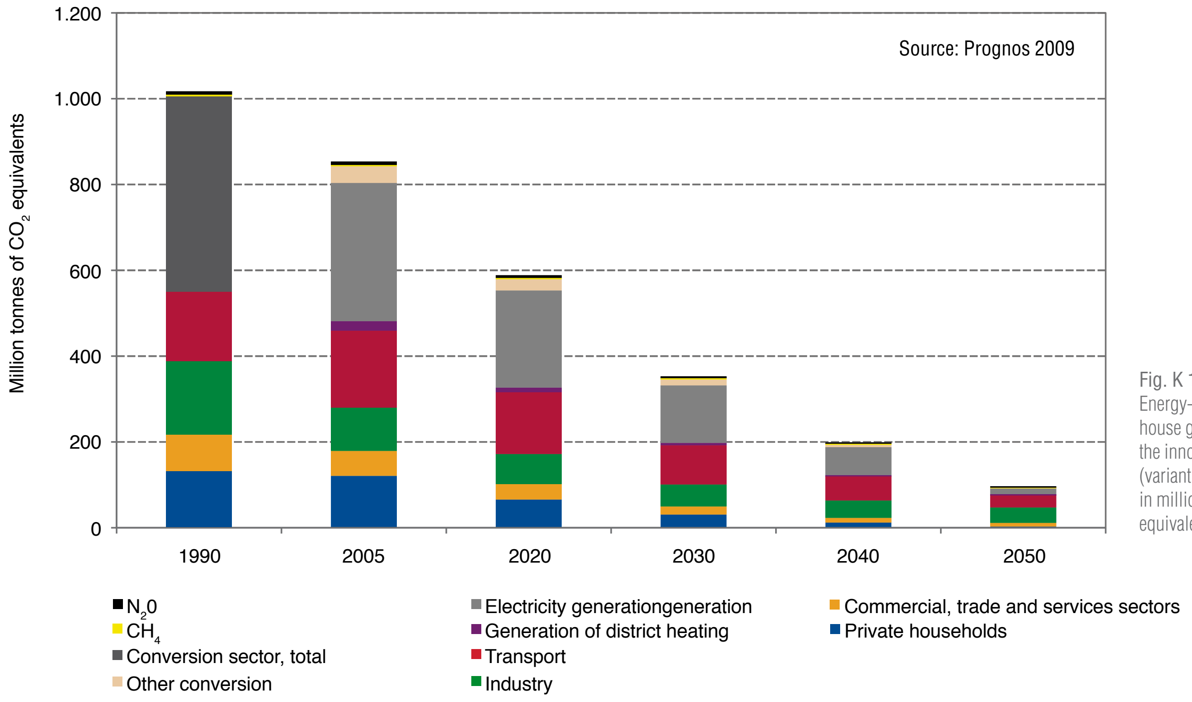

Fig. K 17: Energy-related greenhouse gas emissions in the innovation scenario (variant without CCS) in million tonnes of CO_2 equivalents, 1990 – 2050

In 2050, **energy-related greenhouse gas emissions** (in the variant without CCS) total 96.6 million tonnes of carbon dioxide equivalents and are hence 91% lower than 1990. All sectors contribute to this development although admittedly to different degrees (since it is not possible to consistently compare emissions to 1990, the reduction rates are shown here in comparison to 2005).

Private households account for the relatively highest contribution where emissions fall by 98% between 2005 and 2050. Heating demand for space heating will decline to practically zero.
Due to the high share of space heating and high electricity share, the **services sector** can also reduce its direct emissions significantly (by approx. 85%).
The **transport** and **industry** sectors also reduce their emissions significantly (industry: 64%, transport 83%), however, in 2050 they still emit greenhouse gases due to the use of fossil fuels to generate process heat (a reduction in the metallurgical sector too) as well as fossil fuels for aviation and shipping.
Due to the high share of renewable energy in **electricity generation**, emissions here decline by 98% to 14 million tonnes in 2050. Emissions from the other conversion sector will fall to around 3 million tonnes primarily due to the decline in the **generation of district heating** as well as the strong reduction in the production of mineral oil products.
Other energy-related greenhouse gas emissions (N_2O and CH_4), primarily in conjunction with transport and the combustion of fossil fuels, decline between 2005 and 2050 by 81% to almost 2 million tonnes of carbon dioxide equivalents .

