Germany Chapter

pathways to

deep decarbonization

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SciencesPo.

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Preface

The Deep Decarbonization Pathways Project (DDPP) is a collaborative initiative, convened under the auspices of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), to understand and show how individual countries can transition to a low-carbon economy and how the world can meet the internationally agreed target of limiting the increase in global mean surface temperature to less than 2 degrees Celsius (°C). Achieving the 2°C limit will require that global net emissions of greenhouse gases (GHG) approach zero by the second half of the century. This will require a profound transformation of energy systems by mid-century through steep declines in carbon intensity in all sectors of the economy, a transition we call "deep decarbonization."

Currently, the DDPP comprises 15 Country Research Partners composed of leading researchers and research institutions from countries representing 70% of global GHG emissions and different stages of development. Each Country Research Partner has developed pathway analysis for deep decarbonization, taking into account national socio-economic conditions, development aspirations, infrastructure stocks, resource endowments, and other relevant factors. The pathways developed by Country Research Partners formed the basis of the DDPP 2014 report: Pathways to Deep Decarbonization, which was developed for the UN Secretary-General Ban Ki-moon in support of the Climate Leaders' Summit at the United Nations on September 23, 2014. The report can be viewed at deepdecarbonization.org along with all of the country-specific chapters.

This chapter provides a detailed look at a single Country Research Partner's pathway analysis. The focus of this analysis has been to identify technically feasible pathways that are consistent with the objective of limiting the rise in global temperatures below 2°C. In a second—later—stage the Country Research Partner will refine the analysis of the technical potential, and also take a broader perspective by quantifying costs and benefits, estimating national and international finance requirements, mapping out domestic and global policy frameworks, and considering in more detail how the twin objectives of development and deep decarbonization can be met. This comprehensive analysis will form the basis of a report that will be completed in the first half of 2015 and submitted to the French Government, host of the 21st Conference of the Parties (COP-21) of the United Nations Framework Convention on Climate Change (UNFCCC).

We hope that the analysis outlined in this report chapter, and the ongoing analytical work conducted by the Country Research Team, will support national discussions on how to achieve deep decarbonization. Above all, we hope that the findings will be helpful to the Parties of the UNFCCC as they craft a strong agreement on climate change mitigation at the COP-21 in Paris in December 2015.

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1 Country Profile

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1.1 The National Context for Deep Decarbonization and Sustainable Development

In 2010, Germany, one of the largest economies in the world, decided to deeply transform its energy system across all sectors of the economy with the goal of making the system highly efficient, renewable, and safe. This energy transformation, known as the 'Energiewende,' translates notably into the ambitious objective of reducing CO_2-emissions in 2050 by at least 80% compared to 1990 levels (a more ambitious reduction target of 95% being also envisaged), in parallel with a complete phasing out of nuclear energy by 2022 (from its 22% share of 2010 electricity generation).

This transformation of electricity generation sources is therefore a significant challenge, with its substantial diffusion of renewable energy in parallel with the replacement of nuclear energy. Eight nuclear power plants in Germany were shut down in 2011, equaling 8.4 GW and the remaining nuclear power plants still represent 16% of production in 2012. In parallel, installed capacity of renewable energy reached 75.6 GW at the end of 2012, representing 23% of electricity production (where the largest contribution came from wind energy at 8% of total production). Coal-fired power plants still play a dominant role (producing 45% of total generation), and gas power plants produce 12% of total generation.

Beyond these technological changes, the challenge is further complicated by two additional objectives: energy security and energy affordability (especially for the private consumer), which together with climate (and environmental) protection are referred to as the "energy policy triangle of objectives." A crucial aspect of this transformation is the deep diffusion of renewable energy sources, given the objective that they provide 60% of end-use energy consumption and 80% of electricity generation in 2050. Several studies report that Germany does in fact have the potential to reach these goals with renewable energy by relying on a diverse mix of energy sources such as wind power, biomass, and photovoltaic as well as a strong emphasis on energy efficiency. After an initial phase of doubt, the innovative potential of the energy transition is currently accepted by German industry.

Beyond technological innovation and diffusion, current activities associated with the Energiewende focus on implementation of the required new governance structure for this transition, with a concerted effort to integrate a diversity of views on the energy transformation pathways. Specifically, because of Germany's federal system, it was necessary to launch several coordinating bodies to bring together actors from different levels of government. To monitor the transformation, the federal government initiated a new process called 'energy of the future' to constantly assess the implementation of each step towards the final objectives. The second monitoring report was recently published, and it relies on indicators that synthetize the statistical data from various energy sources that were developed to measure the progress and success of the objectives. The primary indicators include:

- Energy supply: primary energy consumption by source; end-use (of 'final') energy consumption by source; gross-power consumption
- Energy efficiency: primary- and end-energy productivity of the economic system
- Renewable energy: share of the renewable energies on the gross-end-energy- and gross-end-power-consumption
- Power plants: share of heat-power-systems on the net-power production
- Grid: investments in networks

The monitoring of the federal government, supported by the inquiries of the commission on the Energiewende, continuously measure the implementation of the energy policies and objectives in these areas.

