Costs and Potentials of Greenhouse Gas Abatement in Germany

A report by McKinsey & Company, Inc., on behalf of "BDI initiativ – Business for Climate"

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Preface

The Federal Republic of Germany has set an ambitious target for abatement of greenhouse gas emissions in Germany: plans call for reducing emissions by at least 30 percent compared with 1990 levels by the year 2020. Germany's target will be increased to 40 percent if the EU raises its abatement target from the current 20 percent to 30 percent. The EU has announced its intention to aim for the increased target if other countries with high emissions also pledge comparable reductions within the framework of an international climate agreement. In Germany, the targets for reducing greenhouse gas emissions are supposed to be achieved while preserving sustained economic growth and implementing the nuclear phaseout.

The overarching goal of significantly reducing greenhouse gas emissions in Germany enjoys broad acceptance in political, economic, and social circles. At the same time, an intense and often controversial debate is under way concerning the technical and economic feasibility of various target levels. Until now, there was no detailed assessment of the costs and potentials of the individual levers that could reduce greenhouse gas emissions in Germany.

To fill this gap, the initiative "BDI initiativ – Business for Climate" asked McKinsey & Company, Inc. to conduct this study. More than 70 companies and associations participated in assessing more than 300 levers for abatement of greenhouse gas emissions in Germany. Moreover, the latest studies on technological trends were analyzed and evaluated. All results were discussed in numerous interviews with leading experts. Using a uniform methodology, the study investigated several hundred individual measures for the abatement of greenhouse gas emissions in all areas of society, making Germany the first country in the world to have such a comprehensive and objective assessment at its disposal.

This study intentionally avoids any assessment of policies, political implementation programs, and other governmental interventions. Instead, it is intended to be an objective fact base that can serve as a starting point for further policy discussions and decisions.

We would like to thank all of the participating companies and associations as well as the independent experts for their constructive cooperation and tireless efforts over the past months. Broad support by all participants was a key prerequisite for the success of this study. Furthermore, we would like to thank Professor Martin Hellwig, Professor Wolfgang Ströbele, and Professor Carl Christian von Weizsäcker for their support as scientific advisors.

Berlin, September 2007

Jürgen Thumann
President of the Federation of German Industries

Frank Mattern
Office Manager McKinsey & Company, Inc.

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VW
WITZENMANN
WVM WirtschaftsVereinigung Metalle
ZIA Zentraler Immobilien Ausschuss
ZVEI

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Glossary

Abatement costs (in EUR/t CO_2e)	Additional costs (or savings) resulting from the use of a technology with low greenhouse gas intensity compared with the intensity of the current technology projection (excluding secondary effects from a socioeconomic perspective). In this study, these are assessed from the perspective of the relevant decision maker, i.e., taking into account the specific discount rates and amortization periods
Abatement cost curve	Compilation of abatement potentials and costs for a specific sector
Abatement lever	See "lever"
Abatement lever with a positive pay-off (from a decision maker perspective)	An abatement lever that results in savings for the decision maker, taking into account the specific amortization periods and discounting rates
Abatement potential (in Mt CO_2e)	Potential for reducing greenhouse gas emissions by implementing an abatement lever assuming a penetration rate that is ambitious but feasible in practice
Baseline year	Baseline year for measurement of achieved reduction in greenhouse gas emissions in the context of the Kyoto Protocol (1990 for CO_2 emissions; 1995 for a number of other greenhouse gases); see "Nationaler Inventarbericht" (national inventory report) of the UBA (Dessau, March 2007) for details
CCS	Carbon capture and storage – technologies for capturing and storing CO_2
CDM (projects)	Clean development mechanism – mechanism in the framework of the Kyoto Protocol that gives emitters of signatory states the option of investing in projects in developing countries under specified conditions and receiving CO_2 certificates for this
CHP	Combined heat and power (plant)
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent, i.e., specific value of the intensity of a greenhouse gas, expressed in the greenhouse effect of carbon dioxide, e.g., 21 for CH_4 (methane), 310 for N_2O (nitrous oxide)
Current technology	Average energy/greenhouse gas efficiency in today's (2006) mix of sales or investments

Current technology projection	Projection of the trend in greenhouse gas emissions in Germany based on current economic growth forecasts and gradual penetration of the current stock with today's status of technology (for details see below p. 25 sqq.)
Decision maker	The party that decides on making an investment, i.e., the company (e.g., as owner of an industrial facility) or the individual (e.g., as owner of a car or home)
EAF	Electric arc furnace – for steel production, in contrast to the integrated route of blast furnace and oxygen steel converter
EEG	*Erneuerbare-Energien-Gesetz* (Renewable Energy Sources Act)
EU ETS	Emissions Trading Scheme of the European Union
EUR	Euro
Greenhouse gas	Greenhouse gas in the context of the Kyoto Protocol, i.e., CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), HFC/PFC (hydrofluorocarbons), and SF_6 (sulfur hexafluoride)
Gt	Gigaton(s), i.e., one billion (10^9) metric tons
IGCC	Integrated gasification combined cycle – combined gas and steam turbine system with upstream coal gasification system
kWh	Kilowatt hour(s)
(Abatement) lever	Technological approach to reducing greenhouse gas emissions, e.g., use of more efficient processes or materials
Mt	Megaton(s), i.e., one million (1,000,000) metric tons
MWh	Megawatt hour(s), i.e., one thousand (1,000) kWh
PJ	Petajoule, i.e., one quadrillion (10^{15}) joules
Reference technology	Status of current technology against which an efficient greenhouse gas solution is compared with regard to its abatement costs and potential
Sector	Grouping of businesses[1] in this study, specifically:

1 The sectors energy, industry, buildings, and transportation were addressed in dedicated working groups within the framework of this study; representatives of companies and associations active as players and/or suppliers in these sectors participated in these working groups. Both the waste management and agricultural businesses were discussed in a series of individual interviews with experts and representatives of companies and associations, but were not covered by dedicated working groups.

Energy: Emissions from power generation (centralized, decentralized, industrial) and from generation of heat for local and district heating networks

Industry: Direct and indirect emissions of all industrial branches with the exception of power generation and the transportation sector; includes industrial heat generation

Buildings: Direct and indirect emissions from private households and the tertiary sector (commercial, public buildings, buildings used in agriculture)

Transportation: Emissions from *road traffic* (passenger transportation: small, midsize, and large passenger cars; freight transportation: light ["sprinter class"], medium, and heavy trucks; buses), *railroad transportation* (local and long-distance passenger transportation, freight), and domestic *air transportation* (civil passenger and freight transportation in Germany), including effects of changes in fuel mix (oil industry)

Waste management: Emissions from disposal of waste and treatment of sewage

Agriculture: Emissions from livestock farming and soil management

t Metric ton(s)

TWh Terawatt-hour(s), i.e., one billion (10^9) kWh

Summary of Findings

This report is the first objective and comprehensive analysis of costs and potentials of all key levers for greenhouse gas abatement in Germany.

This study was conducted by McKinsey & Company, Inc. on behalf of "BDI initiativ – Business for Climate." It provides an objective and comprehensive analysis of the costs and potentials associated with all key levers for abating greenhouse gas emissions in Germany.

More than 40 companies and associations from all relevant sectors in Germany contributed directly to the analysis. In addition, approximately 30 companies and numerous independent experts participated in discussions on individual topics.

Using a standardized methodology across industries, all key technical levers – a total of more than 300 – for reducing greenhouse gas emissions in Germany were evaluated for the period up to 2020 and 2030. For each single lever, the abatement potential achievable (in Mt CO_2e) and the abatement costs (in EUR/t CO_2e) were quantified. The evaluation of abatement potentials is based on ambitious but realistic penetration rates for the respective technical solutions. All calculations are based on the regular investment cycle determined by the standard lifetime of plants, equipment, or goods.[2] The abatement costs quantified are the costs (or savings) that would result for decision makers from implementing a less emission-intensive solution instead of the current technology.

The study does not consider levers that would impose restrictions on quality of life or result in a slowdown of economic growth. Still, the quantified levers' influence on competitiveness and the prerequisites needed for implementation were assessed on a qualitative basis for each sector.

For the most part, the technologies evaluated are already in use today or have reached an advanced stage of development. However, especially for the period from 2020 onwards, innovative technological developments in all areas could contribute to capturing further potentials. At the same time, the assumption was that the quality and scope of current infrastructure (e.g., grids, traffic infrastructure) would be maintained at the current level.

In the base case scenario, the nuclear phaseout in Germany was assumed as a given.

Quantification and modeling of secondary effects (e.g., consequences of consumer behavior or employment) and their impact on the economy were not part of this study, as they can be evaluated only in the context of specific political scenarios.

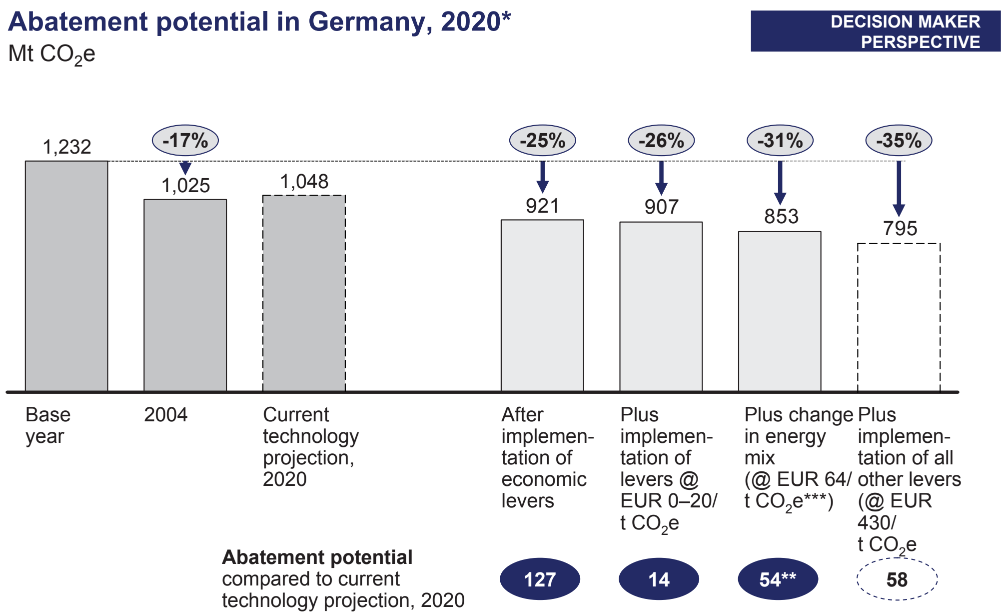
The study focuses on presenting the fact base developed with the participating companies, associations, and experts in many rounds of analysis. This fact base provides

2 Implementing abatement levers outside the normal investment cycle would generally lead to abatement costs that are higher – in some cases, far higher – than the costs assessed in this study.

an answer to which abatement potential can be achieved with the help of which levers at which cost and at which point in time. An assessment of political implementation measures, frameworks, and tools that could be applied for achieving these targets was not in the scope of the study.

By 2020, greenhouse gas emissions in Germany can be reduced by 26 percent (compared to 1990) if all known abatement levers with abatement costs of up to EUR 20/t CO_2e are implemented. A decrease of 31 percent (compared to 1990) could be achieved if – while maintaining the nuclear phaseout – the energy mix is adjusted to include a higher share of renewable energy. This would lead to considerably higher average abatement costs of EUR 32/t CO_2e (power generation from renewable energy sources) and EUR 175/t CO_2e (biofuels).

Since 1990, greenhouse gas emissions in Germany have decreased by 17 percent – from 1,232 Mt CO_2e (base year) to 1,025 Mt CO_2e (2004).[3] In the current technology projection,[4] there would be a slight increase, to 1,048 Mt CO_2e, up to 2020. Against this baseline, the abatement levers evaluated in the study with abatement costs of up to EUR 20/t CO_2e would lead to an annual abatement of 141 Mt CO_2e by 2020. Out of these, 127 Mt CO_2e result from measures that generate a positive payoff for the decision makers; the remaining 14 Mt CO_2e would cost between EUR 0 and 20/t CO_2e.



* Maintaining nuclear phaseout
** Including 6 Mt CO_2e from CCS pilot projects in power generation
*** Power generation: ø EUR 32/t CO_2e; biofuels: ø EUR 175/t CO_2e; both considering the applicable subsidy rates in each case, taxes, and customs

Exhibit 1

Source: Report "Kosten und Potenziale der Vermeidung von Treibhausemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

3 See "Nationaler Inventarbericht" (national inventory report) of the UBA (Dessau, March 2007) for historical emission values (up to 2006); all data excluding LULUCF (Land Use, Land Use Change, and Forestry).
4 See below p. 25 sqq.

If all these levers were implemented, greenhouse gas emissions in Germany could be reduced by 26 percent compared to the base year. Compared to 2004, this would equal a 12 percent decrease. Assuming that the nuclear phaseout takes place as currently planned,[5] the change of the energy mix in Germany – increased use of renewable energy sources for power generation, increased use of biofuels, and first pilot projects for carbon capture and storage (CCS) – would lead to an additional reduction of 54 Mt CO_2e. With the total decrease of 195 Mt CO_2e, annual greenhouse gas emissions in Germany could be reduced by 17 percent compared to 2004; compared to 1990, this would represent a 31 percent reduction.

A total of 127 Mt CO_2e annually by 2020 could be avoided through levers with abatement costs that would pay back within the amortization period of the respective decision maker. The corresponding levers are based on technologies available today (e.g., for building insulation, heating systems, electrical drives in industrial plants, or for certain measures to optimize power trains in cars). In principle, implementing these measures results in an economic advantage for the decision maker: the additional expenditure pays off over the relevant amortization period of the investment, even if there is no explicit price for greenhouse gas emissions. However, penetrating the existing stock takes time – especially in industrial plants and buildings where useful lifetimes can sometimes be several decades long. In consequence, these levers can be implemented only over time. Accelerating investment cycles would result in a significant increase in abatement costs. In addition, in many cases obstacles to implementing these economic measures exist. These obstacles include, for example, the level of initial investment required (e.g., costs of renovating a building even without improving energy efficiency) or a misalignment of the incentives for investors and beneficiaries of a measure. These obstacles have to be removed fast to allow realization of the high abatement potential associated with the respective measures.

Additional abatement potential of 14 Mt CO_2e is associated with abatement costs up to EUR 20/t CO_2e. This includes a number of industry-specific measures in certain production areas (e.g., substitution of clinker in the cement industry, capture and decomposition of nitrous oxide in production of adipic acid), increased efficiency in new lignite power plants, and extended use of CHP plants to produce heat and electricity.

The planned nuclear phaseout will initially lead to an increase in specific emissions from power generation in Germany, as more emission-intensive coal- and gas-fired plants will have to be built to cover demand. To offset this increase, changing the energy mix in Germany toward other, less emission-intensive sources of power generation can lead to additional savings of 54 Mt CO_2e (on top of the levers described above). This change has already been under way for several years. At present, renewable energy sources account for a good 10 percent share of power generation in Germany, and the share of biofuels in relation to total fuel consumption is about 5 percent. Based on current political decisions, the share of renewable energy sources is expected to increase further until 2020. By increasing the share of power generation from renewable sources (especially wind and biomass) to about a quarter of total power generation, greenhouse gas emissions from power generation would decrease by 34 Mt CO_2e compared to the current technology projection. An increase of the share of biofuels

5 For the effect of delaying the nuclear phaseout, see below p. 16.

to 17 percent of the fuel mix would yield a 14 Mt CO_2e reduction in greenhouse gas emissions. In addition, first projects to capture and store carbon dioxide (CCS – carbon capture and storage) from power plants would reduce emissions in Germany by 6 Mt CO_2e by 2020. However, CCS projects can be realized only if the necessary legal conditions are put in place soon and if public acceptance is achieved. Abatement costs of these abatement levers are relatively high, with an average of EUR 32/t CO_2e (power generation)[6] and EUR 175/t CO_2e (biofuels). Still, given the existing political environment, it is very likely that these abatement levers will be implemented, as most of them are already supported or stipulated by specific political measures.[7]

Additional abatement levers with potentials of up to 58 Mt CO_2e generally have abatement costs of far more than EUR 20/t CO_2e – in some cases, up to several thousand EUR/t CO_2e. An additional reduction of greenhouse gas emissions by more than 31 percent (compared to 1990) would therefore result in exponentially increasing abatement costs for each percentage point – both for the companies affected and for the overall economy. Just the additional step of further decreasing from 31 percent to 32 percent would, for example, lead to direct abatement costs of over EUR 450 million each year for the decision makers.