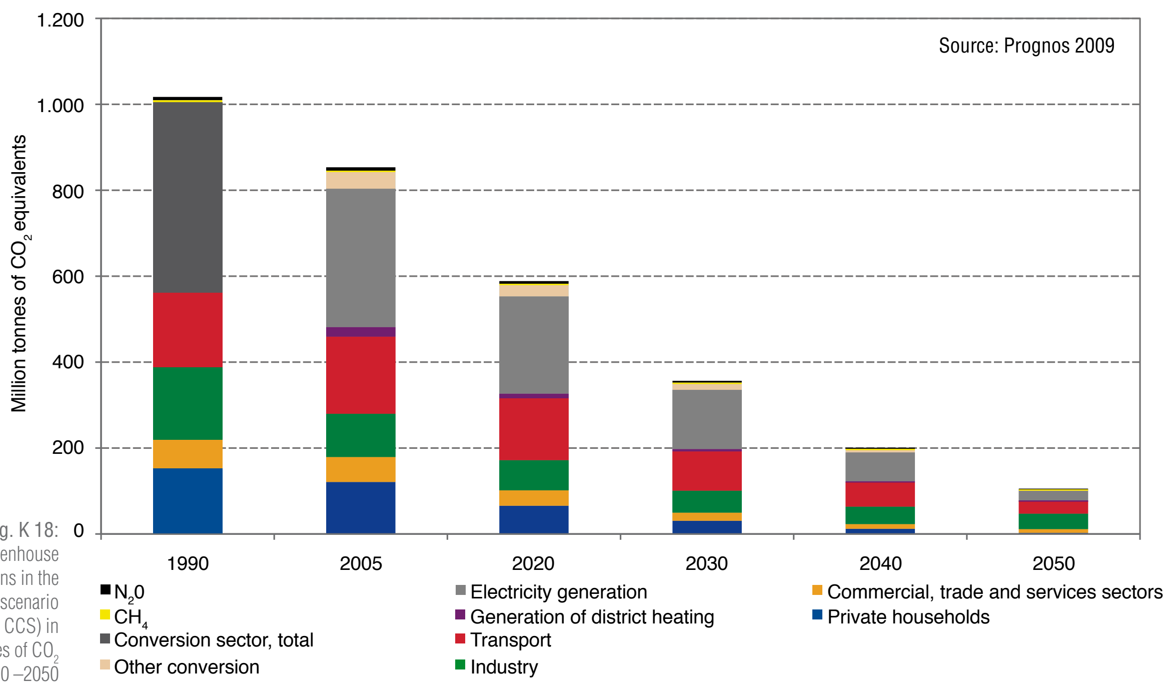

Fig. K 18: Energy-related greenhouse gas emissions in the innovation scenario (variant with CCS) in million tonnes of CO_2 equivalents, 1990 –2050

With the **CCS option, energy-related greenhouse gas emissions** are reduced between 1990 and 2050 by 88% to 106 million tonnes of carbon dioxide equivalents. Compared to the option without CCS, the structure of electricity generation changes. CO_2 emissions by fossil power stations decline by 93%, however, they do not disappear all together. Around 23 million tonnes of carbon dioxide equivalents continue to be emitted by hard-coal and lignite power stations which are equipped with CCS technology.

Other greenhouse gas emissions by other sectors

In addition to combustion-related CO_2, CH_4 and N_2O emissions, a host of other sectors contribute to overall greenhouse gas emissions.
These emissions include:
- volatile greenhouse gas emissions by the energy sector,
- CO_2 emissions from industrial processes,
- CH_4 emissions from industrial processes,
- N_2O emissions from industrial processes,
- emissions of fluorinated greenhouse gases,
- greenhouse gas emissions from waste management,
- greenhouse gas emissions from agriculture,
- CH_4 emissions from agriculture,
- N_2O emissions from agricultural soils,
- greenhouse gas emissions from LULUCF (land use, land use change and forestry).

