PHASING OUT COAL IN THE GERMAN ENERGY SECTOR

INTERDEPENDENCIES, CHALLENGES AND POTENTIAL SOLUTIONS

IMPRINT

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INTRODUCTION

Dear readers,

The 'Growth, Structural Change and Employment' Commission appointed by the German Federal Government convened for the first time on 26 June 2018. In the first quarter of 2019, it is to submit an action plan to gradually reduce and phase out coal-fired power generation (including a final deadline), and develop proposals for economic, social, structural policy and remediation-related flanking measures. The Commission's mandate specifies the following key tasks as its remit:

- Create specific prospects for new, future-proof jobs in the affected regions,
- Develop a mix of instruments combining economic development, structural change, social acceptability, societal cohesion and climate change mitigation,
- Identify necessary investments in the regions and economic sectors affected by the structural change, which are to be subsidised via a fund that supplements the existing financing instruments and mainly draws on Federal Government resources,
- Formulate measures to reach the 2030 greenhouse gas reduction target for the energy sector, in particular measures related to coal-fired power generation, including a comprehensive impact assessment and
- Formulate measures for the energy industry to contribute to closing the gap to the 2020 target of reducing greenhouse gas emissions by 40% compared to 1990 by as much as possible.

Relevant aspects of the options and requirements for reducing and phasing out coal-fired power generation have been under debate for several years. This process has produced a range of strategies, analyses and arguments, outlining how coal use in the energy sector could be reduced and phased out in the planned time frame, and determining structural policy measures suitable to support this. This Coal Report studies the existing analyses and provides an overview of the state of debate. It is intended to provide information on facts and contexts, present the advantages and disadvantages of individual courses of action, and reveal the respective scientific backgrounds. It strives to take a scientific and independent approach, and present facts in concise language, making it easy to follow for readers who are not experts in the field, without excessive abridgements or provocative statements.

Chapter 1 is dedicated to the relevant energy industry aspects of reduction and prospective phase out of coal-fired power generation. Starting with the description of the existing coal-fired power plants and lignite open-cast mines, it incorporates an overview of the cost structures and pricing, and addresses the implications of coal-fired power generation for profitability of gas-fired power plants and risks of future grid bottlenecks. It closes with a presentation of the current regulatory framework for plant closure, focusing on guaranteeing security of supply and the duties of transmission system operators and the Federal Network Agency (BNetzA) for monitoring system security to avoid potential critical situations and determine intervention options.

Chapter 2 presents the climate policy framework relevant for the use of coal in the energy sector. It outlines the consequences of climate change, the Paris climate targets and international trends in use of coal, and derives cornerstones for reducing coal-fired power generation in Germany.

Chapter 3 gives an overview of the technical aspects of an energy supply without coal. It covers requirements like increased flexibility and energy efficiency, expanding renewable energies and electricity grids, using natural gas as a bridge technology and the role of storage systems. It also presents the scope and potential solutions to ensure that electricity and heat can be securely supplied at all times.

Chapter 4 considers the transformation costs of phasing out coal. Based on an overview of the local economies in lignite regions it points out employment effects and options for successful structural change. It also details the impact of the transformation on the electricity wholesale price and on the costs of remediating open-cast mines.

The final chapter, Chapter 5, describes potential policy instruments to reduce coal use in the energy sector.

The Report is supplemented with a list of coal-fired power plants, which provides both technical specifications as well as details of the CO_2-emissions of all German lignite and hard coal-fired power plants with electrical outputs of over 50 MW.

The energy transition process is a complex, challenging transformation. Based on many questions and problems, the information currently available presents us with a series of clearly defined jigsaw pieces, which we can combine in a variety of ways. We hope that the 'Coal Report' will contribute to a transparent presentation of the available options and their implications, to promote an evidence-based discussion on reduction and phase-out of coal-fired power generation. In this light, we hope you find it an informative and interesting read.