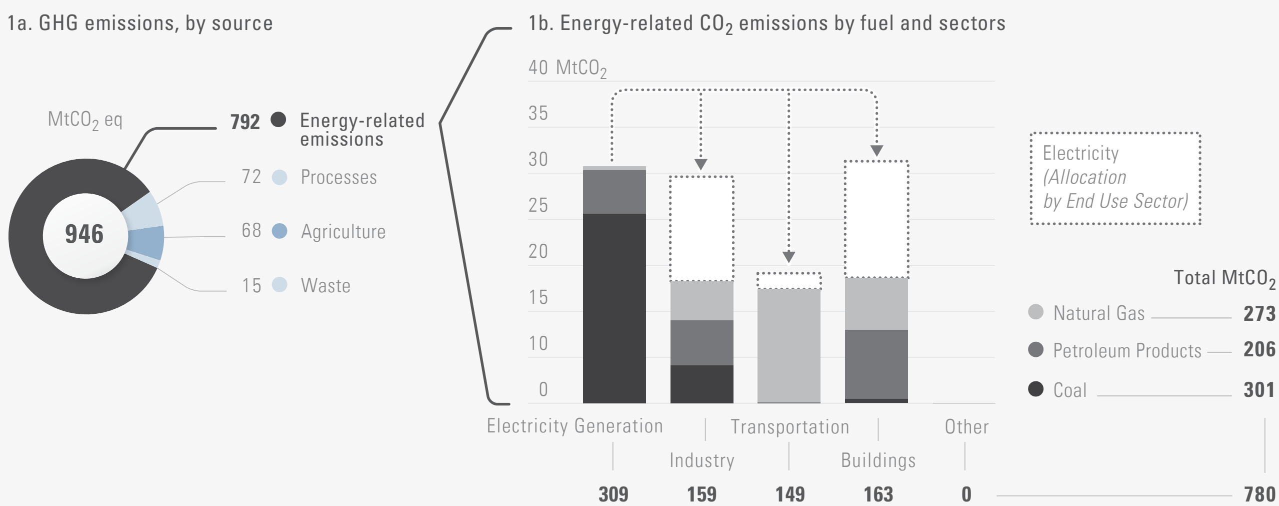
1.2 GHG Emissions: Current Levels, Drivers and Past Trends

The level of GHG-emissions in 2010 was 947 $MtCO_2e$, with energy-related emissions constituting the largest source, followed by industrial and agricultural processes (Figure 1a). Energy-related CO_2 emissions, reaching a high of 9.7 tCO_2/capita in 2010, were dominated by the coal-intensive electricity generation system while the three end-use sectors – industry, transportation and buildings – contribute nearly equal levels of CO_2 emissions, although the structure of fossil fuels is very different among them. Overall, coal is responsible for the largest share of CO_2 emissions, followed by petroleum products and natural gas (Figure 1b).

Since 1990, energy-related CO_2 emissions have decreased despite economic growth due to the combination of the transformation of the East German economy after 1990, a transition away from coal and significant efficiency improvements (Figure 2a). Notably there was a continuous decrease in coal combustion while natural gas increased until the early 2000s and then decreased to the present. These decreases have been possible primarily because of increased reliance on electricity generation from renewable energy resources. However, because of the intermittency of renewable resources such as wind and solar-photovoltaics, fossil power plants are still necessary to provide reliable service.

The largest emissions reductions have occured in the industrial and buildings have been the sectors, primarily from fuel switching and efficiency gains. Electricity emissions have decreased moderately, even as load has grown, due to the decarbonization of generation (Figure 2b). Although energy prices for individual households did increase, it is uncertain whether this led to a behavioral change in energy consumption. Instead, the use of more efficient products is most likely the primary cause of reduced energy use, given that consumers have continued to purchase additional appliances at the same time as they are replacing old less efficient products (the "rebound effect"). In industry, on the contrary, economic savings are a major factor for increasing energy efficiency and decreasing consumption patterns; industry is also the largest consumer of electricity with a share of 43.5%.