All in all, a host of very heterogeneous, sector-specific measures result in a decline of these emissions in the innovation scenario between 2005 and 2050 from 188 million tonnes to 60 million tonnes of CO_2 equivalents. This corresponds to a reduction of 68% compared to 2005 and of 67% compared to 1990.

In order to achieve the "**Blueprint Germany**" in the non-energy sectors, the following **strategic safeguards** must be put in place:
- Greenhouse gas emissions from agriculture should be reduced between 2005 and 2030 by 30% and by 40% by the year 2050.
- With a view to emissions from **land use, land use change and forestry**, the release of CO_2 should be reduced by 70% between 2005 and 2050.

The same applies to the **set of instruments**.
The most important sector-specific instruments are listed below:
- **Instruments in industry**:
  - Fully binding introduction of CCS for process-related emissions in the steel, cement and lime sectors unless such a measure has already been implemented through the CO_2 price signal of emissions trading.
  - Initiation of a set of measures to reduce fluorinated GHGs; comprising regulatory requirements, such as a ban on the use of F-gases as refrigerants from 2015 onwards and a tax on the use of F-gases linked to the greenhouse gas potential.
- **Waste sector measures**
  - Promotion of waste avoidance and recycling, as well as of economical material use for energy-intensive products.
  - Promotion measures for energetic recycling, especially the expansion of gasification and fermentation capacities to approx. two thirds of organic waste.
- **Agricultural measures**
  - Increase in the share of organically farmed in agricultural land up to 25% by 2030 at the latest.
  - Initiation of a set of measures for fertiliser management comprising a duty on nitrogen surpluses in farming on a farm basis as well as promotion measures for improved fertiliser management, and targeted research and information on climate friendly farming methods.
  - Initiation of a set of measures for climate protection and health with regulatory restrictions to livestock numbers per area as well as implementing an information and awareness campaign to reduce meat consumption.
  - Regulatory rules for the gas-tight storage of slurry and promotion measures to boost the energetic recycling of slurry and of harvest residues in biogas plants.
- **Measures in land use**
  - Promotion of measures in forestry that are geared towards sustainable forestry and that maintain and/or boost the sink effect of Germany's forests (integration of CO_2 into forest biomass).
  - Regulatory restriction of land use to convert non-sealed land into residential, transport and settlement areas.
  - Initiation of a set of measures for land transformation comprising promotion measures for the renaturation of peat land and drained grasslands, regulatory establishment of alternative use and the implementation of the goals of the Federal government's biodiversity strategy.
  - Stricter regulations for land protection as a precondition for payments within the scope of a new EU agricultural policy.

Key elements of an integrated climate protection and energy programme 2030

In addition to and to supplement the measures of the Federal government's "Integrated Energy and Climate Programme" from 2008, an "Integrated climate protection and energy programme 2030" can be outlined that should be based on the following key elements (the sector-specific bundle has been described in the respective sector chapters):

1. Legal framework for a long-term climate protection policy

- **Binding** establishment of long-term **goals;**
- **Monitoring methods and action plans** based on strategic goals;
- **Sanction and adaptation measures** for cases where targets are not reached.

2. General instruments

- Further development of the **EU emissions trading system** with a cap that for 2020 is 35% below and for 2030 60% below the 2005 level and with a much stronger restriction of emission reductions made outside the sectors covered by the emissions trading system and which can be counted as proof of commitment;
- Introduction of a **CO_2 tax** for stationary use for energy sources that are not covered by the EU emissions trading system.

3. General instruments to boost **energy efficiency**

- Creation of a **flexible quantity control system** for energy savings with which energy suppliers, using a positive list for energy-saving projects (with defined baseline methods, etc.), must furnish proof each year in the form of freely tradable saving certificates of a certain energy saving amount which is based on the percentage of the energy supplier's sales (rising by one percentage point each year after 2010);
- Re-introduction of the **deduction from taxation** of investments in energy efficiency.