In addition to the direct abatement costs, implementing the abatement levers described above would lead to further costs for the decision makers. Volume and impact of these additional costs would depend on the selection of political frameworks and tools. These costs could include, for example, additional costs from changes in electricity prices due to costs of greenhouse gas emissions being passed on or of subsidies being reallocated. They could also include secondary effects such as costs of remaining greenhouse gas emissions for companies in the EU ETS. Any implementation strategy should therefore include a thorough assessment of the specific burdens that can be allocated to the players in the individual sectors without putting Germany's wealth and growth at risk.

If abatement targets significantly beyond 30 percent are to be achieved by 2020, the biggest and most cost-effective abatement lever would be a delay of the nuclear phaseout. This could lead to an additional abatement of 90 Mt CO_2e[8] in 2020 without generating extra abatement costs. Combined with the levers described above, this could lead to a 38 percent reduction in emissions (compared to 1990). At the same time, abatement costs would decrease by about EUR 4.5 billion annually compared to the base case scenario that assumes nuclear phaseout.

6 Quantification of abatement costs from a decision maker perspective includes the EEG tariffs; excluding these tariffs would result in average abatement costs of just under EUR 80/t CO_2e.

7 Abatement costs from a decision maker perspective consider all benefits for investors, e.g., from the EEG. In 2006, payments through the EEG amounted to EUR 3.2 billion. By 2020, the volume of payments – with decreasing rates and an increasing volume of power generation from renewable energies – is expected to increase to approximately EUR 4 billion per year; this would have corresponding effects on electricity prices for industrial and private customers. The assumption for biofuels is that current benefits will expire by 2020; existing import tariffs on ethanol are assumed to remain in place up to 2020.

8 Following the nuclear phaseout, about 150 TWh gross electricity production from nuclear power stations would have to be replaced, primarily by generation from coal- and gas-fired power plants with an average CO_2 intensity of 0.64 t CO_2/MWh (2020).

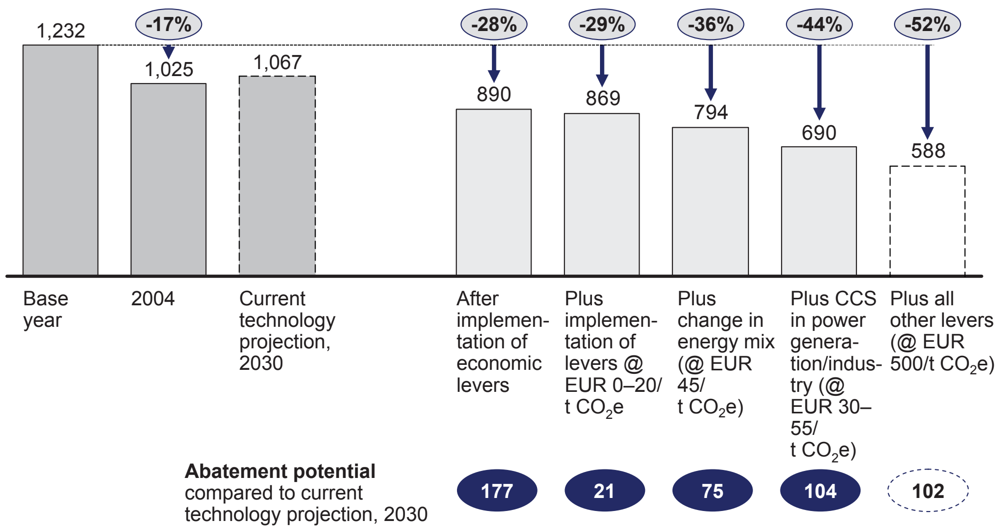
By 2030, annual greenhouse gas emissions in Germany can be reduced by 36 percent, to 794 Mt CO_2e, compared to the 1990 level. This would require further implementation of abatement levers with abatement costs of up to EUR 20/t CO_2e and further change in the energy mix (maintaining the nuclear phaseout). Introducing new technologies to capture and store CO_2 (CCS – carbon capture and storage) can reduce emissions by an additional 104 Mt CO_2e (a further 8 percentage points compared to 1990), assuming technical realization, legal implementation, and commercial distribution are successful and the technology is accepted by the public. As in the case of the change in the energy mix, introducing CCS will also lead to abatement costs significantly higher than EUR 20/t CO_2e – ranging from EUR 30/t CO_2e (lignite) to EUR 55/t CO_2e (industry). If implementation of these measures does not take place in a global context, the competitive position of German companies affected would be severely distorted.

From 2020 to 2030, greenhouse gas emissions are expected to increase slightly to 1,067 Mt CO_2e in the current technology projection. Against this baseline, the continued implementation of abatement levers with abatement costs of up to EUR 20/t CO_2e and further change in the energy mix after the nuclear phaseout could reduce emissions by 273 Mt CO_2e – even without the introduction of CCS technologies. This represents a decrease of 22 percent compared to the 2004 level. Compared to 1990, this would equal a 36 percent decrease in greenhouse gas emissions in Germany.

Abatement potential in Germany, 2030*

Mt CO_2e

DECISION MAKER PERSPECTIVE



* Maintaining nuclear phaseout

** Power generation: ø EUR 31/t CO_2e; biofuels: ø EUR 95/t CO_2e; both considering the applicable subsidy rates in each case, taxes, and customs

Source: Report "Kosten und Potenziale der Vermeidung von Treibhaushasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 2

Through measures with a positive payoff for decision makers, an additional 50 Mt CO_2e reduction can be achieved by 2030, on top of the abatement of 127 Mt CO_2e that can be achieved by 2020. This reduction is primarily due to further penetration of the installed stock with efficient technologies already known today, mainly in building renovation, in cars, and in the industrial sectors.

The levers with abatement costs of up to EUR 20/t CO_2e also have additional abatement potential based on further penetration of the installed stock. This potential amounts to 7 Mt CO_2e from 2020 to 2030, on top of the 14 Mt CO_2e that can be achieved by 2020.

A further increase in power generation from renewable energy sources after the nuclear phaseout would lead to additional abatement of 27 Mt CO_2e between 2020 and 2030.[9] Increasing power generation from offshore wind can make a significant contribution here (an additional 15 Mt CO_2e between 2020 and 2030). During this period, the average abatement costs for the decision makers for the respective technologies are expected to remain around EUR 30/t CO_2e.

After the nuclear phaseout, the largest additional lever for greenhouse gas abatement beyond 2020 is the rollout of technologies to capture and store CO_2 (CCS). In power generation and in energy-intensive industries (especially steel production), these technologies can lead to an annual abatement of up to 104 Mt CO_2e in 2030. According to current estimates, the corresponding abatement costs range from EUR 30/t CO_2e (lignite) to EUR 55/t CO_2e (industry).[10]

Implementation hurdles for introducing CCS technologies are high. To capture this potential, the necessary legal conditions have to be put in place to allow over 100 Mt CO_2e per year to be transported and stored in suitable sinks by 2030. Moreover, pilot projects already initiated need to be driven at a fast pace to reach technical maturity as soon as possible. In addition, it is currently unclear whether the infrastructure associated with CCS (e.g., pipelines, sinks) will gain public acceptance.

It is important to note that a unilateral implementation of CCS technology abatement measures in Germany will lead to an immediate loss of international competitiveness in energy-intensive industries such as steel and cement. The implementation of CCS technology in electricity generation alone would cause an increase in electricity costs of EUR 15 to EUR 25/MWh, which would especially affect industries with a high electricity consumption such as non-ferrous metals. The competitiveness of the industries affected would be significantly damaged if these measures were not embedded in an international context.

9 In addition to the abatement of 48 Mt CO_2e that would already be achieved by 2020 as a result of the change in the energy mix (excluding 6 Mt CO_2e assumed for 2020 from CCS pilot projects and demonstration plants).

10 For gas-fired power stations up to EUR 90/t CO_2e.

All economic sectors in Germany can make a significant contribution to greenhouse gas abatement; their respective shares of abatement potential roughly correspond to their share of current emissions. The type of abatement levers and the corresponding abatement costs do, however, vary considerably across sectors.

All sectors analyzed in this study (energy, industry, buildings, transportation, waste management, and agriculture) can contribute to the abatement potential in Germany with a share that roughly equals their current share of total emissions. However, the abatement levers and corresponding abatement costs vary considerably across sectors:

- In the *energy sector* – taking the nuclear phaseout[11] as a given – further expansion of power generation from renewable energy sources in the context of the politically induced change in the energy mix is the most important abatement lever (34 Mt CO_2e) up to 2020. This lever is associated with abatement costs of, on average, EUR 32/t CO_2e (2020).[12] Implementing the corresponding abatement measures would change the energy mix in Germany in 2020 substantially compared to today: renewable energy sources, hard coal, and lignite would each provide a quarter of Germany's electricity; gas would provide about a fifth. Through the described levers, in combination with the reduced electricity consumption in the industrial sectors and in buildings as well as with the increased efficiency of conventional power stations, the sector's emissions could – despite the nuclear phaseout – be reduced by 21 percent compared to today's level.

- In the *industrial sectors*, greenhouse gas emissions can be decreased, on the one hand, by improving energy efficiency (e.g., through more efficient drives and various industry-specific measures) and, on the other hand, by capturing greenhouse gases (e.g., nitrous oxide in chemicals). Almost two-thirds of the levers evaluated (30 Mt CO_2e) pay off for the decision makers; additional levers with an abatement potential of 11 Mt CO_2e would cost up to EUR 20/t CO_2e. Through implementation of these measures, energy efficiency in the production processes would increase on average by 1.6 percent annually up to 2020.[13] In the same period, the industrial production volume is expected to grow by just under 2 percent annually. Nevertheless, compared to today's level, absolute greenhouse gas emissions are expected to remain constant up to 2020, as a shift to less emission-intensive products and processes will be taking place at the same time.

- In the *buildings sector*, levers to reduce energy consumption and increase energy efficiency (e.g., insulation, replacement of heating systems, facility management systems, efficient electrical devices and lighting) contribute most to greenhouse gas abatement. Complete renovation of old, inefficient buildings yields greater improvement than just applying standards to individual parts of buildings. As the additional investments required for these levers often lead to high energy savings, almost 90 percent of the abatement levers (63 Mt CO_2e) in the buildings sector pay off for the decision makers within the respective amortization period. How-

11 For the effects of delaying the nuclear phaseout, see below p. 34.
12 Quantification of abatement costs from a decision maker perspective includes the EEG tariffs; excluding these tariffs would result in average abatement costs of just under EUR 80/t CO_2e.
13 Energy efficiency refers to the development of consumption of electricity and primary energy compared to the production index.

ever, implementing these abatement levers often requires overcoming substantial obstacles. These include the total investment needed, relatively long amortization periods of more than ten years, and the unequal distribution of costs and benefits of a measure (e.g., between tenants and property owners). If full implementation of economic measures in the buildings sector by 2020 is possible, emissions can be reduced by roughly 20 percent compared to today's level.

- In the *transportation sector*, key levers are technical optimization, often providing end users with an economic benefit, and an increased use of biofuels, which generates additional abatement costs. In road traffic (private cars), the most important technical lever is further optimization of both gasoline and diesel engines. The latter is also the most important lever for light trucks. Some of the technical levers, especially the forced introduction of hybrid vehicles in all classes, would lead to high abatement costs. Improvements in drive systems offer the highest abatement potential for medium and heavy trucks but at a high cost. In addition, an integrated approach across all parts of the mobility chain contributes further to greenhouse gas abatement (e.g., traffic flow management, driving behavior). In rail traffic and aviation, the highest abatement potentials lie in further technical optimization of equipment and in optimizing capacity utilization. In the transportation sector, a total of approximately 40 percent of abatement levers pay off for the decision makers (14 Mt CO_2e). However, they often require comparatively high initial investments. Implementation of these levers in addition to the politically favored use of biofuels (with additional abatement costs) could reduce emissions in the transportation sector by a total of 28 Mt CO_2e by 2020. This reduction corresponds to an 11 percent decrease compared to today's level.

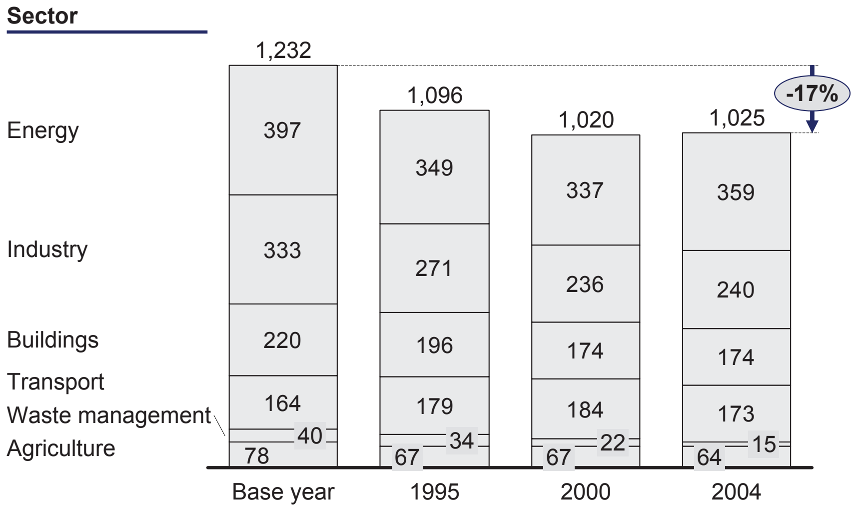
- In *waste management*, the current technology projection already foresees an 80 percent reduction in emissions. The significant drop from 15 Mt CO_2e (2004) to 3 Mt CO_2e (2020/2030) would result mainly from the expected drop in emissions from waste deposits following implementation of TASi (*Technische Anleitung Siedlungsabfall*) regulations on waste storage. Remaining emissions from the sector come mainly from treatment of wastewater; additional abatement levers were not identified.

- In *agriculture*, emissions in the current technology projection are expected to decrease from 64 Mt CO_2e (2004) to 54 Mt CO_2e (2020) and 49 Mt CO_2e (2030). The drivers here are the expected decrease in the number of animals kept and the use of fertilizers in agriculture. In addition to this decrease, further greenhouse gas abatement of 9 Mt CO_2e (2020) and 12 Mt CO_2e (2030) pay off for the decision makers, especially as a result of the shift to organic farming and targeted measures to reduce methane emissions from cattle farming.

Historic Trend and Current Technology Projection

In the baseline year of the Kyoto Protocol,[14] greenhouse gas emissions in Germany were 1,232 Mt CO_2e. Since then, they have declined by 17 percent, to 1,025 Mt CO_2e (2004). This is primarily due to structural transformations in Eastern Germany.

Historical development of greenhouse gas emissions in Germany, from base year to 2004
Mt CO_2e



Source: UBA

Exhibit 3

In the baseline year of the Kyoto Protocol, greenhouse gas emissions in Germany were 1,232 Mt CO_2e. In the ten years after 1990, they dropped by 17 percent, to 1,020 Mt CO_2e (2000). This decline is primarily due to structural transformations in Eastern Germany. Since 2000, greenhouse gas emissions in Germany have remained fairly constant (2004: 1,025 Mt CO_2e; 2006: 1,002 Mt CO_2e).