Figure 1. Decomposition of GHG and Energy CO_2 Emissions in 2010

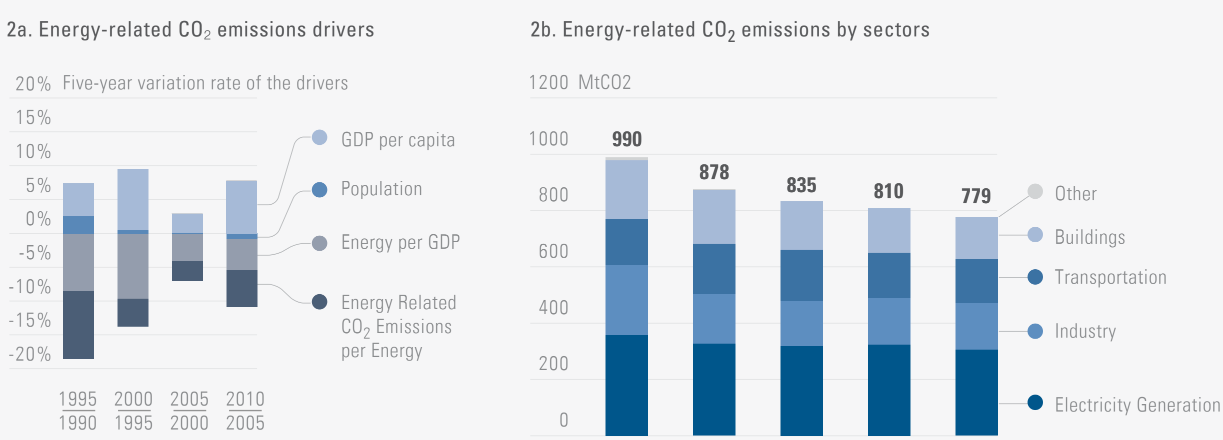


Source:

BMU(2011): "Long-term scenarios and strategies for the deployment of renewable energiesin Germany in view of European and global developments", global report available at: http://www.dlr.de/tt/en/Portaldata/41/Resources/dokumente/institut/system/publications/leitstudie2011_kurz_en_bf.pdf

Based on IEA(2012): IEA, « Energy balances of OECD countries- 2012 edition »

Figure 2. Decomposition of historical energy-related CO_2 Emissions, 1990 to 2010



Source: Based on OECD database (http://stats.oecd.org/)

2 National Pathways to Deep Decarbonization

2.1 Illustrative Deep Decarbonization Pathway

2.1.1 High-level characterization

Forecasts based on demographic trends predict a notable decrease of population between 2010 and 2050, from 81 to 69 million. On the other hand, GDP is expected to see a significant increase, as shown by a doubling of GDP per capita over this time period (Table 1).

For the illustrative deep decarbonization pathway, energy-related CO_2 emissions decrease to 154 $MtCO_2$ in 2050 (2.3 tCO_2/cap), which is attributed to significant change in the structure of energy used with a significant reduction of coal (from 25% of total primary energy in 2010 to 2% in 2050) in parallel with a rapid and strong diffusion of renewables and biomass satisfying more than half of total energy needs in 2050 (Figure 3a). In parallel, a significant decrease of final energy consumption is experienced, from 9.1 EJ in 2010 to 5.2 EJ in 2050, corresponding to a decrease in all end-use sectors (47% in residential, 33% in commercial and 40% in transportation). These trends are accompanied by a rising importance of electricity, heat, and biomass in end-use energy (Figure 3b).

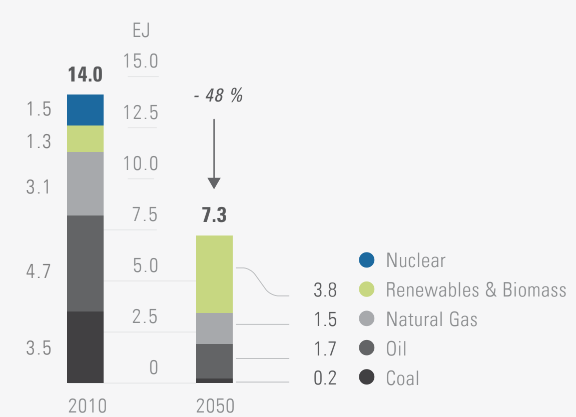
The share of different sectors in energy consumption will largely stay the same until 2050, where (commercial and heavy) industry, private households, and transportation are responsible for 48%, 25%, and 27% of final energy consumption, respectively.