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1 ENERGY ECONOMICS

Summary

In Germany, roughly 21 GW of net nominal capacity from lignite and approx. 24 GW from hard coal-fired power plants were in operation at the end of August 2018. In 2017, lignite accounted for 23% and hard coal for 14% of gross power generation. As a result, the question of the importance of lignite and hard coal for security of supply is at the centre of the debate on reducing coal-fired power generation. However, recent developments on the German electricity market include drops in electricity prices to the disadvantage of gas-fired power plants, as a result of growth in renewable energy. This suggests that a reduction and phase-out of coal-fired power generation is not only essential for climate policy, but also makes sense with a view to the electricity market.

In order to highlight the background and implications of the current debate for the electricity market, this section firstly describes the existing coal-fired power plants and open-cast mine structures (Chapter 1.1). This is followed by a description of the cost structure for coal-fired power generation (Chapter 1.2) and a description of pricing and competition on the electricity market (Chapter 1.3). Subsequently economic arguments for a reduction of coal-fired power generation are presented (Chapter 1.4). The final section describes the current regulatory framework on power plant closures and monitoring system security (Chapter 1.5).

COAL-FIRED POWER PLANTS AND COST STRUCTURES

The German lignite-fired power plants and lignite open-cast mines are concentrated in the Rhineland, Lusatian and Central German coalfields. By contrast, hard coal-fired power plants are widespread throughout Germany, but most are situated in Western Germany. The average age of coal-fired power plants is 30 to 35. Due to their fuel and firing-specific properties, coal-fired power plants have significantly lower efficiencies and higher emissions than natural gas-fired power plants. Combined heat and power generation plants based on coal – generally hard coal – are achieving an overall efficiency of 85 to 90%.

Most hard coal and gas-fired power plants currently cannot compete with the low costs of lignite. As a result, many hard coal-fired power plants are making losses or can only cover their operating costs with additional revenues from the heating sector. Compared with hard coal, modern combined-cycle power plants (gas and steam power plants) often have lower costs, but costs are still significantly higher than the costs of lignite-fired power plans. As a result, gas-fired power plants are rarely used in spite of their relatively high flexibility and low CO_2 emissions.

The high utilisation rate of lignite means that most lignite-fired power plants can cover their ongoing operating costs. However, if additional investments are necessary the associated costs may exceed the slim profits that can be achieved with the expectable low wholesale prices. Integration of power plants and open-cast mines makes the cost structure of lignite unique. As all power plants and open-cast mines in a lignite coalfield are generally interconnected, individual coalfield sections can be operated or closed without affecting continued operation of the others.

PRICING ON THE ELECTRICITY MARKET AND COMPETITION BETWEEN COAL AND NATURAL GAS

Electricity pricing on the spot market is based on a system known as merit order. All participants on the electricity market offer electricity at least at their marginal costs. These marginal costs are generally based on the variable power generation costs. Power is purchased from the plants in the order of their bids, until demand is covered in full. The electricity wholesale price is calculated based on the costs of the most expensive power plant required to meet demand at a given point in time.

In Germany, the merit order is typically topped by renewable energy sources, followed by nuclear power and fossil energy sources. Besides the efficiency of a power plant, the competitive situation

between the fossil energy sources depends largely on the raw material prices and the European emissions trading CO_2 certificate price (see also Chapter 5.1). If there is a long-term increase in the CO_2 price to approx. 20 to 50 euros/t CO_2, it is assumed that operating lignite-fired power plants will be more expensive than other fossil fuels.

ENERGY-ECONOMIC ARGUMENTS FOR A REDUCTION IN COAL-FIRED POWER GENERATION

Due to their high flexibility combined with low CO_2 intensity, gas-fired power plants supplement fluctuating renewable energy sources ideally for a transitional period (see Chapter 3.3). Conversely, lignite-fired power plants and older hard coal-fired power plants can only adapt to fluctuating power generation from wind and solar energy to a limited extent. While existing coal-fired plants could operate more flexibly, this causes greater material wear and thus leads to higher costs. However, gas-fired power plants in Germany currently suffer from a low capacity utilisation of approx. 30%, which is why many plants have already been shut down. Hard coal and lignite-fired power plants have capacity utilisations of approx. 40% and 75%, respectively.