In the *energy sector*, emissions declined by 12 percent from 1990 to 1995 due to a slight decrease in gross power generation (minus 13 TWh as a consequence of the industrial restructuring in Eastern Germany) as well as a decrease in specific emissions (as some power plants were renovated or replaced). The lowest absolute emissions were attained only in 2000: despite a rise in gross power generation, further replacement of inefficient power plants and the resulting reduction in specific emissions[15] led

14 See “Nationaler Inventarbericht” (national inventory report) of the UBA (Dessau, March 2007) for historic emission values (up to 2006); all data excluding LULUCF (Land Use, Land Use Change, and Forestry).

15 From 0.69 t CO_2e/MWh (baseline year) to 0.57 t CO2e/MWh (2004) – calculated on the basis of net power generation (i.e., including internal energy consumption of power plants and excluding grid losses).

to a decrease to 337 Mt CO_2e. Specific emissions have remained constant since 2000, with the result that absolute emissions increased in line with gross power generation up to 2004: a 7 percent increase, resulting in emissions of 359 Mt CO_2e.[16]

In the *industrial sectors*, emissions declined between 1990 and 1995. During this period, direct emissions dropped by 62 Mt CO_2e. From 1995 to 2004, the German industry was able to reduce its direct emissions by another 31 Mt CO_2e, while over the same period the industrial production grew by over 2 percent annually. From 1990 to 1995, industrial electricity consumption dropped by 13 TWh but went back up to 249 TWh by 2004. Associated emissions, however, were reduced due to the declining CO_2 intensity of power generation. All in all, up to 1995, the effects following German reunification contributed significantly to the decline in overall emissions.[17] Further emissions reduction after 1995 was achieved, on the one hand, by further improving energy efficiency in all industrial sectors; on the other hand, many industries were also able to significantly reduce their process emissions.

The primary reason for the decline of emissions in the *buildings sector* was the decrease in direct emissions by a total of 45 Mt CO_2e in households and in the tertiary sector. Especially Eastern Germany saw extensive building renovations (including insulation) and widespread modernization of heating systems. One example: low-temperature gas and oil boilers have almost fully replaced lignite-fired residential heating systems. Despite a slight rise in consumption, emissions from central heat supply systems also dropped by nearly 40 percent due to substantial efficiency gains. Electricity consumption in buildings went up by nearly 20 percent during the same period. However, emissions stayed stable, since the improved CO_2 intensity in power generation offset this increase.

In the *transportation sector*, greenhouse gas emissions increased by a total of 5 percent from 1990 to 2004 (from 164 to 173 Mt CO_2e, respectively).[18] After the German reunification and due to the EU enlargement to the east, resulting in the free flow of traffic across the borders, the traffic output increased. Primarily affected were freight road traffic (with an increase of 130 percent) and passenger road traffic (with an increase of 50 percent). Accordingly, greenhouse gas emissions in this sector rose to 184 Mt CO_2e in 2000. Since then, emissions have declined again (173 Mt CO_2e in 2004), with considerable efficiency gains partially offsetting the rise in greenhouse gas emissions from higher traffic volumes. Key factors here were the improved fuel efficiency of passenger cars and trucks and greater energy efficiency in rail transportation. Improvements in rail transportation were mainly due to the broad-based introduction of new train technology and the use of alternating current with energy regeneration.

Greenhouse gas emissions from *waste management* decreased by about 25 Mt CO_2e from 1990 to 2004. This reduction resulted mostly from capturing methane emissions from disposal sites and either feeding them into the gas grid or burning them off. Pretreatment of sewage also contributed to reducing emissions, especially in Eastern Germany.

16 The trend in gross power generation over the observed time period was as follows: 550 TWh (1990), 537 TWh (1995), 577 TWh (2000), 616 TWh (2004).

17 See "Ursachen der CO_2-Entwicklung in Deutschland in den Jahren 1990 - 1995," DIW/Fraunhofer Institute, 1998.

18 Excluding an additional approximately 10 Mt CO_2e indirect emissions from electricity consumption of rolling stock.

In *agriculture*, emissions declined by about 14 Mt CO_2e from 1990 to 2004. This decline resulted primarily from a drop in livestock and from a decline in specific use of fertilizers.

In the current technology projection, greenhouse gas emissions in Germany would reach a level of 1,048 Mt CO_2e in 2020 and 1,067 Mt CO_2e in 2030. This assumes that economic growth in Germany continues as currently forecast. In addition, it is assumed that goods and facilities that reach the end of their useful lifetime are replaced by technologies at today's efficiency levels (current technology projection) following the regular investment cycles.

To assess the technical levers to reduce greenhouse gas emissions in Germany, this study established a current technology projection as a baseline. This extrapolation of emission trends for each sector is based on two principles:

1. The currently projected growth in volume (e.g., production growth in various industrial sectors, changes in kilometers traveled for specific means of transportation) is assumed as given. In total, the growth assumed here corresponds to an annual growth in Germany's gross domestic product of 1.6 percent.

2. All newly purchased goods are assumed to mirror the average efficiency attained in today's mix of sales and investments. The specific useful lifetimes of different goods and facilities are taken into account for the various sectors of the economy.

In this current technology projection, the average efficiency of today's mix of sales and investments penetrates the stock over time. Finally – after complete replacement of all goods and facilities – the efficiency of today's mix of sales and investments is achieved for the complete stock. This current technology projection allows an assessment of technical abatement levers that excludes the risk of double counting. Thus, the current technology projection differs from a "business as usual" projection. Most "business as usual" projections implicitly assume not only a penetration of the stock with technologies that are more efficient than the average efficiency of today's mix of sales and investments but also an accelerated development of new technologies.

The current technology projection assumes that replaced goods and facilities disappear completely from Germany (i.e., they would no longer consume any energy nor generate any more emissions in Germany). Emissions resulting from the export of "retired" goods (e.g., the resale of old vehicles or aircraft to foreign countries) were – in line with the Kyoto Protocol reporting – not included in the future greenhouse gas emissions in Germany. Furthermore, it was assumed that the level of additional emissions potentially generated by a continued use of "retired" goods within Germany (e.g., continued use of old refrigerators or televisions as second or third appliances) would not have a significant impact on total energy consumption or total emissions.

The current technology projection does not take into account political targets or self-imposed commitments on the part of individual industries. The same applies to governmental payment schemes such as the payments for power generation from renewable energies based on the *Erneuerbare-Energien-Gesetz* (EEG – Renewable Energy

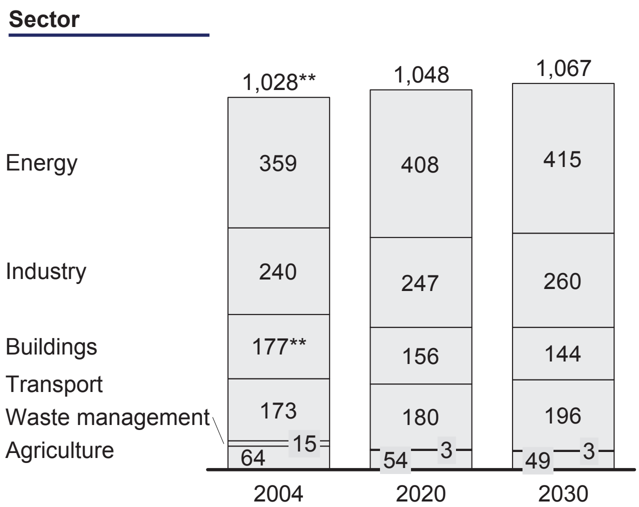
Sources Act). Only those projects that are already in planning or under development were included as part of the current technology projection. The nuclear phaseout in Germany was assumed as a given.

In total, in the current technology projection greenhouse gas emissions in Germany are increasing slightly. By 2020, greenhouse gas emissions will rise to 1,048 Mt CO_2e; this represents an increase of 23 Mt CO_2e compared with 2004 (1,025 Mt CO_2e). By 2030, emissions in Germany will rise by another 19 Mt CO_2e, to approximately 1,067 Mt CO_2e. This rise in emissions results from the fact that, over this period of time, economic growth outpaces the efficiency gains resulting from the increasing penetration of today's technology, if no additional abatement levers are implemented. Despite the rise, emissions in the current technology projection for 2020 are still almost 15 percent below the value for the baseline year (1,232 Mt CO_2e), and for 2030 they are still 13 percent below this value.

The current technology projection assumes ambitious investment activities. The projected replacement of goods and facilities within the regular investment cycles as well as the increasing penetration of today's technology result in significant efficiency gains in many industrial sectors.

The current technology projection shows different developments in the individual sectors.

Current technology projection for greenhouse gas emissions in Germany, 2004–2030*
Mt CO_2e



* Maintaining nuclear phaseout
** Climate adjusted for 2004: temperature correction based on degree days

Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 4

- In Germany's *energy sector*, greenhouse gas emissions rise substantially in the current technology projection. In particular, in the period up to 2020 the nuclear phaseout will necessitate – without further political intervention – building more CO_2-intensive gas and coal power plants. This increases emissions from the energy sector in the current technology projection. With gross power production increasing slightly overall,[19] emissions will increase from 359 Mt CO_2e (2004) to 408 Mt CO_2e (2020) and 415 Mt CO_2e (2030). Accordingly, the CO_2 intensity of power generation will increase from 0.57 t CO_2/MWh (2004) to 0.64 t CO_2/MWh (2020) and 0.62 t CO_2/MWh (2030).[20]

- In the *industrial sectors*, production is forecasted to grow across the board from today until 2020 and 2030 at just about 2 percent per year. In particular, the German machinery and industrial equipment manufacturers, the electrical equipment industry, and some processing industries will experience above-average growth, according to current forecasts. Other industries – e.g., steel, cement – expect today's level of production to remain fairly constant. At the same time, the replacement of the stock with the current technology leads to improvements in energy efficiency and greenhouse gas efficiency. Furthermore, in some industries (e.g., the chemical industry), the product and process portfolio will shift toward less greenhouse gas-intensive solutions. Based on these two effects, greenhouse gas emissions will increase across all industrial sectors by approximately 0.6 percent annually from 2004 to 2020 and 2030. Direct emissions in the industrial sectors will increase from 240 Mt CO_2e (2004) to 247 Mt CO_2e (2020) and 260 Mt CO_2e (2030). The increase in emissions from the use of primary energy sources and from process emissions is somewhat lower than the increase in total emissions, which – largely due to the growing CO_2 intensity in power generation[21] – will increase from 376 Mt CO_2e (2004) to 412 Mt CO_2e (2020) and 436 Mt CO_2e (2030).

- In the *buildings sector*, the current technology projection forecasts that, up to 2020 and 2030, efficiency increases from stock replacement or renovation will more than outpace the expected growth of emissions through an increase in building space. Despite an increase in the residential building space (by about 11 percent from 2004 to 2030), emissions from direct energy consumption will decline from 177 Mt CO_2e (2004)[22] to 156 Mt CO_2e (2020) and 144 Mt CO_2e (2030). This is due to continual progress in renovating the existing building stock and more efficient new buildings. Over the same period, electricity consumption in the buildings sector will drop slightly, from 267 TWh (2004) to 260 TWh (2020) and 255 TWh (2030), despite a further increase in the penetration of electrical appliances (e.g., tumble dryers, PCs, consumer electronics, dishwashers, air conditioners) in households. This is due to the fact that the average appliance efficiency approaches the average efficiency of today's technology. Driven by the heightened CO_2 intensity of power generation, indirect emissions in the sector will overall still remain roughly at today's level. This means that total emissions in the buildings area will decline at a slightly slower

19 Gross power production will rise from 616 TWh (2004) to 636 TWh (2020) and 661 TWh (2030). In addition to electricity consumption from the industrial and buildings sectors (2004: 516 TWh), this also includes electricity consumed by rail vehicles and power plants as well as grid losses.

20 Calculated on the basis of net power production (i.e., including internal consumption of power plants and excluding grid losses).

21 Electricity consumption in the industrial sectors is expected to rise from 249 TWh (2004) to 272 TWh (2020) and 295 TWh (2030).

22 For 2004, energy consumption in the buildings sector was slightly adjusted upward – utilizing a temperature correction based on degree days – to obtain a reference point for analytical comparisons over many years.

pace than direct emissions, from 342 Mt CO_2e (2004) to 331 Mt CO_2e (2020) and 312 Mt CO_2e (2030).

- In the *transportation sector*, continued strong growth in traffic is expected in the years up to 2020 and 2030, especially in freight transportation on roads and rail (both at 2.8 percent annually) and in air freight (at 3 percent annually). Passenger road traffic, in contrast, is expected to experience very little growth, at only 0.4 percent annually. This development is countered by efficiency improvements from gradually replacing the existing vehicle stock. However, considering the average age of today's fleet and the current replacement rate, the efficiency improvements cannot fully compensate for the volume increase in the current technology projection. Thus, greenhouse gas emissions in Germany's transportation sector will increase from 173 Mt CO_2e (2004) to 180 Mt CO_2e (2020) and 196 Mt CO_2e (2030).[23]

- In *waste management*, stagnating population growth will result in essentially constant volumes of garbage and sewage. Further implementation of already existing laws will drive down emissions from waste disposal sites from today's 15 Mt CO_2e to 3 Mt CO_2e (2020 and 2030) in the current technology projection. Residual emissions originate primarily from sewage and are expected to remain constant.

- In *agriculture*, the current technology projection forecasts a decrease of 10 Mt CO_2e by 2020 (and 15 Mt CO_2e by 2030) in methane and nitrous oxide emissions from the 2004 level of approximately 64 Mt CO_2e. This development is fueled by the trend toward organic farming. A linear extrapolation of this trend from 2000 would result in about 15 percent of total farmland being cultivated organically by 2020. The accompanying reduction in the use of chemical fertilizers is expected to lead to a reduction of nitrous oxide emissions reaching almost 6 Mt CO_2e. A second development is increased efficiency in milk production, which will decrease the number of cows by over 20 percent. This will mean less methane from ruminant digestion (around 2 Mt CO_2e) and fewer greenhouse gases from liquid manure (around 2 Mt CO_2e).

23 Excluding indirect emissions from electricity consumption of rolling stock, which amount to 9 Mt CO_2e (2004), 11 Mt CO_2e (2020), and 12 Mt CO_2e (2030).

Levers for Greenhouse Gas Abatement in the Sectors – Abatement Potentials and Costs for 2020

In the energy sector – taking the nuclear phaseout[24] as a given – further expansion of power generation from renewable energy sources in the context of the politically induced change in the energy mix is the most important abatement lever (34 Mt CO_2e) up to 2020. This lever is associated with abatement costs of, on average, EUR 32/t CO_2e (2020).[25] Implementing the corresponding abatement measures would change the energy mix in Germany in 2020 substantially compared to today: renewable energy sources, hard coal, and lignite would each provide a quarter of Germany's electricity; gas would provide about a fifth. Through the described levers, in combination with the reduced electricity consumption in the industrial sectors and in buildings as well as with the increased efficiency of conventional power stations, the sector's emissions could – despite the nuclear phaseout – be reduced by 21 percent compared to today's level.

Compared with the current technology projection, demand for electricity in Germany will decrease after implementation of abatement levers in the industrial sector, in buildings, and in rail transportation. This will result in a 117 TWh decline in gross power generation to 519 TWh (2020), representing a 16 percent reduction compared to 2004 figures (616 TWh). As a consequence, greenhouse gas emissions in the energy sector would be reduced by 70 Mt CO_2e in comparison to the current technology projection.[26] The decline in demand for electricity also results in savings of 16 TWh from avoided losses that result from lower internal electricity consumption at power plants and grid losses which represents approximately 10 Mt CO_2e.

Despite the declining demand for power resulting from implementation of abatement levers in the industrial sector and in buildings, new power generation capacity to produce 220 TWh will have to be built up in Germany. The planned phaseout of nuclear power will leave a gap of about 150 TWh annually that will have to be filled through other sources. Moreover, a number of power plants are reaching the end of their service lives and have to be replaced or significantly modernized. Production capacity for approximately 70 TWh will need to be replaced.