4. Innovation and **infrastructure-specific measures**

- Revision and expansion of the German **biomass strategy** which contains long-term prioritisation and concrete steps in the field of biofuels (including the specification of aviation fuels based on biomass), biomethane supplies and the generation of electricity from biomass.
- **Innovation programme for biofuels** of the second generation, with a target of having only this biofuel quality on the market by 2020.
- **Innovation and market launch programme** for **electric cars**, including efficiency-dependent bonuses.
- **Innovation programme** to develop and promote smart **distribution grids** with intelligent load management options.
- Fastest possible implementation of CCS pilot and demonstration projects and, if applicable, the drawing up of a "**German CCS development plan**" to define the solution contributions by CCS under different boundary conditions, the infrastructure required, underground regional planning to manage competition for underground use and use prioritisation.
- Preparation of a "**German energy infrastructure conversion programme**"; this can be used as a basis for investment incentives and obligations for the transmission grids as well as for the expansion of the CO_2 infrastructure, implementation within the framework of Deutsches Netz AG.
- **Improved promotion of research** with milestones in the field of energy efficiency improvements through further development and the application of new key technologies, e.g. for processes and materials. Targeted market launch of initiatives to optimise these technologies and to achieve their widespread implementation.

Conclusions and outlook: changes in energy and climate policy, innovation and global frameworks

With a continuation – no matter how ambitious – of **today's energy and climate policy**, i.e. a continuation of the technologies commonly used today as well as today's consumption patterns for energy and resources, it will **not be at all possible to reach the reduction target of 95%** for total greenhouse gas emissions by the middle of the century (compared to the 1990 baseline). The continuation of today's ambitious level in energy and climate policy assumed in the reference scenario can at best be expected to achieve about 45% reduction of greenhouse gas emissions in the period from 1990 to 2050.

An emissions reduction path that is consistent with international efforts to restrict mean global temperature rise to a value below 2°C compared to pre-industrial levels must set new courses at an early point in time. An analysis of the innovation scenario and the additional analyses highlight the following challenges for the **changes necessary by the year 2050**:

- Considerable efforts must be made immediately to significantly **boost energy efficiency**. If energy productivity is not increased by at least 2.6% annually, it is extremely unlikely that this climate protection target will be reached.
- In all sectors, the remaining energy demand must be almost fully covered by **renewable energy**, the use of CCS is unavoidable for the greater share of any emissions that remain from fossil fuels and industrial processes.
- A large part of the changes necessary involve **plants and infrastructures with a long service life**, long lead times or complex conversion processes. Political strategies and measures will have to be continuously examined with a view to their compatibility with the required long-term developments.
- Especially emission reductions in the mid-term and long-term perspective call for **extensive innovations** that are specifically initiated and that must be quickly launched on the market.
- In addition to measures in the field of energy-related greenhouse gas emissions, **significant emission reductions in the field of non-energy related emissions** are also unavoidable. Greater reductions in emissions from industrial processes, agriculture and land use play a central role.

Even though there are no alternatives to the efforts to reduce the entire range of greenhouse gas emissions, it is highly unlikely that the 95% target for the year 2050 will be reached if the following **new courses** are not set:

- A significant **decline and stabilisation of electricity demand** to a level that is 25% below today's values in 2030 and 35% in 2050. This also applies in the case of a large-scale launch of electric drivetrains in the transport sector.
- An **expansion of electricity using renewable energy sources** to 95% (employing more than 50% of CCS power stations).
- The **refurbishment of existing buildings** up to a space heating demand of (practically) zero and the early introduction of zero-energy standards for new buildings.
- **Considerable modal shifts in transport**, which, for instance, require a doubling of rail freight transport capacities and a huge expansion of public passenger transport.
- **Improved efficiency of the vehicle fleet** by an average of 60% and improved efficiency of **road freight transport** by more than 30%.
- Extensive shift in motorised individual transport to **electric drivetrains** with sustainably generated **biofuels** covering the remaining fuel demand in passenger, freight and air transport.
- **Avoidance of process-related CO_2 emissions** by the iron and steel industry and in cement production through significant material savings and/or substitution and the use of CCS in industry.
- Sustainably generated **biomethane** to cover the remaining **demand for process heat in industry.**
- **Enormous emission reductions** in **agriculture** and in **land use**.