Table 1. The development indicators and energy service demand drivers in Germany

	2010	2020	2030	2040	2050
Population (Million)	81	79	77	73	69
GDP per capita (US $/capita, 2010 value)	27,309	31,949	35,026	43,110	52,217

Figure 3. Energy Pathways, by source

3a. Primary Energy



3b. Final Energy

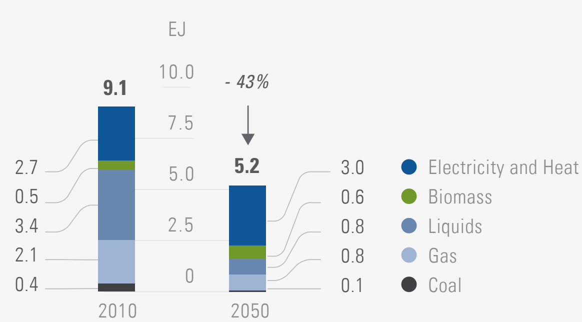


Figure 4a shows that the decarbonization of fuels and energy efficiency are two drivers of equal importance in the overall decrease of CO_2 emissions, as measured by the 68% decrease of the energy intensity of GDP and the 62% decrease of the CO_2 emissions intensity of energy by 2050.

The former effect is triggered by significant improvements in all economic activities, whereas the latter is permitted by the combination of three factors: an end-use fuel switch away from fossil energy sources (see discussion above); a decarbonization of electricity, which sees its carbon intensity dropping to 37 gCO_2/kWh due primarily to increased reliance on renewable energy; and the rise in electrification to displace the combustion of fossil fuels (electrification of end-uses increases to 27% in 2050) (Figure 4b). These two effects are sufficient to ensure a steady decrease of emissions despite continuous economic growth.

All sectors experience a deep reduction of their emissions between 2010 and 2050 (Figure 5), which is achieved without a decrease in individual comfort or economic development and conducted in such a manner that they give positive impulses for the economic development. Emission reductions are particularly important in electricity generation and industry; beyond technological aspects, a key aspect in industry is structural change through a shift away from energy-intensive production.

Figure 5. Energy-related CO_2 Emissions Pathway, by Sector, 2010 to 2050

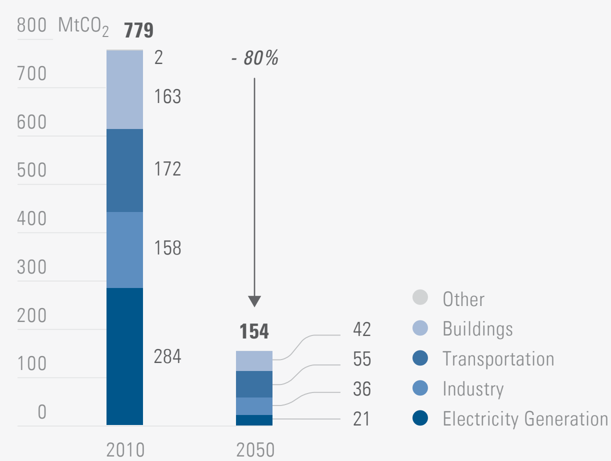
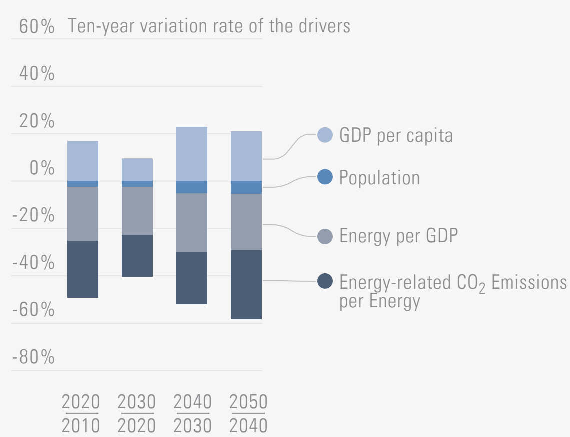
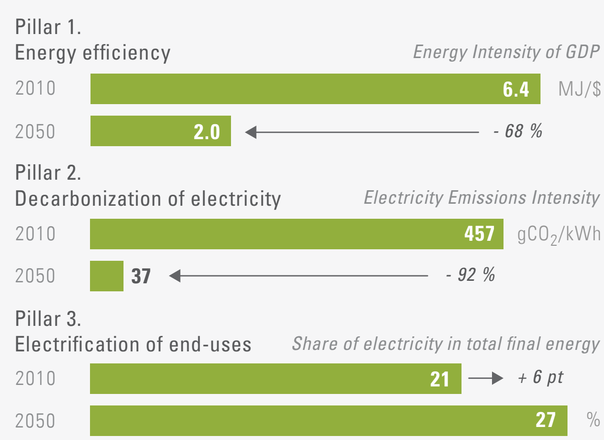