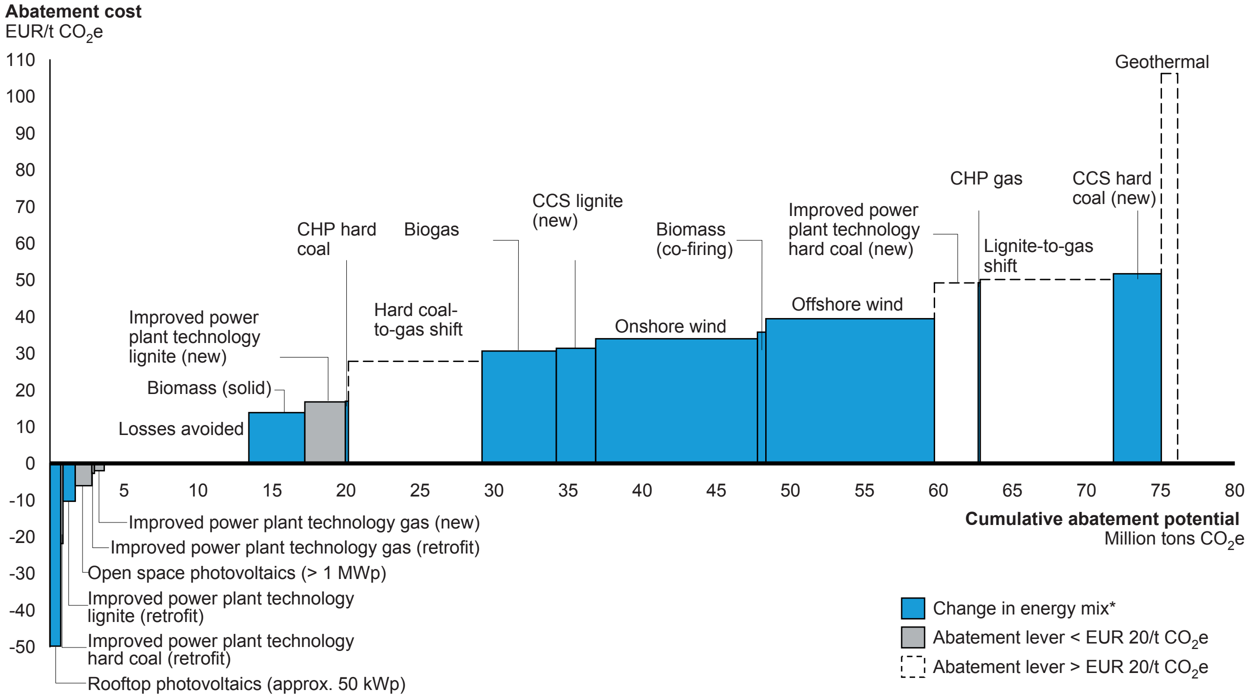
In realizing the necessary investments for replacements and/or modernization, a significant change in the structure of power generation in Germany is expected to take place. Firstly, new power plants will be far more efficient than today's fleet. Furthermore a considerable share of future power generation is required to come from renewable energy sources.

24 For the effects of delaying the nuclear phaseout, see below p. 34.
25 Quantification of abatement costs from a decision maker perspective includes the EEG tariffs; excluding these tariffs would result in average abatement costs of just under EUR 80/t CO_2e.
26 Abatement potentials of the energy efficiency measures were assigned to the sectors that consume electricity.

Energy sector: Abatement cost curve in Germany, 2020*

DECISION MAKER PERSPECTIVE

BASIC SCENARIO, 2020



* Maintaining exit from nuclear power and considering promotion for renewable energies (EEG)

Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 5

All conventional technologies for power generation will undergo important technological improvements that will increase power plant efficiency over the years up to 2020. The improvements will include fluidized bed drying in power generation from lignite and the 700°C power plant (hard coal). The current technology projection already forecasts a shift in average net utilization level of power plants for lignite from today's 34 percent to 39 percent; for hard coal from 38 percent to 43 percent; and for gas from 50 percent to 58 percent. As the current technology projection already includes the introduction of efficient power plant technology, any potentials resulting from further improvement of technologies are comparatively low. For instance, efficiency increases resulting from retrofitting older power plants and optimization of newly built power plants would only lead to an additional potential of under 5 Mt CO_2e at abatement costs of up to EUR 20/t CO_2e.

Renewable energy sources could make the greatest contribution to greenhouse gas abatement in power generation in Germany, compared to the current technology projection. By 2020, about a quarter of Germany's power generation will be required to come from these sources. This structural shift will contribute to a 34 Mt CO_2e reduction in greenhouse gas emissions. Wind (onshore and offshore at approximately 11 Mt CO_2e each) and biomass (solid/gaseous, together approximately 9 Mt CO_2e) will constitute the largest share of power generation from renewable energy sources.

The further increase in the use of photovoltaics will lead to a contribution of just under 2 Mt CO_2e with a net benefit to the decision makers due to high compensations within the framework of the EEG. In contrast, intensified utilization of geothermal energy (approximately 1 Mt CO_2e) is available at abatement costs of over EUR 100/t CO_2e and was therefore not included in the total abatement potential.

Abatement costs resulting from the change in the energy mix are at an average level of EUR 32/t CO_2e, which is significantly higher than historical CO_2 prices in the EU ETS.[27] Currently, most of the abatement levers outlined are supported through schemes outside of the EU ETS, preventing any direct impact on CO_2 prices. If this were to change in the future, restructuring the energy mix would result in significant additional costs, especially for industrial companies. Industrial companies would have to bear both an increase in direct costs for remaining emissions and an increase in the wholesale price for electricity (by approximately EUR 15/MWh at a CO_2 price of EUR 30/t CO_2e).

By 2020, the first pilot and demonstration facilities for capturing CO_2 from power plants will have been put into operation. In the energy sector, this will lead to further reductions of about 6 Mt CO_2e at abatement costs of just above EUR 30/t CO_2e (lignite) and just above EUR 50/t CO_2e (hard coal). Including these abatement levers in the context of the EU ETS would result in a EUR 15 - 25/MWh price increase for electricity.

The levers outlined above also include intensified use of combined heat and power (CHP) plants, calculated based on the heat requirements of the consuming sectors (buildings and industry). Overall, heat produced from CHP is expected to increase from today's level of 134 TWh_{th} to 191 TWh_{th}. Taking into account improved CHP coefficients of the increasingly efficient plants, electricity production by CHP facilities will in consequence grow from today's level of 63 TWh_{el} to 100 TWh_{el} in 2020, which is about 19 percent of total power generation in that year. The highest absolute increase (19 TWh_{el}) from CHP plants comes from decentralized supply through block heat and power plants (10 KW_{el} to 10 MW_{el}), especially in development areas. In contrast, the use of CHP units in the industrial sector is growing by only about 10 TWh_{el}. The abatement potentials resulting from conversion to CHP facilities in the heat supply for buildings and industrial facilities were taken into account in the respective sectors.

Overall, in the energy sector, abatement potentials of 55 Mt CO_2e were taken into account, compared to the current technology projection. In combination with the decline in demand (70 Mt CO_2e), implementation of these abatement levers would reduce emissions in the sector to 283 Mt CO_2e, which represents a 21 percent decrease compared to today's level. This equals a reduction of about 29 percent in relation to the baseline year.

In addition to the continuously increasing efficiency in all power generation technologies, greater use of natural gas (instead of lignite or hard coal) could contribute sub-

27 In the calculation of abatement costs from the decision maker perspective, EEG compensation is included. The costs of individual technologies up to 2020 in a comparative analysis (with/without consideration of compensation payments) are as follows:
- Wind onshore: decision maker view EUR 34/t CO_2e; overall economic view: EUR 55/t CO_2e
- Wind offshore: decision maker view EUR 39/t CO_2e; overall economic view: EUR 104/t CO_2e
- Biomass (solid): decision maker view EUR 14/t CO_2e; overall economic view: EUR 40/t CO_2e
- Biomass (gaseous): decision maker view EUR 31/t CO_2e; overall economic view: EUR 57/t CO_2e
- Photovoltaic (open plain): decision maker view EUR -6/t CO_2e; overall economic view: EUR 153/t CO_2e
- Photovoltaic (building): decision maker view EUR -49/t CO_2e; overall economic view: EUR 213/t CO_2e

stantially to reduce greenhouse gas emissions. If 75 percent of new capacities were gas-fired power plants, as opposed to the 50 percent assumed in the current technology projection, this would yield a further abatement of nearly 18 Mt CO_2e (2020). However, this coal-to-gas shift would generate abatement costs of almost EUR 28/t CO_2e (natural gas instead of hard coal) and around EUR 50/t CO_2e (natural gas instead of lignite).

The base scenario does not include extending the service lives of existing nuclear power plants beyond an average life of 32 years. Operating German nuclear power plants for 60 years, or even just 45 years, as is technically feasible and usual practice in other Western industrial nations, would result in an additional abatement potential of about 90 Mt CO_2e for 2020, compared to the base scenario.[28] At the same time, abatement costs would decrease by EUR 4.5 billion annually compared to the base scenario that assumes implementation of the scheduled nuclear phaseout.

In the industrial sectors, greenhouse gas emissions can be decreased, on the one hand, by improving energy efficiency (e.g., through more efficient drives and various industry-specific measures) and, on the other hand, by capturing greenhouse gases (e.g., nitrous oxide in chemicals). Almost two-thirds of the levers evaluated (30 Mt CO_2e) pay off for the decision makers; additional levers with an abatement potential of 11 Mt CO_2e would cost up to EUR 20/t CO_2e. Through implementation of these measures, energy efficiency in the production processes would increase on average by 1.6 percent annually up to 2020.[29] In the same period, the industrial production volume is expected to grow by just under 2 percent annually. Nevertheless, compared to today's level, absolute greenhouse gas emissions are expected to remain constant up to 2020, as a shift to less emission-intensive products and processes will be taking place at the same time.

In the industrial sectors (excluding power generation and transportation), abatement levers for direct and indirect emissions with a total potential of 49 Mt CO_2e (2020) were quantified. About 60 percent of the abatement levers (nearly 30 Mt CO_2e) pay off for the decision makers within the regular investment cycles – even without an explicit price for greenhouse gas emissions. The growing use of more efficient drive systems, as well as the mechanical system optimization, will contribute the most to abating greenhouse gas emissions (2020: 21 Mt CO_2e). The historical increase in energy efficiency in the industry sector indicates that a large share of these abatement measures can be expected to be implemented within the normal investment cycles even without any additional incentives. However, some levers require decision makers to be willing to intervene in established processes, with the challenge of preserving the process stability during these changes. Optimizing the energy efficiency of buildings in the industrial sectors also contributes to reducing greenhouse gases while paying off for the decision makers; measures in this category could save about 6 Mt CO_2e.[30]

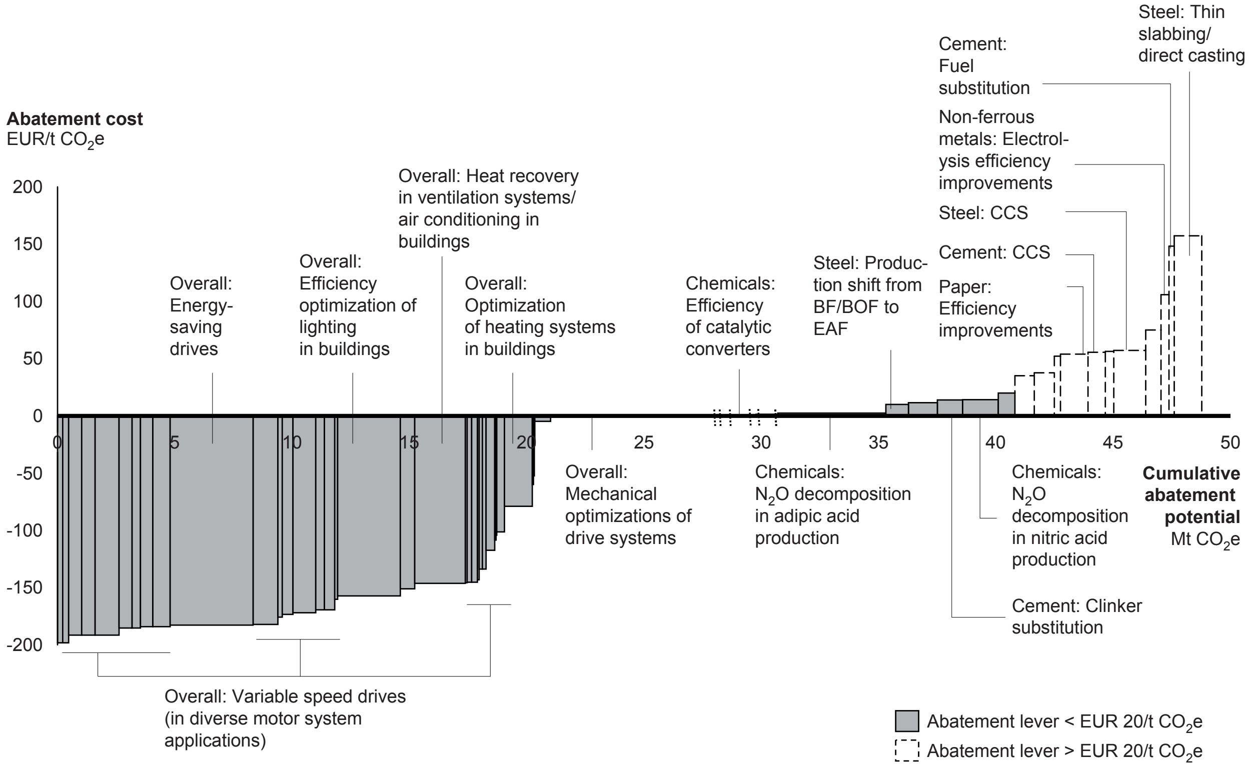
28 Due to the phaseout of nuclear power plants, about 150 TWh gross electrical power generation must be covered by a mix of power plants fired by coal and natural gas with an average CO_2 intensity of 0.64 t CO_2/MWh (2020).

29 Energy efficiency refers to the development of consumption of electricity and primary energy compared to the production index.

30 Greenhouse gas abatement in industrial buildings can be achieved through the abatement levers for the tertiary sector outlined below in the section for the buildings sector, see p. 37 sqq.

Industrial sector: Abatement cost curve in Germany, 2020

DECISION MAKER PERSPECTIVE



Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 6

The potentials and economic viabilities of these measures for individual industrial sectors depend heavily on the individual conditions of specific industries. Some of the potentials described could presumably be implemented in less energy-intensive industrial sectors. However, due to the highly fragmented nature of the less energy-intensive industries, an allocation of the potentials from improving drive systems and energy efficiency of buildings to individual industries was not conducted in the scope of the study.[31]

Further levers with a positive payoff from the decision maker perspective are process-specific measures in individual industries with a potential of just under 3 Mt CO_2e. These measures include further process optimization in reactor design and improvement of catalysts in the chemical industry.

31 For energy-intensive industries, rough estimates were made based on electricity consumption (drive systems) and the number of employees (buildings). The resulting abatement potentials allocated to different industries are: chemicals: 3.4 Mt CO_2e; pulp and paper: 1.8 Mt CO_2e; steel: 1.3 Mt CO_2e; oil: 0.6 Mt CO_2e; cement: 0.4 Mt CO_2e; non-ferrous metals: 0.2 Mt CO_2e. The remaining nearly 20 Mt CO_2e were assigned to all other industries, not explicitly reported, but were not allocated to individual industries.