In addition to a host of technical innovations, **changes in production and consumption patterns** will have to be made across the entire board along with huge structural change. Moreover, the changes will not be possible unless a **persistently systematic view of the necessary changes** is developed:

- The diverse changes at the energy demand and supply sides call for **extensive reshaping of the infrastructure** for electricity, gas and CO_2 as well as systematic and long-term approaches to system integration and **market integration of climate-friendly technologies**, especially in the field of fluctuating supplies of electricity from renewable energy sources.
- The enormous reductions in emissions call for a strategic **re-evaluation** of the **use of scarce resources** for a series of important climate protection options. The use of biomass must not only be examined in view of the quantities available in Europe and the demand for the most efficient use possible, but also with a view to the areas where no alternative to **biomass** exists in the long-term. Limited CO_2 storage reservoirs mean that priority must be given to the use of CCS and corresponding management of storage reservoirs.
- The strategies needed to provide sustainably generated biomass will have to include the drafting and implementation (with a considerable lead time) of strict **sustainability standards**.

The **additional costs** of a huge reduction in emissions for the strategies pursued in the innovation scenario appear to be reasonable on the investment side, totalling a max. of 0.6% of GDP. The burdens, however, are **distributed unevenly** (e.g. high, non- amortisable investments in the field of buildings). **Suitable instruments** will be needed here to **allocate and distribute additional costs**.

Many more ambitious instruments will hence be needed than those discussed up to now in energy and climate policy; these instruments will have to be embedded in long-term, calculable targets and political strategies and will require **widespread social consensus for the strategic goals and a balanced distribution of burdens**. This consensus must also include the exploitation of the potential offered by renewable energy and/or the storage options for CO_2, in particular, as well as the need for changed mobility and consumption patterns.
Apart from the technical/economic potential to reduce emissions and the political instruments required to implement this, it will also be extremely important to find supportive **acceptance** in society for the restructuring process required. This calls for a broad, social discussion process. It will be a high priority task of politics to initiate and accompany this process with other social groups.

The implementation of emission reductions across the board calls for new political frameworks in addition to a host of new actors. An energy and climate policy that is geared towards ambitious climate protection goals will have to aim for a diverse range of actors and **a high degree of competition** and will prevent the formation of market structures that hinder innovation.
The strategic goals along with the required development of technologies, infrastructures and business models call for integration into an **international context** which avoids one-sided burdens for industries competing on a global level and leakage effects. This integration should include comparable (ambitious) commitments by all industrial nations and today's newly industrialised countries, technology transfer as well as international balancing mechanisms. In order to save time and in the interest of cost efficiency, technology development should be internationally co-ordinated and based on co-operative work sharing.
Irrespective of the apparent nature and necessity of the European and international integration of many implementation measures for an emissions reduction path based on the "Blueprint Germany", this does not alter the fact that a country like Germany should develop a sound, national strategy for a long-term reduction in emissions along the lines of the 95% reduction target. Such a strategy is needed to test the consistency of all political measures. The strategies and measures outlined in this study could form a reliable basis for a national policy development process that is strictly orientated towards innovation, climate protection and a pioneering role.

Table of abbreviations, acronyms and symbols

GDP	Gross domestic product
CCS	Carbon Capture and Storage
CH_4	Methane
CO_2	Carbon dioxide
EU	European Union
EUR	Euro
g	Gram
IPCC	Intergovernmental Panel on Climate Change
J	Joule (physical unit for work)
km	Kilometre
kWh	Kilowatt hour
l	Litre
LED	Light Emitting Diode
HGV	Heavy goods vehicle
m^3	Cubic metre
max.	Maximum
m	Millions
N_2O	Nitrogen oxide
NOx	Oxides of nitrogen
O_2	Oxygen
OLED	Organic Light Emitting Diode (LED based on organic materials, e.g. dyestuffs)
PV	Photovoltaics
t	tonne
GHG	Greenhouse gases
cf.	compare
V	Volt
W	Watt (physical unit for power)
Wh	Watt hours

Prefix signs:

Designation	Factor	Designation	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	$1x10^{-12}$	$0.2778x10^{-6}$
TJ	$1x10^{12}$	1	$0.2778x10^{6}$
kWh	$3.6x10^{6}$	$3.6x10^{-6}$	1
GWh	$3.6x10^{12}$	3.6	$1x10^{6}$

List of figures

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