Figure 4. Energy-related CO_2 Emissions Drivers, 2010 to 2050

4a. Energy-related CO_2 emissions drivers



4b. The pillars of decarbonization



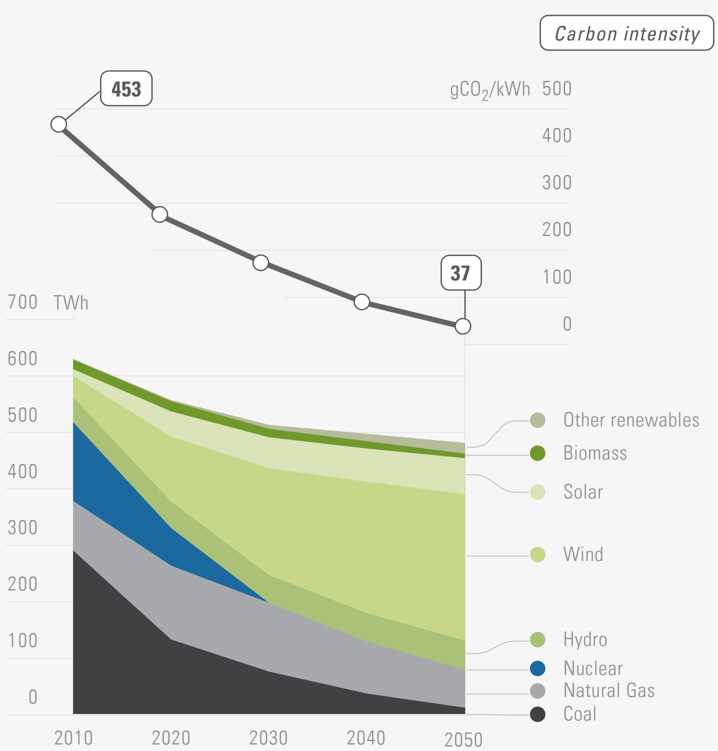
2.1.2 Sectoral trajectories and measures

Power

In the power sector, the transformation envisaged in the illustrative deep decarbonization pathway includes the rapid phasing out of nuclear power (just after 2020) and the long-term closing of almost all coal-fired power stations by 2050. As there is only a moderate decrease in electricity demand during this time period, a substantial amount of new renewable energy is required to serve the load. A majority of the growth comes from onshore and offshore wind, while a smaller but still substantial contribution is made by solar photovoltaics (Figure 6). Conventional power plants fueled by natural gas (at 16% of generation in 2050) are still required to support grid stability due to the intermittent nature of the wind and solar resources. In addition, combined heat and power systems fueled by natural gas will contribute to the electricity generation mix, playing an important role in the near-term by providing 25 percent of generation in 2020.

Note that this is a national-scale vision, and resource availability is not uniform across the country. In particular, in the south of Germany there is insufficient wind and solar resource to support the load, so upgrades to the grid will be needed to support such a high level of penetration.

Figure 6. Energy Supply Pathway for Electricity Generation, by Source



Industry

As part of this decarbonization pathway, the industrial sector experiences the most significant reduction of all end-use sectors (a 77 percent reduction between 2010 and 2050). This is possible due to a substantial decrease in energy demand (a 33 percent reduction between 2010 and 2050) resulting from efficiency gains and a restructuring of industrial processes towards low-energy activities. Additionally, changes in the fuel mix lead to a halving of the carbon intensity of industrial energy, due to a nearly complete phase-out of coal and oil as well as a substitution of electricity for natural gas in activities where it is possible (Figure 7a).

Buildings

The buildings sector (in which private households make up almost 60% of the consumption) experiences a 73% decrease of carbon emissions from 2010 to 2050. To reach this level of decarbonization in a sector with slow stock turnover, existing buildings will be aggressively renovated to new efficiency standards and new buildings will be built with ambitious low-carbon standards. Additionally, fossil fuels are progressively replaced by low-carbon energy sources for heating needs, leading to a significant decrease in the carbon intensity of building energy.

Transportation

Passenger transport represented 71% of total energy consumption from transportation in 2010, and this subsector experiences the most drastic drop in energy needs (a reduction of 55% between 2010 and 2050) due to a transformation in personal mobility. The personal vehicle fleet will see large efficiency gains across all vehicle types, an increase in the use electric and hydrogen-fueled vehicles and a partial modal shift. The increased use of electric vehicles, biofuels, and hydrogen also leads to a significant decrease in carbon intensity of fuels.