Additional levers with abatement costs ranging from EUR 0 to EUR 20/t CO_2e contribute nearly 11 Mt CO_2e to the abatement potential. The vast majority of these are individual industry-specific measures.[32]

- Chemicals (approximately 6 Mt CO_2e): Further reduction of nitrous oxide emissions in the synthesis of adipic acid and nitric acid
- Steel (approximately 2 Mt CO_2e): Expanded use and optimization of the EAF process
- Oil (approximately 2 Mt CO_2e): Various efficiency improvements depending on the individual facility (e.g., efficiency improvement of furnaces at individual sites)
- Cement (approximately 1 Mt CO_2e): Clinker substitution

In addition, across all energy-intensive industries, further abatement potentials of 8 Mt CO_2e with costs of over EUR 20/t CO_2e were identified. Since costs at this level would seriously impair the competitiveness of numerous industries in the global market, these potentials were not considered in the total. In detail, the potentials result from the following abatement levers:

- Chemicals: Fuel substitution (0.8 Mt CO_2e at abatement costs of EUR 35/t CO_2e)
- Steel: Direct casting (1.2 Mt CO_2e at abatement costs of EUR 157/t CO_2e); pilot facilities with CCS (1.4 Mt CO_2e at abatement costs of EUR 57/t CO_2e)[33]
- Oil: Various efficiency and process improvements depending on the processing facility (0.9 Mt CO_2e at abatement costs of EUR 52 and EUR 75 EUR/t CO_2e)
- Cement: Efficiency improvement in clinker production (0.6 Mt CO2e at abatement costs of EUR 56/t CO_2e), fuel substitution (0.6 Mt CO_2e at abatement costs of EUR 148/t CO_2e); pilot facilities with CCS (0.7 Mt CO_2e at abatement costs of EUR 55/t CO_2e)
- Pulp and paper: Further efficiency improvements e.g., by increased use of shoe presses (1.2 Mt CO_2e at abatement costs of EUR 54/t CO_2e)
- Non-ferrous metals: Efficiency improvements in electrolysis and heat treatment, e.g., by better heat integration (total of 1.2 Mt CO_2e at abatement costs of EUR 106/t CO_2e and EUR 38/t CO_2e respectively)

Overall, the industrial sectors in Germany can reduce their greenhouse gas emissions by 41 Mt CO_2e up to 2020 by implementing abatement levers with abatement costs of up to EUR 20/t CO_2e, compared to the current technology projection. After implementing these abatement levers, total emissions in this sector will be 371 Mt CO_2e, which is slightly below the 2004 level (376 Mt CO_2e) and nearly 25 percent below the level of the base-

32 To avoid double counting, individual industries' share of the measures related to increasing the efficiency of drive systems and buildings is not itemized again here.
33 The specific costs for early introduction of CCS in the industrial sector are higher than for power plants, since smaller volumes need to be captured and disposed of at the same infrastructure expense.

line year (488 Mt CO_2e). Implementing the measures will allow the industry to increase energy efficiency by an average of 1.6 percent annually compared to today.[34]

Beside the direct costs associated with implementing the levers outlined above, it is very important to understand which additional costs result from the CO_2 regime in place and/or from changes in prices for fuel and electricity, especially in energy-intensive industries. Even CO_2 prices up to EUR 20/t CO_2, which would result if the measures outlined here were to be implemented as part of the EU ETS, could place enormous stress on the global competitiveness of many industries – the actual impact depending on the specific allocation rules. Without embedding national measures in a global context, implementation of these levers would result in substantial distortions in the competitiveness of German companies.

In the buildings sector, levers to reduce energy consumption and increase energy efficiency (e.g., insulation, replacement of heating systems, facility management systems, efficient electrical devices and lighting) contribute most to greenhouse gas abatement. Complete renovation of old, inefficient buildings yields greater improvement than just applying standards to individual parts of buildings. As the additional investments required for these levers often lead to high energy savings, almost 90 percent of the abatement levers (63 Mt CO_2e) in the buildings sector pay off for the decision makers within the respective amortization period. However, implementing these abatement levers often requires overcoming substantial obstacles. These include the total investment needed, relatively long amortization periods of more than ten years, and the unequal distribution of costs and benefits of a measure (e.g., between tenants and property owners). If full implementation of economic measures in the buildings sector by 2020 is possible, emissions can be reduced by roughly 20 percent compared to today's level.

Overall, abatement levers with a potential of 72 Mt CO_2e (2020) were assessed in the buildings sector. Nearly 90 percent of this potential (63 Mt CO_2e) has a positive payoff from a decision maker perspective and a further 4 Mt CO_2e could be realized at costs ranging from EUR 20 to EUR 100/t CO_2e; one of the key levers here is the use of optimized air conditioning systems in the tertiary sector. About a tenth of the abatement potential (5 Mt CO_2e) would generate costs of over EUR 100/t CO_2e for the decision maker. In particular, this refers to measures that further reduce primary energy demand for space heating in existing residential buildings beyond the "7-liter standard" (i.e., energy consumption of 70 kWh or 7 liter per square meter per year) to as little as 20 kWh or 2 liters per square meter per year ("2-liter standard" or "passive house standard").

The largest single lever in the buildings sector is holistic upgrading of insulation and heating for residential buildings built before 1979 to a "7-liter standard". Assuming an annual energy-based renovation rate of 3 percent for all residential buildings built before 1979[35] and not yet renovated would yield an abatement potential of 20 Mt CO_2e (2020).

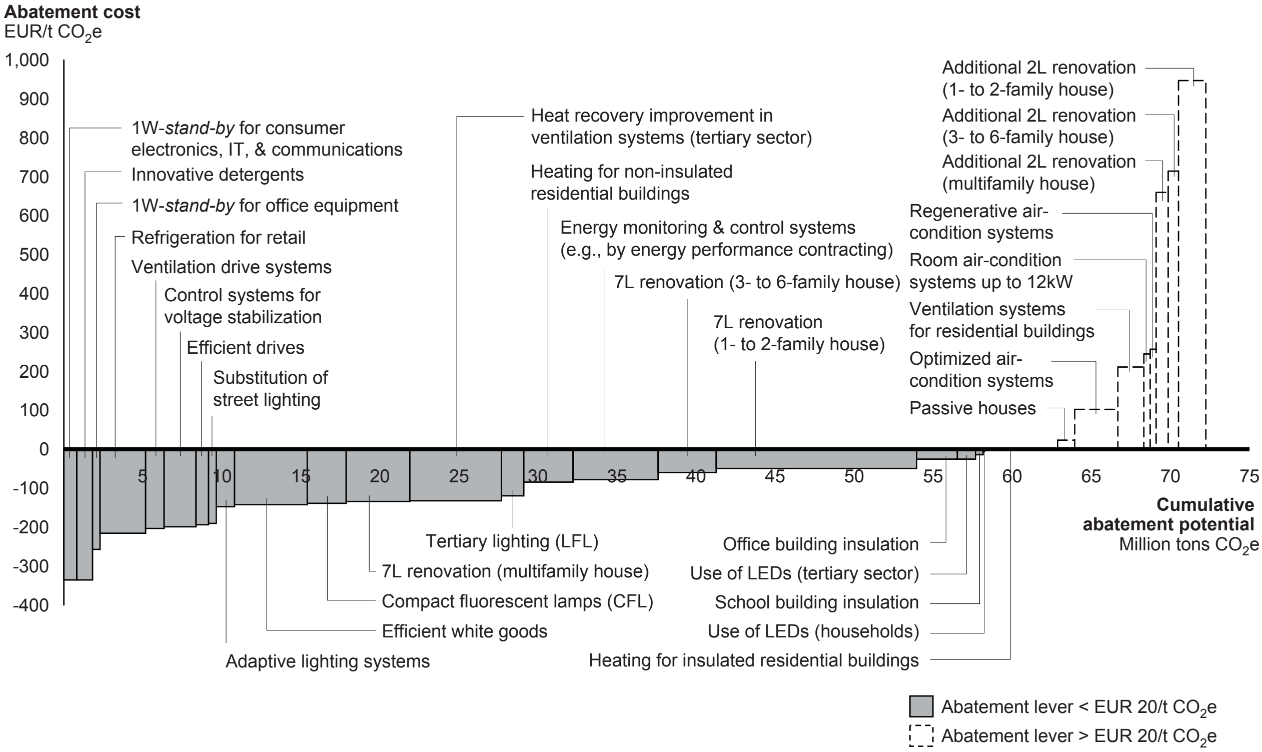
34 Energy efficiency here refers to the trend in consumption of electricity and primary energy sources in relation to the production index.

35 This renovation rate corresponds to an annual renovation rate of about 1.7 percent of all residential buildings. It is more than twice as high as the historical value of about 0.75 percent and is therefore very ambitious. If a share of these renovations were not implemented – due to barriers that cannot be removed – then the stand-alone replacement of heating units would already make a contribution toward reducing greenhouse gas emissions.

Without exception, these measures pay off for the decision makers over the amortization period and are expected to achieve average savings of just under EUR 70/t CO_2e, provided that they are executed in conjunction with an overall renovation being undertaken. However, amortization periods are often far longer than 10 years.

Buildings sector: Abatement cost curve in Germany, 2020

DECISION MAKER PERSPECTIVE



Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 7

The underlying calculation can be illustrated based on the example of a detached single-family house that is lived in by its owner (120 square meters living area, built in 1975, not yet renovated). If the owner were to just maintain the building and replace the heating system with a system according to today's current technology, an investment of approximately EUR 77,000 would be needed. This total breaks down into EUR 41,000 for work on the building shell and EUR 8,000 for a standard renovation of the heating system. In addition, maintenance costs on the interior totaling EUR 28,000 would be incurred (e.g., for renovation of walls and floors, bathrooms, kitchen). If the owner were to upgrade to a "7-liter standard" in addition to the mere maintenance work, the investment would increase by approximately EUR 16,500. This total breaks down into EUR 5,000 for insulating the facade, EUR 3,000 for insulating the upper story ceiling, EUR 2,500 for higher quality windows, and EUR 3,000 for insulating the basement ceiling. Introduction of a modern condensing boiler with solar hot water heating instead of standard heating would require an additional investment of approximately EUR 3,000. Based on the significant reduction of primary energy requirements for space heating and hot water by approximately 200 kWh per square meter per year, the investments amortize after approximately 15 years. The annual energy cost savings for the property owner are about EUR 1,300.

Beside holistic renovation of buildings, old heating systems that are less efficient by today's standards can be replaced in already renovated buildings, as well as in previously unrenovated old buildings. This exchange would contribute 8 Mt CO_2e and result in savings of up to EUR 86/t CO_2e.

Additional renovation of residential buildings to reach passive house standard (primary energy required for space heating of 20 kWh or 2 liter per square meter per year) would increase the abatement potential by an additional 3 Mt CO_2e but would be relatively expensive. In this case, the decision maker would incur abatement costs of EUR 650 to EUR 950/t CO_2e.

In the tertiary sector (commercial, public, and agricultural buildings), increased efficiency of existing ventilation systems and improved energy monitoring and management systems contribute the most to greenhouse gas abatement (11 Mt CO_2e in 2020). These systems could be introduced as part of energy savings contracting. In implementing these measures, the decision maker also realizes savings; they amount to about EUR 110/t CO_2e.

Energy-related renovation (insulation to achieve the "7-liter standard") of schools and office buildings represents an additional abatement measure with a potential of 3 Mt CO_2e, with a positive payoff for the decision maker of about EUR 20/t CO_2e. This potential appears low compared to residential buildings but it in fact derives from smaller total floor area and shorter heating periods of the respective buildings.

Application of benchmark technology in electrical devices, especially household appliances, consumer and communication electronics, office equipment, and cooled display cabinets in retail stores, can lead to an abatement of 9 Mt CO_2e. Use of the most efficient lighting systems for interior lighting and street lighting can add another 7 Mt CO_2e. All of these abatement levers make an immediate contribution with savings ranging from EUR 25 to EUR 350/t CO_2e.

Various other levers with a positive payoff from the a decision maker perspective (e.g., reducing electricity consumption by using innovative detergents) add up to an additional 5 Mt CO_2e.

In sum, greenhouse gas emissions in the buildings sector can be reduced by 63 Mt CO_2e to a level of 268 Mt CO_2e (2020) by implementing levers with a positive payoff. Compared to 2004, this represents a 20 percent reduction; in relation to the baseline year, greenhouse gas emissions for the sector would be reduced by nearly 30 percent.

Although a majority of the abatement levers in the buildings sector have a positive payoff from a decision maker perspective, there are a number of barriers to overcome to implement the levers in practice. Many private decision makers have insufficient information about the technical possibilities and economic benefits of energy-saving measures. Furthermore, amortization periods for the specific measures are often long, and investments for both the general renovations and for the energy-related improvements are relatively high. This can be daunting for individual groups of decision makers – young families or senior citizens, for example – as well as for financial investors or public sector investors who are subject to budgetary constraints. Another barrier to implementation of abatement levers occurs in the area of rental apartments. Generally, the property owner assumes the costs of energy-related renovation of the living space, while the tenant benefits from the energy savings. In order to exploit the abatement potential in the buildings sector, these barriers must be eliminated quickly and on a sustainable basis.

In the transportation sector, key levers are technical optimization, often providing end users with an economic benefit, and an increased use of biofuels, which generates additional abatement costs. In road traffic (private cars), the most important technical lever is further optimization of both gasoline and diesel engines. The latter is also the most important lever for light trucks. Some of the technical levers, especially the forced introduction of hybrid vehicles in all classes, would lead to high abatement costs. Improvements in drive systems offer the highest abatement potential for medium and heavy trucks but at a high cost. In addition, an integrated approach across all parts of the mobility chain contributes further to greenhouse gas abatement (e.g., traffic flow management, driving behavior). In rail traffic and aviation, the highest abatement potentials lie in further technical optimization of equipment and in optimizing capacity utilization. In the transportation sector, a total of approximately 40 percent of abatement levers pay off for the decision makers (14 Mt CO_2e). However, they often require comparatively high initial investments. Implementation of these levers in addition to the politically favored use of biofuels (with additional abatement costs) could reduce emissions in the transportation sector by a total of 28 Mt CO_2e by 2020. This reduction corresponds to an 11 percent decrease compared to today's level.

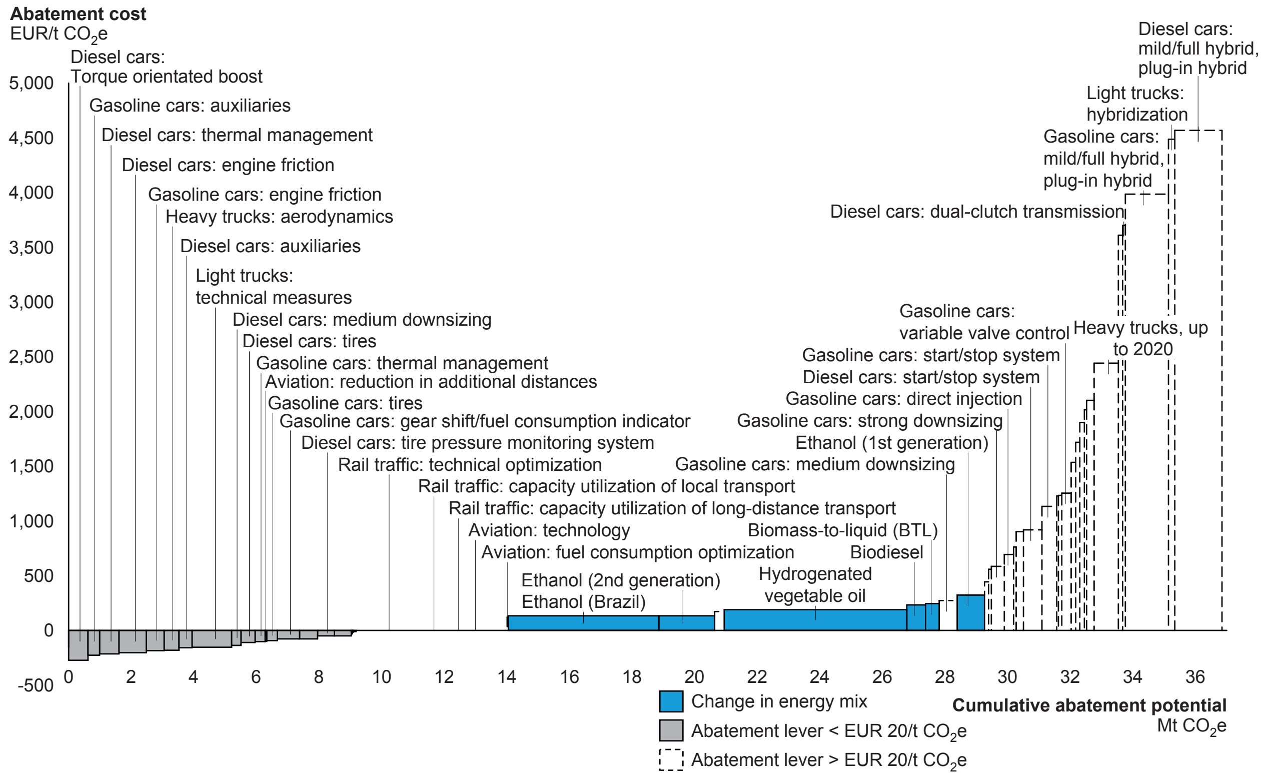
In the transportation sector, abatement potentials were assessed separately for each means of transportation (road, rail, and air). Overall, abatement levers with a total potential of 37 Mt CO_2e (2020) were assessed. Nearly 40 percent of these levers (14 Mt CO_2e) have a positive payoff from the decision maker perspective; another 40 percent are expected to be realized based on the politically induced changes in the energy mix through the introduction of biofuels (14 Mt CO_2e). However, implementation of these levers would generate costs of over EUR 130/t CO_2e for decision makers. The remaining abatement potential of 9 Mt CO_2e would generally be subject to costs of over EUR 300/t CO_2e for decision makers.[36]

The overall potential of technological measures for passenger cars can be subdivided into several bundles of measures, which overall would reduce emissions by a total of 15.6 Mt CO_2e. At least half (8.2 Mt CO_2e) of these measures have a positive payoff from a decision maker perspective.