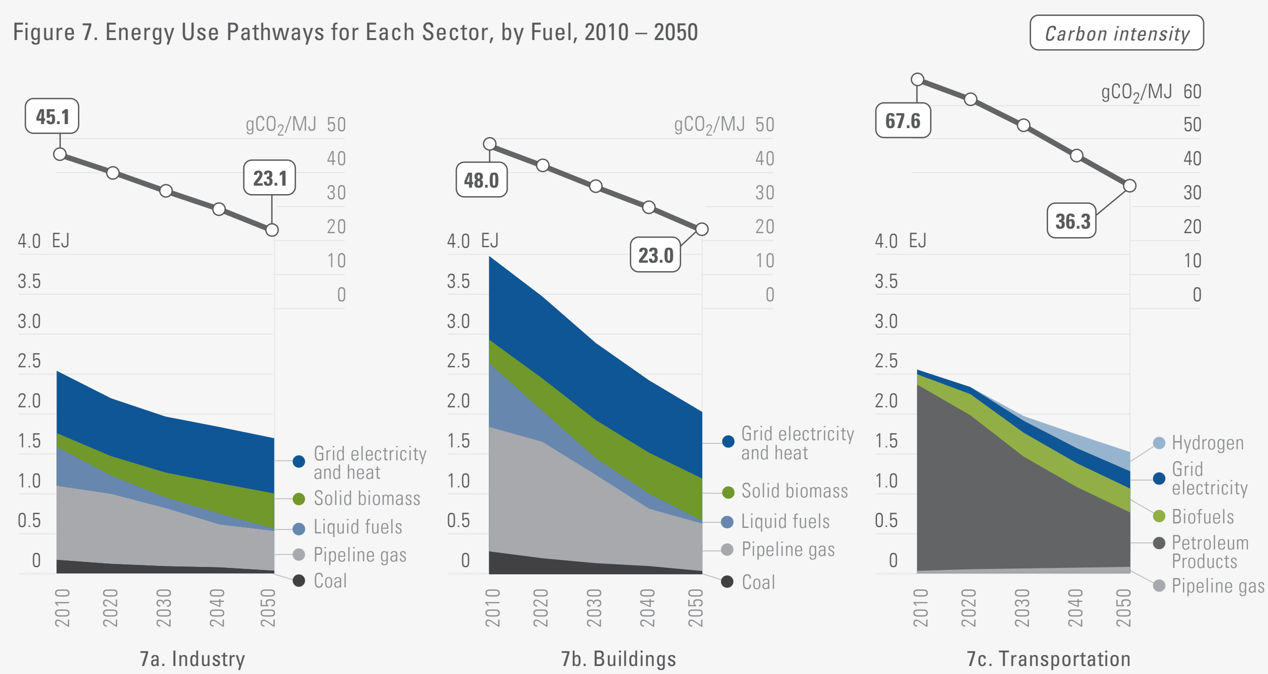
For freight transport, energy demand is expected to increase slightly between 2010 and 2030 before decreasing to 2010 levels by 2050. Given that GDP almost doubles over this period, this represents a significant decoupling of freight transport and economic activity, which is possible though improved truck efficiency and a reorganization of the production and distribution processes. In addition, hydrogen-fueled trucks enter the market and electricity-fueled trains increase in use, all of which contribute to the decarbonization of freight transport.

Also note that biofuels become important for (passenger and freight) air transport, meeting 35% of energy demand for this mode in 2050.

2.2 Technical Options and Assumptions for National Deep Decarbonization

The transformation of the energy sector in Germany is ongoing and many fundamental decisions have already been made in the recent years. A core policy decision, which helps to define the nature of the decarbonization pathway, is the phasing out of nuclear power by 2022. As a result, barring the use of carbon capture and sequestration (CCS), this decision places an emphasis on energy efficiency and a reliance on renewable resources. The long-term plan to substantially develop renewable energy resources is on track given that renewables were the second largest source of energy in Germany in 2012 (at 12.4% of total final energy consumption) and represent 23.6% of electricity generation. However, the decarbonization pathway requires a significantly greater reliance on renewable resources given the expected tripling of installed wind capacity (from 27 GW in 2010 to 82 GW in 2050) and the quadrupling of

Figure 7. Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



solar photovoltaic capacity (from 17 GW in 2010 to 67 GW in 2050). This in turn would require substantial investments (around 3.5 billion euros per year on average from 2010 to 2050) when assuming a significant decrease in costs (44% and 71% decrease in the cost per kWh produced for wind and solar photovoltaic respectively). Given such decreased costs, there will be substantial incentives for innovation and investment. Finally, biomass is expected to play a large role in the plan, reaching approximately 60,000 GWh per year in 2050, requiring significant investments.