36 For sample calculations of abatement costs, see below p. 62.

Transport sector: Abatement cost curve in Germany, 2020

DECISION MAKER PERSPECTIVE



Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 8

- *Optimization of engines and transmissions* yields potentials of 6.7 Mt CO_2e. At least half of the measures have economic benefits; these include, for example, reducing internal friction in engines and thermal management. Other measures are subject to significant abatement costs (e.g., the installation of a dual clutch transmission at a cost of over EUR 1,000/t CO_2e).

- *Optimizations to the overall vehicle* (e.g., improving aerodynamics, optimizing weight and reducing rolling resistance of the tires), can reduce greenhouse gas emissions by 1.2 Mt CO_2e (2020), at costs of about EUR 250/t CO_2e.

- The *introduction of hybrids (mild/full)* can save an additional 3 Mt CO_2e. However, a forced introduction across all vehicle segments would lead to costs of over EUR 3,000/t CO_2e. A share of the fuel-consumption benefits could be realized at a lower cost using micro-hybridization,[37] e.g., if start-stop systems were to achieve a relatively high market share. In the assumed scenario, additional abatement potential for micro-hybrids is 1.7 Mt CO_2e. For specific niche applications (e.g., city buses) hybrid technology is about cost-neutral, at least for amortization periods of eight years and more, since the hybrid can play out its advantage especially well while driving in the inner city, where many starts and stops are needed.

37 Micro-hybridization involves progressive electrification of subassemblies and the introduction of a start-stop system with braking energy recovery combined with improved energy management.

- Further measures not currently covered in the driving cycle (standardized fuel-consumption test) have potential for reducing consumption. These include *shifting point and fuel consumption display, tire pressure monitoring systems, and optimized air conditioning systems*. In sum, a potential of 3 Mt CO_2e could be realized through these measures, with savings of EUR 30/t CO_2e from a decision maker perspective.

- Furthermore alternative powertrain technologies based on natural gas, hydrogen, and fuel cell technology were looked at in the scope of the study. Due to the lack of reliable cost data shared across the industry and due to the fact that significant abatement potentials for the innovative powertrain technologies are expected only over very long time horizons, they were not quantified in detail.

In the trucks segment, technical measures for light commercial trucks and midsize/heavy commercial vehicles (including buses) were evaluated separately. In total, 3 Mt CO_2e (2020) can be abated in these two segments. In light commercial trucks, reduction of internal engine friction by using low-friction oils, improved aerodynamics, and start-stop systems all contribute to reduced fuel consumption. In mid-size to heavy commercial vehicles, a set of measures (balancing emissions and fuel economy considerations) were defined to primarily address the optimization of the powertrain. Further abatement potentials from a significant aerodynamic improvement of long-distance trucks have economic benefits, but can, however, be implemented only if the legal situation changes. From a decision maker perspective, a total potential of 1.6 Mt CO_2e pays off, e.g., from various engine-related measures for light trucks. The additional 1.4 Mt CO_2e are cost-intensive (e.g. the measurement bundle for heavy trucks with costs of over EUR 1,000/t CO_2e).

In road transportation as a whole, greenhouse gas emissions can be reduced by an additional 4 Mt CO_2e by supplementing technical levers with a fuel-conserving driving style (eco driving), optimized traffic control (infrastructure and traffic flow management), and improved truck fleet management. However, a comprehensive and detailed cost assessment has not been carried out. Implementation of the above measures will require an integrated approach by automotive OEMs, traffic participants, infrastructure producers and operators,[38] and the oil industry – a joint effort by all parts of the mobility chain.

In rail transportation, increasing capacity utilization in local and long-distance passenger traffic represents a significant lever up to 2020 with abatement potential of 1.6 Mt CO_2e (2020). Technical improvements in locomotives and operating equipment[39] could lower emissions by 1.8 Mt CO_2e. Abatement costs for the total potential of 3.4 Mt CO_2e were set to zero, since no detailed cost estimates are yet available for this area.[40] Additional emission reductions in rail transportation may result from reductions in the CO_2 intensity of power generation after implementation of measures in the energy sector. Compared to 2004 levels, this effect represents an additional decline of about 10 percent (referenced to persons/metric ton kilometer) in specific emissions in rail transportation.

38 This study assumes that the current quality level of infrastructure will continue to be maintained for all means of transportation.
39 For example, measures for improved energy use/recovery, lightweight modular construction and dual-level vehicles.
40 A cost assessment is currently being conducted in the EU project “Rail Energy”.

In air transportation, important levers include continual optimization of aircraft construction above and beyond the current technology status (e.g., materials applications, engine optimization) and technical improvement of the existing vehicle fleet (e.g., retrofitting with winglets, installing lighter seats). Optimized fuel consumption in flight operations (e.g., by luggage optimization) and avoidance of additional distances (including reduction of normal distances, improved air traffic management) also play a key role. All assessed levers, with an abatement potential of 0.6 Mt CO_2e, pay off for decision makers.[41]

A rise in the share of biofuels in total fuel consumption, from 5 percent today (2006) to 17 percent (on an energy basis) by 2020, based on targets discussed by the German government, would contribute an additional potential of 14 Mt CO_2e for passenger cars and trucks.[42] In the case of gasoline, potentials can be achieved by using first-generation ethanol, imports from Brazil, and a share of second-generation ethanol beginning in 2015. A calculation based on current import tariffs of 19 cent/liter leads to abatement costs for 2020 from EUR 130/t CO_2e to EUR 320/t CO_2e. In the case of diesel, the increase in biofuels will mainly come from hydrogenated vegetable oils, which are also largely imported. Biodiesel from domestic rapeseed oil will grow only slightly and biomass-to-liquid (BTL) will achieve only a small market share. Abatement costs here range from EUR 190/t CO_2e to EUR 240/t CO_2e (2020).

Whether the additional costs to the decision maker – the car buyer for example – pay back over the average usage period of 4.5 years in the form of reduced fuel consumption will depend on the specific measurement bundle. Nonetheless, the technological measures identified will result in higher prices for end customers, which could represent a barrier to purchasing. For example, in the case of passenger cars, if all technical measures except the mild/full hybrid are introduced and cost degression effects are considered, the average cost of a new car will increase by EUR 1,250 by the year 2020. An additional (partial) transition to hybrid vehicles (mild/full hybrid) would increase the average new car price by over EUR 3,000 in 2020.

In absolute terms, greenhouse gas emissions in the transportation sector will decrease by 28 Mt CO_2e compared to the current technology projection through the introduction of biofuels and the implementation of abatement levers with costs of up to EUR 20/t CO_2e. This represents a 15 percent reduction. Compared to 2004 levels, greenhouse gas emissions in this sector will be reduced by 11 percent and by 7 percent in relation to the baseline year.

41 Additional potential can also be achieved in the future by blending biofuels; however, competition for the scarce resource of biofuel must be considered, See below p. 53 sqq.

42 The 17 percent biofuel share was applied equally to gasoline and diesel in estimates.

Further Developments after 2020 – Abatement Potentials and Costs by 2030

By 2030, annual greenhouse gas emissions in Germany can be reduced by 36 percent, to 794 Mt CO_2e, compared to the 1990 level. This would require further implementation of abatement levers with abatement costs of up to EUR 20/t CO_2e and further change in the energy mix (maintaining the nuclear phaseout). Introducing new technologies to capture and store CO_2 (CCS – carbon capture and storage) can reduce emissions by an additional 104 Mt CO_2e (a further 8 percentage points compared to 1990), assuming technical realization, legal implementation, and commercial distribution are successful and the technology is accepted by the public. As in the case of the change in the energy mix, introducing CCS will also lead to abatement costs significantly higher than EUR 20/t CO_2e – ranging from EUR 30/t CO_2e (lignite) to EUR 55/t CO_2e (industry). If implementation of these measures does not take place in a global context, the competitive position of German companies affected would be severely distorted.

For the period from 2020 to 2030, the study first assessed how much abatement potential will be achievable from further implementation of abatement levers that are already available by 2020. In addition, the study took a close look at CCS, which is currently being developed as a key technology for reducing greenhouse gas emissions. Of course, in the years until 2030, an appearance of new and innovative technologies on the market can be expected. This would then contribute to further abatement of greenhouse gas emissions. However, estimating the potential offered by such possible future technologies was not part of the scope of this study.

In transportation, buildings, and the industrial sectors between 2020 and 2030, further penetration of efficient technologies that pay off for the decision makers will result in additional abatement potential. Beyond the 127 Mt CO_2e that are achievable by 2020, a further 50 Mt CO_2e could be abated between 2020 and 2030 through measures with a positive payoff for the decision makers. In the transportation sector (additional potential of 12 Mt CO_2e), increasingly complex and expensive technology is expected to be introduced (e.g., layered gasoline direct injection, variable valve control, multiphase turbo charging for gasoline and diesel vehicles). The anticipated tightening of regulations on exhaust emissions is expected to lead to future improvements in drive technology for trucks. By comparison, new technology does not play a key role in the buildings sector. The major contribution here will come from step-by-step implementation of the renovation measures described above (additional potential of 22 Mt CO_2e). The same holds true for the industrial sectors, where further improvements in electrical drive technology and efficiency gains in the buildings area can be expected (additional potential of 10 Mt CO_2e).[43]

43 The remaining additional potential comes from agriculture (3 Mt CO_2e) and from further losses avoided in electricity generation (3 Mt CO_2e).

Between 2020 and 2030, abatement through levers with abatement costs of up to EUR 20/t CO_2e also rises. At this cost level, in addition to the 14 Mt CO_2e that can be achieved by 2020, an additional 7 Mt CO_2e can be achieved by 2030. Increased potential from improved power plant technology for new lignite facilities makes a key contribution here (8 Mt CO_2e in 2030, as opposed to 3 Mt CO_2e in 2020).

After the nuclear power phaseout, according to current political guidelines, the change in the energy mix should further progress between 2020 and 2030. In particular, the use of renewable energies is expected to increase substantially. In addition to the already existent potential[44] for 2020, further abatement potential of 27 Mt CO_2e is expected, primarily from additional electricity generated from wind (offshore: 15 Mt CO_2e; onshore: 5 Mt CO_2e) and biomass (4 Mt CO_2e). Abatement potential from photovoltaic electricity generation will also go up (by 1.3 Mt CO_2e). For biofuels, no further increase beyond the 2020 level has been assumed.[45] From a decision maker perspective, average abatement costs for electricity generation from renewable energies will remain at about the 2020 level (just above EUR 30/t CO_2e) because of diminishing funding. In fact, some abatement levers will become even more expensive (e.g., electricity generated from biomass, photovoltaics). In contrast, the average abatement costs for biofuels will fall from EUR 175/t CO_2e to about EUR 95 EUR/t CO_2e because of the expected reduction of import tariffs for ethanol.

Based on the continued change in the energy mix already initiated prior to 2020 and further implementation of abatement levers that will be technically mature before 2020, a total of 273 Mt CO_2e can be abated by 2030 in comparison to the current technology projection. The resulting emissions level is expected to be 794 Mt CO_2e in 2030, approimately 22 percent less than the 2004 level (1,025 Mt CO_2e) and 36 percent less than the baseline year level (1,232 Mt CO_2e).

In addition to the levers detailed above, present estimates forecast that CCS technology will have reached a stage of development that allows extensive implementation between 2020 and 2030. If this development is realized as projected,[46] it would generate additional abatement potential of 104 Mt CO_2e[47] in the energy and industrial sectors. If this lever should not be available in the quantity expected, there is currently no foreseeable alternative.[48]

- In the *energy sector*, the introduction of CCS technology will create an abatement potential of 66 Mt CO_2e by 2030. This assumes that after 2020 all new hard coal and lignite power plants and every second gas-fired power plant will be equipped with CCS technology and that about a third of those built between 2005 and 2020 will be retrofitted with this technology. The abatement costs for CCS technology vary between EUR 30 and EUR 50/t CO_2e.[49] The exact level of abatement costs will depend on the technology introduced (e.g., oxyfuel, IGCC), the fuel used, the resulting efficiency loss of the power plants, and the costs for transportation and storage of the CO_2 captured.

44 48 Mt CO_2e, excluding potential of CCS pilot and demonstration facilities in electricity generation (6 Mt CO_2e).
45 Further increase could be possible if additional potential can be opened up worldwide (e.g., by increased use of second-generation methods); however, as the share of imports is already assumed to be two-thirds for 2020 to achieve the share of biofuels of 17 percent of total fuel consumption, no further increase of this volume is assumed.
46 See below p. 51 sq.
47 6 Mt CO_2e from pilot and demonstration projects in electricity generation already announced for 2020 are included.
48 The building of new nuclear power plants is not considered in this study.
49 Up to EUR 90/t CO_2e for gas-fired power plants.

- In the *industrial sectors*, the introduction of CCS technology could generate an abatement potential of 38 Mt CO_2e. About three-quarters (28 Mt CO_2e) come from the steel industry, 7 Mt CO_2e from the cement industry, and 3 Mt CO_2e from the chemical industry (ammonia synthesis). Abatement costs of EUR 45 to EUR 55/t CO_2e (2030) for introducing CCS technology in these industries are higher than those in the energy sector because, on average, smaller quantities have to be captured and transported at almost the same infrastructure costs (capture plants, pipelines).

If all requirements for broad-based introduction of CCS are met, then this lever will reduce greenhouse gas emissions in Germany to a level of 690 Mt CO_2e by 2030. This is a reduction of almost 33 percent compared with the current level (2004) and 44 percent less than 1990.

It is important to note that a unilateral implementation of CCS technology abatement measures in Germany will lead to an immediate loss of international competitiveness for energy-intensive industries such as steel and cement. The implementation of CCS technology in electricity generation alone would cause an increase in electricity costs of EUR 15 to EUR 25/MWh, which would especially affect industries with a high electricity consumption such as non-ferrous metals. The competitiveness of the industries affected would be significantly impaired if these measures are not embedded in an international context.

Prerequisites for Implementation

The political, social, and economic challenges resulting from the implementation of the described levers for abating greenhouse gas emissions in Germany are significant. In order to ensure successful implementation – in particular, of those levers that do in principal pay off for the decision makers – a stable environment for the necessary investments is a critical prerequisite. In addition, for each individual industrial sector, the potential effect of the levers on the industry's competitiveness has to be examined closely within the context of different possible policy frameworks. If the politically induced change in the energy mix is to be implemented, critical preconditions for new technologies have to be put (and remain) in place, particularly for CCS. In addition, the shifts in the use of different sources of energy will have to strike an appropriate balance across all economic and social sectors to ensure security of supply.