Substantial investments are also needed in the transmission and distribution electricity grid, including storage facilities to complement gas-fired power stations needed to help manage the intermittency of renewables and increase the flexibility of the energy system. To achieve these objectives, it will be important that the federal government takes on a coordinating role. Additionally, in order to achieve the long-term objective of a national-scale deployment of renewables, the decarbonization strategy needs to invest significantly in new transmission lines to link the load to the generation, since the highest potential for wind generation is located in the northern part of Germany and significant load is located in the south.

In the buildings sector, the rate for energy-related renovations will need to double in order to achieve the objectives, from 1% annual efficiency improvements at its current rate to 2% per year as needed under deep decarbonization. Although there is no commonly agreed upon definition for the specific required renovations, it is acknowledged that the buildings sector is one of the most important to achieve the overall objectives and that new standards are needed.

The electrification of passenger transportation is also crucial, and current progress must be significantly expanded. The deployment of electric cars depends not only upon national strategies but requires international cooperation, in particular at the European level, to ensure a development of an industry that can undergo fast diffusion in the short-term to realize annual sales of one million electric cars in 2020. Furthermore, there needs to be an increase in the use of public transport instead of cars, especially for commuters, which requires development at the city level (notably in terms of urban infrastructure).

2.3 Alternative Pathways and Pathway Robustness

The robustness of the pathway could be called into question given the fairly high share of intermittent renewables in the electricity mix. In principle, if nuclear power plants were to continue producing electricity beyond 2022, the proposed pathway could accept more modest deployment of wind and solar. However, given the strong political and societal commitment to nuclear phase-out this is a highly unlikely. Another – more acceptable – alternative option would be the deployment of CCS, which is not included in the pathway but could allow for decarbonization with continued use of coal or gas-fired power plants. Other sources of non-intermittent renewables, such as geothermal, could also be investigated, but further analysis of the technical potentials is needed.

The robustness of the pathway may also be questioned by the deep changes in the energy mix in end-use sectors. This is notable in the industrial sector, where technical constraints on the processes may limit the magnitude of overall energy efficiency and of the substitution of fossil fuel by low-carbon energies at the pace supposed in the Illustrative Pathway (fossil energies drop from 62% in 2010 to 33% in 2050 of total end-use). CCS could be a solution employed in the industrial sector, to decrease the magnitude of these effects without additional net CO_2 emissions.

Finally, commuters to cities can be steered away from individual car transport towards shared public transport, reducing the need for long-range electric vehicles. Innovations are urgently needed in urban development for novel transportation solutions.

2.4 Additional Measures and Deeper Pathways

The deployment of CCS in addition to the technologies proposed in the Illustrative Pathway could further decrease emissions from the industrial sector and drive CO_2 emissions close to zero by mitigating emissions from the natural gas-fired power stations. These emissions equal 21 $MtCO_2$, 13% of the total, in 2050, which could therefore be largely abated through sequestration.

Behavioral changes towards lower-carbon lifestyles have not been included extensively in the energy transformation discourse (and therefore in the Illustrative Pathway) although they can significantly change overall energy consumption and provide options for reducing energy needs and carbon emissions (e.g., the use of more efficient products, changes in traffic behavior with switching to public transport or heat and electricity efficiency in private households). Opportunities for behavioral changes need to be investigated, and their implementation would require policy measures to encourage change. An increased focus on behavior would also require social science research to complement natural and engineering sciences research as technical solutions need public support for successful implementation.

2.5 Challenges and Enabling Conditions

On a structural level, a clear framework is urgently needed for all involved actors. Deep decarbonization will be implemented by multiple generations, with the groundwork laid out now. Unambiguous incentives and objectives need to be communicated to foster trust in the development of sustainable energy markets. That also implies stable rules and regulations of investments that are not changed constantly but consistent for the medium-term.

The role of the state is important as long as energy prices do not reflect the true costs (economical and ecological). The current and past system was designed for centralized energy production and predisposes decision makers to believe that decentralized, intermittent renewable technologies will not make business sense. Thus, the state has set some specific incentives to overcome market failures, which must be pursued and adjusted when necessary. A crucial example is the Renewables Energies Act (EEG) guaranteeing the price for power from renewables for the producer hence leading to a massive investment into renewables; reforms of the EEG can be tailored to future needs in the renewables sector in particular to give room for a new holistic design of the electricity market in the medium-term. Another example can be found in the question of storage facilities, for which the coordinating role of the federal government is necessary to articulate technical and institutional aspects. Finally, it must be noted that the European policy making process should be integrated with the national strategy. This is notably the case for industry where European trade certificates are expected to have significant impacts.

On the societal side, several issues need to be discussed and identified as challenges. First of all, the social consequences of the planned energy transformation need to be taken into account, without playing social policy against energy, environmental, and climate policy. It is important to consider the effects of new costs on households and how those costs are distributed across the entire society.

Further challenges are the social acceptance of the planned energy transformation. Although its general concept and, notably, the phasing out of nuclear power still receive support by the citizens, debate continues surrounding the best approach to developing an energy system consistent with the different objectives of the transformation. For example, wind power creates problems in many communities, with citizen initiatives forming against the construction of wind farms in their neighborhood due to aesthetic and health concerns. Similarly, the development of a new electricity transmission system from the north to the south of Germany faces opposition as all planned routes face citizen' initiatives that seek to prevent construction. Some technical options like CCS are currently not considered because of a lack of social acceptance even though there has been no articulation discourse on technology trade-offs.

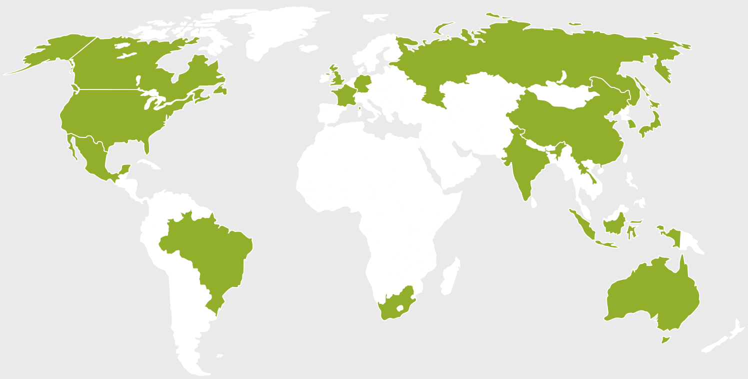
Thus, a challenge is to have citizens participate in the energy transition in an appropriate way. The energy transformation cannot be achieved without including citizens – a lesson nuclear power proponents did not learn. This calls for conducting a wide public debate taking into account all technological options and the interactions between these choices.

In the end, a successful implementation of the energy transformation does also mean that it must be independent of normative worldviews and become an objective for societal development, and for this it must become more self-evident for consumers to be part of it. For example, if consumers of energy become "prosumers," i.e. consumers and producers at the same time (for example through solar photovoltaic), and if the energy generation of prosumers is fed into the system in a transparent way, this might increase the willingness to participate. Current research investigates neighborhood storage facilities that function like a bank, where prosumers pay in and withdraw the electricity they produce/need. However, even ignoring the fact that behavioral changes are often hard to implement through goodwill alone, rebound effects can counteract good intentions. Rebound can occur in many ways, for example, energy saving household goods are often used in parallel with older household goods which they are supposed to replace - thus increasing energy consumption. These questions need to be addressed by social science research in order to change consumption styles and to foster energy efficient behavior.

2.6 Near-Term Priorities

All of the following conditions are necessary for the effective transition of the energy system and call for short-term action:

- Energy efficiency: a crucial near – term priority of the planned energy transition is an increase in energy efficiency, which has to be accelerated a great deal to meet the 2022 objectives. Indeed, final energy intensity per unit of GDP has not met expectations for the years 2008 through 2012, where an annual increase of 2.1% was needed but only 1.1% was achieved. Different instruments must be set in place, including increasing renovation work, regulations, and monetary incentives.
- Increase of renewable energy: flexibility of the energy market plays a pivotal role in the interplay of different generation sources. Continued efforts in research and development and incentives for investing in these energies must be enforced.
- Optimization of the electric generation system: the system needs to be more flexible in order to balance intermittent energy sources. Therefore, a capacity management mechanism and energy storage facilities must been developed in the near-term to facilitate the use of intermittent resources.
- Increase of grid construction: several laws and regulations have been issued to increase the speed of constructing power grids, which must be a high priority for the next decades. Two crucial objectives are to adopt technical solutions permitting the transport of renewable energy from the north to the south, and to reach public agreement, through dialogue, on the best possible routing.
- Buildings: the implementation of higher energy saving standards for new buildings and buildings under major renovation are necessary. To a large degree, action plans rely on a combination of financial instruments, e.g. subsidies, and regulation to foster the retrofitting of privately owned buildings and the implementation of high efficiency standards. The implementation of several EU relevant guidelines is part of the program to increase efficiency, and research in the field of energy efficiency is specifically subsidized.



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