A Stable Environment for Investments

In addition to already planned investments, the abatement levers described above will lead to further short-term costs for decision makers in all sectors, even if the additional investments are cost-effective in the medium to long term (e.g., in buildings). Some decision makers – e.g., property owners who are pensioners or public investors who are subject to budgetary constraints – are already hesitating over necessary investments or are delaying them *ad infinitum*. Given this prevailing attitude, investments in measures for greenhouse gas abatement depend even more on a high transparency and reliability of the anticipated returns.

Some important influencing factors such as fuel prices or general business trends cannot be controlled and have to be hedged by appropriate risk strategies. However, two major parameters can be influenced, and their definition is key to ensure that the required investments are actually being made within the regular stock turnover.

- *Transparency of the costs for greenhouse gas emissions:* Especially for energy-intensive industries with high emissions, it is indispensable to have a clear picture of the costs that arise for greenhouse gas emissions. This transparency needs to be created on the amount of free allocations as well as on the possibility of acquiring CO_2 certificates through projects in other regions (e.g., CDM projects). In addition, end users must have clarity on how costs for greenhouse gas emissions affect their expenses (e.g., electricity prices or taxes and duties) and how they can influence these costs themselves (e.g., by reducing their individual fuel consumption or adopting an energy-conscious style of driving).

- *Alignment of investment incentives and investment criteria of decision makers:* Incentive programs to support the abatement of greenhouse gas emissions must be organized so that the duration and level of funding match the investment criteria of decision makers. For large industrial plants, funding for only a few years is just as unattractive as very long amortization periods are for private individuals.

For the abatement levers to be implemented to the extent described here, it is essential that the appropriate investment decisions be made soon – even if payback can be expected only in several years or even decades. The sooner an appropriate and reliable environment for investments can be created, the greater the probability that the targeted abatement potential can be realized by 2020 and 2030, respectively.

Competitiveness of German Companies

The abatement levers described above can be implemented without affecting German wealth and economic growth only if German companies are still able to compete in the international arena.[50]

If a global context for the reduction of greenhouse gas emissions (with comparable costs for greenhouse gas emissions worldwide) was defined, competitiveness would be impaired only depending on the details of national implementation. Thus, for instance, within the European Emissions Trading Scheme (EU ETS), the adverse effects on individual industries and companies are not dependent on the CO_2 price but are determined by the national allocation plans.

As long as reduction of greenhouse gas emissions is not driven globally, there will be clear distortions in competitiveness. A study for the European Commission shows that a significant influence on competitiveness can already be observed in the case of an almost free allocation (90 to 95 percent) of emission certificates and with a CO_2 price of about EUR 20/t CO_2e.[51] Therefore, measures with higher abatement costs can be implemented only in an appropriate global or at least regional context[52] – with the exception of some sectors in which the cost can be passed on (as in some areas of real estate). The specific effect on individual industries would differ:

- *Industries with high process-related emissions* (e.g., cement or steel) are dependent on not being burdened for emissions that remain even after achieving the benchmark level for CO_2 efficiency of their processes. To maintain the international competitiveness of the affected industries in regions of Europe that are easily accessible logistically, even at a price of EUR 20/t CO_2e, extensive free allocations would be required. If by 2020 extensive or indeed full auctioning was introduced within the EU ETS, these industries would no longer be competitive in international markets. An introduction of CCS for process emissions for these industries at a price of EUR 55/t CO_2e would be possible only in a global framework.

- *Industries with high indirect emissions* (such as aluminum and other non-ferrous metals) are dependent on low-cost access to raw materials and energy for their competitiveness. Assuming an increase in electricity costs of EUR 10/MWh (corresponding to a CO_2 price of EUR 20/t CO_2e), the costs for average aluminum production would rise by over 10 percent. Such cost increases are not sustainable over the business cycle because it cannot be assumed that they can be passed on to

50 Besides the abatement costs for greenhouse gas emissions, a multitude of other factors influence the competitiveness of individual industries. The following comments must, therefore, be understood *ceteris paribus*.

51 See "EU ETS Review. Report on International Competitiveness," European Commission/McKinsey/Ecofys, December 2006.

52 This is also true for the transportation sector, where international standards for fuel consumption make an important contribution to the retention of competitiveness of German companies.

the consumer over the long term. The affected industries are heavily dependent on support of their competitiveness, as long as the regulations for greenhouse gas emissions are not embedded in a global system.

The following (simplified) example of the steel industry illustrates the importance of these aspects for the competitiveness of individual industries. The direct cost from implementing all measures for abatement of greenhouse gas emissions in the steel industry up to EUR 20/t CO_2e will total EUR 10 million annually in 2020; if all the possible measures described in this study are considered, the annual costs would be EUR 270 million in 2020.[53] In addition, the costs of the remaining greenhouse gas emissions have to be considered. Assuming that 10 to 20 percent of emission certificates would be auctioned in a trading system at a CO_2 price of EUR 20/t CO_2e, the additional costs would amount to EUR 110 to 220 million; at a price of EUR 50/t CO_2e they would be at EUR 260 to 520 million. For this calculation, an inelastic market behavior is assumed. In addition, the steel industry would have to pay a higher price for electricity. In total, the rise in the electricity price at EUR 20/t CO_2e would lead to extra costs of about EUR 120 million; at a price of EUR 50/t CO_2e, to EUR 300 million. The price of steel production in Germany would increase by up to EUR 10 per metric ton at a CO_2 price of EUR 20/t CO_2e and up to EUR 20 per metric ton at a CO_2 price of EUR 50/t CO_2e. In many product lines, cost increases of this magnitude can not be passed on to end customers and would, in any case, reduce the relative profitability of German companies. This calculation is of course extremely simplified and ignores secondary effects such as elasticity of demand from customers or for emissions. However, the potential result is clear: in the case of a unilateral implementation of the measures described within Germany or within Europe, the cost position of the German steel industry – and, as a result, of the steel processing industries – would no longer be competitive.

The same is true for other energy- and emission-intensive industries in Germany.

Prerequisites for New Technologies

Most of the abatement potential evaluated in this study can be realized by implementing technology that is already known and tested. Nevertheless, after 2020 technologies that are as yet only in a very early stage of development will become relevant, especially those for carbon capture and storage (CCS), for offshore windparks, and for second-generation biofuels. All three technologies are expected to make a substantial contribution to greenhouse gas abatement in Germany between 2020 and 2030 (and in some cases, by 2020). It will not be possible to realize this abatement potential to the expected extent if certain critical prerequisites are not fulfilled.

- *CCS technologies* are still in an early stage of development. Several pilot and demonstration facilities are planned or are currently being built in Germany. However, even these already face major hurdles, especially in the areas of legal structures and public acceptance (e.g., lack of regulations regarding the transportation of CO_2 and long-term storage). Implementation of CCS technologies to the extent described above requires that an amount of 100 Mt CO_2 not only has to be captured annually in Germany by 2030 but also has to be transported to suitable storage facilities and

53 Including the first facilities with CCS (1.4 Mt CO_2e, with costs of EUR 78/t CO_2e) and direct casting (1.2 Mt CO_2e, with costs of EUR 184/t CO_2e).

kept there for long durations. This places high demands on the regulatory system and the creation of a suitable infrastructure. As of today, it is unclear whether all the barriers to implementation can be overcome. Besides the legal conditions, the success of CCS technologies will largely be decided by how quickly they can be deployed at an acceptable cost on an industrial scale. A targeted support for the most promising technologies can make an important contribution by allowing steep learning curves for the new processes that need to be developed.

- Electricity generation in *offshore windparks* faces a particular challenge, as most of the offshore windparks in Germany are planned in much deeper water than the facilities that have been tested (in Scandinavia, for example). The extent and the cost of the technical and operational difficulties that this will cause (e.g., susceptibility of materials, increased risks when servicing, long transportation distances to the mainland) cannot be estimated reliably today. Support schemes to encourage the construction of offshore windparks will have to take this uncertainty into account to ensure that the technology is quickly developed at an industrial level.

- In Germany, *biofuel* is currently produced through conversion of raw materials that are also used in food production (e.g., grain and vegetable oil). Their energy yield per hectare, their relative abatement potential, and their abatement costs are currently not optimal. So-called second-generation processes that use biomass containing lignocellulose as a raw material (e.g., grass, straw, or wood) are currently being developed. If this technology can be successfully brought to the market in a context of appropriate political targets and conditions, it would unlock a global potential that could cover over 30 percent of the total global fuel requirement at low cost and with high relative abatement potentials. Fast-track further development of these technologies is therefore an important condition for the abatement of greenhouse gas emissions, especially in transportation.

Security of Supply and Balanced Use of Different Energy Sources

Implementation of the abatement levers evaluated would reduce Germany's oil imports, especially for transportation. At the same time, the use of natural gas would shift from buildings to electricity generation and the industrial sectors, and the share of biomass in energy supply would increase sharply. The implementation of the appropriate abatement levers must, therefore, be carefully coordinated in order to avoid competition for the use of different energy sources, and the resulting shortages and price increases, and to secure a sustainable energy supply for Germany for the long term.

Germany's security of supply is considered high when the mix of energy sources (especially oil, gas, coal, and biomass), as well as the mix of supplier countries and individual suppliers, is balanced. Germany's oil demand will be reduced by the measures for greenhouse gas abatement. Lignite will continue to be used for generating electricity, based on its local availability, its relative cheapness, and its long-term availability and thus will make a significant contribution to security of supply in Germany. For hard coal (for electricity generation), Germany will continue to be able to draw on deliveries from various regions and suppliers. However, the situation for the supply of natural gas and biomass is different.

Natural Gas

Due to the increasing use of natural gas for central electricity and heat generation, demand for gas will increase from 115 TWh in 2004 to 160 TWh in 2020 and 165 TWh in 2030. Industrial demand for natural gas will rise from 364 TWh in 2004 to 380 TWh in 2020 and 390 TWh in 2030, roughly in line with growth in production (minus efficiency increases). At the same time, natural gas consumption in buildings will drop from 450 TWh in 2004 to 350 TWh in 2020 and 280 TWh in 2030 due to the lower energy demand of renovated and newly built buildings. Thus, implementing all the abatement levers will reduce Germany's total natural gas consumption from 929 TWh in 2004 to 890 TWh in 2020 and 835 TWh in 2030. Most important, by 2030 there will be a significant shift in consuming sectors – away from usage in buildings to usage in the industrial sectors and in electricity generation.

In order to avoid a medium-term increase in demand for gas, it will be necessary to implement the abatement measures in the quantities assumed in this study and at the same speed across sectors. Otherwise, demand for gas could grow, especially if the implementation of abatement levers in the buildings sector is delayed. Additional supplies would have to be imported from traditional supplier countries, primarily Russia. This increased dependency – depending on the volumes required – could substantially weaken Germany's security of supply.

Biomass

After implementation of the abatement levers assessed in this study, biomass will contribute 1,300 PJ (primary energy). This will represent roughly 10 percent of Germany's energy requirements, corresponding to three times its share in 2004. About two-thirds of the biomass would be used as biofuel, one quarter in the energy sector, and the rest in buildings. This growth would require a sharp increase in imports, especially for biofuels.

With the implementation of the abatement levers assessed, about 300 PJ (primary energy) of biomass will be used for electricity generation in 2020. This would generate roughly 36 TWh electricity, equal to about 7 percent of gross electricity generation. It is assumed that the required biomass could come from increased usage of forestry waste products, sawmill by-products, and biogas from liquid manure, straw, harvest waste, grass cuttings, and waste from food production. The currently increasing price for wood could contribute to unlocking unexploited potentials from forestry waste products.

About 175 PJ (primary energy) biomass will be used for heating purposes in buildings. This includes wood and wood-pellet heating systems, stoves, and individual and block combined heat and power facilities (CHP) in smaller communities and in individual houses. While biomass consumption in heating systems and stoves is expected to diminish as demand for space heating recedes, biomass consumption in CHP facilities (wood, biogas, and biofuel) is expected to rise. It is assumed that the resulting demand can also be covered by local resources.

About 825 PJ (primary energy) biomass will be needed in the transportation sector to increase the share of biofuels from 5 percent of total fuel demand today to 17 percent in 2020 (share of final energy). That equates to about 350 PJ (final energy), or an amount of about 13 billion liters per year. Biomass for the production of biofuels will mostly come from renewable raw materials used in agricultural production. Already in 2006, at least 1.6 million hectares, or 10 percent of total agricultural land, was being cultivated for energy crops. Rapeseed for production of biodiesel accounted for most of this. Assuming that food and feed production will remain constant, several studies estimate[54] that by 2020 an additional 0.7 million hectares will be available for cultivating energy crops. Depending on the expected profits, farmers will decide on how to allocate the total 2.3 million hectares between the production of biofuels and biogas. This study assumes that in 2020, with implementation of the abatement levers assessed here, about two-thirds of the area available for the production of renewable raw materials will be used for cultivating energy crops to produce first-generation biofuels. Of the remaining third, half will be used for producing second-generation biofuels, which have a far better yield per hectare than first-generation biofuels, and half for biogas. Thus, local production can cover only a third of the demand for biofuels from the transportation sector.

In order to close the remaining supply gap, about two-thirds of the required biofuel (or the corresponding raw materials) would have to be imported. Imports of ethanol from sugar cane and/or vegetable oil for biofuel play a particularly important role here. On a global scale, there is sufficient unused land available, and export capacity (especially ethanol from Brazil) is currently being expanded. However, the availability of the quantities required by Germany is largely dependent on how ambitiously other states introduce the use of biofuels. Depending on whether supply and demand in the world market remain balanced, supply bottlenecks and/or higher prices could occur. Furthermore – similar to the German situation – sustainability issues could limit the available areas.

In view of the competition between biofuel and biogas in the case of limited overall land available for energy crops, it is questionable whether a significant part of the natural gas that is distributed through the grid and mostly used for heating buildings can be replaced by biogas beyond the assumed quantity.[55]

Even with such a conservative estimate of the availability of local biomass from agriculture, it is possible that the increased ability of energy users to pay (partly caused by regulatory intervention) will lead to stiffer competition with classic material users. For wood, this especially applies to boarding material, cellulose pulp, and, in some product ranges, sawmills. In agricultural biomass (grain, rapeseed, energy crops, straw), stronger demand for biofuel and biogas could lead to price increases for raw material in the food and feed industries, particularly in the context of already foreseeable shortages on a global scale. The change from first- to second-generation biofuel production can reduce this threat.

In as much as local biomass potential can be used for the production of biofuel, security of supply rises. As soon as biofuels have to be imported, security of supply becomes dependent on the liquidity of the global market for biofuel.

54 See "Stoffstromanalyse zur nachhaltigen energetischen Nutzung von Biomasse," Referenzszenario, Öko-Institut, 2004.
55 For biogas to achieve 10 percent of the total gas requirement in all sectors (about 350 PJ final energy), besides fully utilizing the potential of liquid manure, harvest waste, grass cuttings, and non-agricultural waste by-products (sewage sludge, etc.), it would be necessary to cultivate about 1 million hectares with energy corn. Starting with 200,000 hectares in 2006, such an expansion seems problematic

Opportunities for German Businesses

Many levers for greenhouse gas abatement are based on technologies, products, and services for which German companies already offer innovative solutions. Implementing these levers in Germany and exporting the corresponding technology, products, and services can have a positive impact on Germany's economy and employment situation. However, the upside potential will be realized only if the negative impact on the competitiveness of German companies can be mitigated at the same time.

Implementing abatement levers results not only in a reduction of greenhouse gas emissions in Germany and – in many cases – in economic benefits for decision makers (e.g., from measures for energy efficiency in buildings), but often it will also have a positive impact on Germany's overall economy and employment situation. Additional products and services can contribute to new momentum in business activity.

Many German companies are among the market and technology leaders in developing solutions for helping to protect the climate. They have distinct expertise, for example, in plant engineering, electronics, chemicals, and alternative energies. If Germany as a leader in climate protection can develop an international market for German products, these companies can strengthen and extend their global position in products and services for the abatement of greenhouse gases. However, to a large extent, the assessment of export potentials does depend on the energy and climate policies of other countries.

Over the broad range of sectors, some industries will probably benefit more than others from the expected market dynamics. Key examples are:

- *Construction industry:* particularly in the renovation of old buildings, additional revenues can be created from the installation of efficient insulation (for facades and cellar ceilings and in roof areas) as well as the installation of high-quality windows and exterior doors. Furthermore, construction and demolition of power plants along with their maintenance as well as possible extension of transportation infrastructure offer opportunities for the construction industry.

- *Building technology:* the installation of more efficient heating, ventilation, climate control, lighting, and control technology will allow expansion in the businesses of technology suppliers over the long term. Also, suppliers of the appropriate IT systems to steer such technologies will benefit.

- *Electronics:* better energy management often requires complex monitoring and control systems. This applies to buildings as well as to vehicles and industrial facilities. The technical measures for cars and trucks, for instance, include an increasing amount of electronics, especially for engine control units, for comprehensive energy management, and for the various construction stages of hybrid drives. Increasing energy efficiency in household appliances and electric drives also increases the need for innovative electronics.

- *Mechanical and plant engineering:* substantial changes in energy generation (in particular, a higher proportion of wind energy, gas, and biofuels) and transmission and distribution (extension of the grid) require investments of several hundred billion euros in new plants and equipment. In addition, investments for the optimization of industrial processes will also be needed.

- *Vehicle manufacturers and supplier industries:* innovation opportunities exist for manufacturers of automobiles, trains, and planes as well as for their corresponding suppliers. Examples of these opportunities are development of innovative power-trains, further development of vehicle construction (e.g., optimization of the power-train and vehicle as a whole, lightweight construction), or transportation management (e.g., vehicles networks and networking vehicles with the infrastructure).

- *Chemicals industry:* in many solutions for abating greenhouse gas emissions, chemical products provide a significant contribution. Examples include insulation materials for buildings, new organic substances for energy-saving lighting (OLEDs), plant biotechnology for more efficient energy crops, enzymes for the production of biofuels, organic sensors for highly efficient photovoltaics, nanotechnology as a key technology for many uses in energy and materials, materials for fuel cells and other energy storage systems, catalysts for processes and optimization of emissions, and high-performance polymers for weight reduction in vehicles.

- *Non-ferrous metals:* greater energy efficiency in energy conversion and distribution as well as greater energy efficiency in the transportation and buildings sectors are opening up a growing market for non-ferrous metals. The high electrical conductivity of copper, for instance, makes a key contribution to more energy-efficient electrical powertrains. The low specific gravity of aluminum reduces fuel consumption of vehicles. The durability of copper, zinc, and aluminum lengthens the life of low-energy buildings.

- *Steel:* In the development of products for the end-user steel contributes its share to save energy, resources and emissions. The relevant performance criteria for the steel of the future include increased temperature resistance and compressive strength, e.g. for efficiency optimization in power plants, increased durability und creep resistance, and improved characteristics concerning resistance against corrosion and wear. In the automotive industry, the usage of tailored rolled products has can contribute to improved crash attributes and weight reduction compared to the conventional construction. For the usage in electrical systems, steels have been developed that increase the efficiency and reduce losses, e.g. in the transmission of electricity through high voltage lines. In addition, steel continues to fulfill new requirements with regards to health, security and environmental requirements, The end-users of steel can benefit from the innovative activity of the steel producers.

- *Waste management:* assuming an efficient organization of the underlying flow of materials, an increase in the recycling rate, and a resulting increase in the share of secondary raw materials, in many sectors a contribution to energy efficiency could be made.

- *Agriculture and forestry:* German agriculture and forestry is expected to benefit from higher demand for biomass in electricity generation and heating and also for the production of biofuels. The demand anticipated in this study considerably exceeds the supply that German agriculture and forestry can possibly deliver, even if the area cultivated can be increased. Demand-driven price increases for wood and agricultural products are already apparent today.

The described opportunities for German companies resulting from the implementation of levers for greenhouse gas abatement are illustrative examples. Each abatement lever must be analyzed in detail to understand which German companies can benefit from developing which products and services – or which preconditions must be in place first for this to happen.

Appendix: Methodology

The methodology applied in this study is based upon that used for creating a global cost curve for greenhouse gas reduction by McKinsey & Company, Inc. and Vattenfall.[56] This methodology was developed in cooperation with the McKinsey Global Institute (MGI); Professors Robert Socolow, Stephen Pacala, and Robert H. Williams (Princeton University); and Professor Dennis Anderson (Imperial College, London). The methodology used for Germany was further discussed with Professors Martin Hellwig (MPI Bonn), Wolfgang Ströbele (University of Münster), and Carl Christian von Weizsäcker (University of Cologne).

Study Scope

The study considered all greenhouse gases included in the Kyoto Protocol. Besides CO_2, these are CH_4 (methane), N_2O (nitrous oxide), HFC/PFC (chlorofluorocarbons), and SF_6 (sulfur hexafluoride). Non-CO_2 gases were converted to CO_2 equivalents (CO_2e) using the standard relations. So-called LULUCF emissions (emissions from land use, land use change, and forestry) were not considered in the study.

The scope of the investigation includes all the greenhouse gases attributed to Germany in the logic of the Kyoto Protocol reporting. Thus, all emissions from the production of goods and services in Germany are included even if the product is later used or consumed abroad. Excluded are emissions caused by the production of imported products, pre-products, and raw materials. Emissions caused by transportation were considered according to the terms of the Kyoto Protocol reporting, thus only domestic transport was included. International flights, which are responsible for the majority of emissions from air transportation, were not considered.

In principle, the study evaluated all available technical levers for the abatement of greenhouse gas emissions. Behavioral changes that would result in restrictions on quality of life (e.g., reduced consumption, limits in the range of private cars, lower room temperatures) were not part of the assessment. At the same time, it was assumed that all sectors of the German economy would continue to grow as currently forecast. Specifically, this means that beyond present trends no additional relocation of CO_2-intensive production processes abroad were assumed.

Evaluation of the Abatement Levers

More than 300 technical abatement levers were evaluated in the study. According to the participating companies and associations, these levers cover all technical approaches currently discussed that have a medium to high probability of being realized. Abatement levers that would lead to a reduction in quality of life or would fundamentally alter the structure of industry were not evaluated.

56 "A cost curve for greenhouse gas reduction," The McKinsey Quarterly, 2007 Number 1.

A current technology projection (described in detail on p. 25 sqq.) was employed as the starting point for evaluating the abatement levers. The study used 2020 as well as 2030 as the reference years for evaluation of abatement costs and potentials because significant technological developments can be expected in the period between these years, especially in the area of carbon capture and storage (CCS). A further extension of the time horizon was not considered because estimating far-reaching technological developments beyond 2030 entails too much uncertainty. However, additional innovative technologies that allow a further increase in energy efficiency or a further reduction in emissions can be expected between now and 2030.

Each measure was evaluated for its potential to reduce greenhouse gas emissions and its net costs in comparison to the reference technology in the current technology projection.

The *evaluation of abatement potential* was conducted in three stages.

1. Identification of the maximum technical abatement potential while taking into account external limitations, such as technical feasibility, shortage of resources, or normal investment and replacement cycles.

2. Definition of the expected penetration rate under the hypothetical assumption that additional costs of the measure would be offset for the decision maker. Compared to the maximum technical abatement, the penetration was adjusted downward to reflect decision makers' preferences based on non-economic motivations (e.g., refusal to use energy-saving lightbulbs because of special lighting requirements). In general, the assumptions concerning the penetration rate represent ambitious but realistic implementation rates.

3. Consideration of interdependency with other abatement levers (e.g., the increased efficiency of insulation limits the savings potential from more efficient heating).

For the *calculation of abatement costs*, the difference between the costs of the abatement lever and the costs of the respective reference technology was assessed based on a full cost calculation (including operating costs and investments). For new technology, a technology-specific learning rate was assumed that leads to a cost degression in the run-up to 2020 and 2030. Two examples from the transportation sector illustrate this. If improved thermal management could save EUR 5 per vehicle because reduced fuel consumption overcompensates the extra costs in 2020, then a CO_2 reduction of 0.05 t CO_2e – equivalent to 0.2 liter/100 km reduction in consumption, or 5 t CO_2e/km, assuming 10,000 km driven per year – would result in savings of EUR 100/t CO_2e. A gasoline direct injection vehicle, which would generate extra costs of EUR 100 annually for the end customer (in 2020) and a reduction of emissions of 0.2 t CO_2e, would result in abatement costs of EUR 500/t CO_2e.

Abatement costs were calculated from a decision maker perspective and from an economic perspective. In the overarching evaluation of abatement potentials and costs, the differences between the two perspectives are very limited, but the costs of individual levers can vary substantially depending on the perspective used.

- The evaluation of abatement levers from the *decision maker* perspective based calculations on the specific amortization periods (e.g., 4.5 years average ownership period by first buyers of private cars). In addition, the evaluation took into account the interest rate relevant for the decision maker in question (from 4 percent for private households to 9.5 percent for industry). Finally, the industrial or end-user price for energy was also included in the calculation, as were relevant taxes, funding, and promotion programs (e.g., EEG) and current customs tariffs (e.g., for ethanol imports). Changes in willingness to purchase, which could result from implementation of individual abatement levers, were not included. This report shows abatement costs from the perspective of the decision maker, unless expressly stated otherwise.

- The evaluation from an *economic perspective* is based on the economic amortization period and average capital costs (7 percent). Cost savings (e.g., from reduced energy costs) were calculated at the manufacturing cost of the products or services saved. Funding programs, taxes, and transaction costs were not considered in the economic perspective. A separate description of the overall economic perspective is not included in this report, since the attractiveness of the individual abatement lever for the respective investor plays the key role in the implementation of that lever.

Abatement potentials and costs for each sector were consolidated in an abatement cost curve. On this curve, the X axis shows the contribution to the abatement of greenhouse gas emissions made by each abatement lever. On the Y axis, the abatement costs per metric ton of CO_2e for each abatement lever are shown for a particular year. The abatement levers on the left end of the abatement curve (on or below the baseline) have economic benefits over the expected useful lifetime from a decision maker perspective (i.e., they are either cost-neutral or result in a saving). The measures are sorted according to their increasing abatement costs from left to right. Their sequence does not imply that the abatement levers should be implemented in the portrayed order. The abatement levers do not overlap (also for those levers that are mutually exclusive), so that the abatement potential for all levers in the curve can be added together. However, it is not possible to add up the cumulative abatement costs for the various sectors because there are overlaps, due to the fact that the decision maker perspective has been used.

When calculating abatement potentials in the energy sector, the first step was to identify demand for electricity after implementation of all measures to increase efficiency. The abatement levers for greenhouse gas emissions in the energy sector were evaluated based on this reduced demand. Calculation of abatement costs of levers in the energy sector was done in comparison with the respective reference technology or plant that would be replaced through the implementation of that lever. As an example, the development of renewable energies replaces the development of other capacities in the current technology projection.[57] For CCS technology, the reference technology is the specific technology for electricity generation used for that particular energy source (i.e., lignite with CCS replaces lignite with improved power plant technology, etc.).

57 Added capacity in the current technology projection from today to 2020: 42 percent hard coal, 25 percent lignite, 26 percent gas, 7 percent oil and other; from 2020 to 2030: 47 percent hard coal, 31 percent lignite, 20 percent gas, 2 percent oil and other.

The evaluation of measures to increase efficiency of electricity usage in the industrial, buildings, and transportation sectors used average CO_2 intensity of power generation of the added capacity from the current technology projection.[58] Measures that reduce CO_2 intensity in power generation were attributed to the energy sector. Similar effects from power generation by industrial combined heat and power (CHP) plants were also attributed to the energy sector, even though the increased deployment of such plants is being driven by the industry. The abatement potential of heat generation in industry was attributed to that sector.

In relation to the base scenario, an oil high price scenario was also evaluated. In this, the abatement costs of most measures decrease by EUR 10/t CO_2e, to EUR 50/t CO_2e, compared to the respective reference technology. This is because higher oil prices in general result in greater monetary savings from energy efficiency measures. Only an increased use of natural gas in power generation (instead of hard coal or lignite) would generate greater abatement costs in this scenario due to increased gas prices.

Key macroeconomic basic assumptions are summarized in the following table.

Cross-sectoral assumptions

		Assumptions 2010	2020	2030	Source
General assumptions	• Annual GDP growth	1.6%	1.6%	1.6%	Global Insight
	• Population, millions	82.0	80.7	78.5	DESTATIS
	• Discount rates (real)				
	– Energy sector	7%	7%	7%	Working groups
	– Industrial sector	9.5%	9.5%	9.5%	Working groups
	– Commercial	9%	9%	9%	Working groups
	– Individuals	4%	4%	4%	Working groups
Energy prices, real (2005)	• Oil, in USD per barrel*	57	52	59	Annual Energy Outlook 2007 (EIA)
	– High price scenario	63	66	75	EWI/EEFA**
	• Hard coal, in EUR/MWh	7.2	7.6	8.1	EWI/EEFA**
	• Lignite, in EUR/MWh	4.3	4.3	4.3	EWI/EEFA**
	• Natural gas***, in EUR/MWh	20.1	18.8	20.3	EWI/EEFA**
	– High price scenario	22.0	23.0	25.0	EWI/EEFA**

* Exchange rate: 1 EUR = 1.2 USD
** Energiewirtschaftliches Gesamtkonzept 2030
*** Delivery at power plant; based on EIA oil price

Source: Report "Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland" by McKinsey & Company, Inc. on behalf of "BDI initiativ – Wirtschaft für Klimaschutz"

Exhibit 9

58 The average CO_2 intensity of the additional mix of coal and natural gas after own use and grid losses in the current technology projection falls from 0.72 t CO_2e/MWh (2004) to 0.64 t CO_2e/MWh (2020) and then rises to 0.68 t CO_2e/MWh (2030).

Consideration of Secondary Factors

The study delivers a significant contribution to quantifying the economic costs of greenhouse gas abatement in Germany but does not claim to represent a complete quantification of all costs for society. Abatement levers are largely evaluated without considering secondary effects. In particular, the study does not include: the possible impact implementation of abatement levers could have on real income; the effects of higher energy and product prices or of reduced energy demand on consumption; and increased capital commitment resulting from higher investments to reduce greenhouse gas emissions.

These types of secondary economic effects depend heavily on national and international policy, as do effects from redistributions between countries or between governments, industry players, and end users (e.g., the allocation of income from CO_2 trading or CO_2 taxation systems). For these reasons, quantification of secondary effects was not conducted.

Contacts

BDI initiativ – Business for Climate

Joachim Hein
j.hein@bdi.eu

Klaus Mittelbach
k.mittelbach@bdi.eu

Martin Schröder
m.schroeder@bdi.eu

Internet:
www.businessforclimate.eu

McKinsey & Company, Inc.

Leo Birnbaum
leo_birnbaum@mckinsey.com

Anja Hartmann
anja_hartmann@mckinsey.com

Christian Malorny
christian_malorny@mckinsey.com

Jens Riese
jens_riese@mckinsey.com

Thomas Vahlenkamp
thomas_vahlenkamp@mckinsey.com

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Responsible for the content: Thomas Vahlenkamp

Editorial staff: Philipp Beckmann, Leonhard Birnbaum, Philipp Carlsson-Szlezak, Daniela Cornelius, Kalle Greven, Anja Hartmann, Jan-Henrik Hübner, Florian Kühn, Christian Malorny, Clemens Müller-Falcke, Thorsten Parr, Michael Peters, Jens Riese, Thomas Vahlenkamp, Stephan Weyers, Richard Winkelmann