The current high level of electricity exports from Germany, much of it electricity from coal, also reduce utilisation of gas-fired power plants in neighbouring countries. If coal is phased out in Germany, the utilisation of national and international gas-fired power plants, and thus their profitability, would increase.

The slight increase in the electricity wholesale price caused by a coal phase-out would also incentivise necessary investments in demand management as well as storage and efficiency technologies. Greater price spreads and peak prices can also stimulate investments in the development and use of power-to-X applications, synthetic fuels and various battery technologies as well as energy efficiency measures. Migration of the most energy-intensive industries out of Germany is unlikely, as changes in the electricity wholesale prices are expected to be minor (see Chapter 4.4).

In addition, reducing coal-fired power generation can also limit the strain on the grid situation in Germany, in particular in areas where a high continuous supply from coal-fired power plants currently coincides with a significant supply from renewable sources. The lack of flexibility of lignite plants in particular (conventional minimum generation) places a strain on the electricity grid. Accordingly, reducing electricity generation from these plants can help alleviate grid bottlenecks. Studies submitted to date on the development of the electricity trade balance show that a full coal phase-out by 2030 would make Germany at most a minor net importer.

MONITORING TO ENSURE SECURITY OF SUPPLY

Germany has a comprehensive regulatory framework to guarantee security of supply and ensure that power plant closures do not endanger it. Planned power plant closures must be announced to the Federal Network Agency (BNetzA) 12 months before the planned shutdown date. The responsible transmission system operator (TSO) then assesses the system relevance of the power plant. If it is system-relevant, the power plant must be kept available for power generation, and the costs will be reimbursed to the operator.

In addition, Germany maintains various reserves and load management options with a total capacity of 11.3 GW. Moreover, TSOs are required to analyse the power supply system annually, by investigating potential critical threshold situations. The TSO or BNetzA can create additional guaranteed capacity by transitioning power plants to a reserve, or building power plants as technical grid equipment. Cross-border interconnectors can be expanded to other European countries as a further option.

1.1 COAL-FIRED POWER PLANTS AND OPEN-CAST MINES

» **In Germany, 21 GW of lignite-fired and 24 GW of hard coal-fired power plants are operational (net rated capacity).**

» **Due to their integration with open-cast mines, lignite-fired power plants are highly concentrated in specific regions. They are located in the Rhineland, Lusatian and Central German coalfields. Hard coal-fired power plants are geographically widespread, in particular in the states of former West Germany.**

» **Currently, closures of roughly 5.6 GW have been announced to the Federal Network Agency (3.8 GW of hard coal and 1.8 GW of lignite (as part of the lignite security reserve)).**

In 2017, coal-fired power plants accounted for 37% of gross power generation.

Coal-fired power plants are responsible for 26% of all German CO_2 emissions.

23.8 GW of hard coal generation capacities are installed in Germany. Of that, 23 GW are made up of 55 large-scale plants (>100 MW) and 0.8 GW of 27 smaller plants (<100 MW). The 20.5 GW of lignite-fired power plants can be broken down into 20 GW and 38 large-scale plants and 0.5 GW in 6 smaller plants.

At the end of July 2018, lignite-fired power plants totalling approx. 21 GW, and hard coal-fired power plants totalling approx. 24 GW were operational in Germany. In 2017, lignite accounted for 23% of the gross power generation and hard coal made up 14% (approx. 150 TWh from lignite and approx. 90 TWh of hard coal) (AG Energiebilanzen e.V. 2018). The locations of German coal-fired power plants are shown in Fig. 1.1.1. At the same time, they are responsible for 153 million t CO_2 (lignite) and 87 million t CO_2 (hard coal). That corresponds to approx. 26% of the German CO_2 emissions in 2016 (UBA 2017a, 2018a). Coal-fired power plants also emitted other pollutants like sulphur oxides, nitrogen oxides, soot and dust, as well as toxic metals like mercury, lead, arsenic and cadmium (UBA 2017a), which are harmful to humans and contaminate the air, soil and water (SRU 2017) (see Chapter 4.4).

Tab. 1.1.1: Number and capacity of the operational lignite and hard coal-fired power plants (public supply and industrial power plants)

		Total		small plants* > 50 MW & < 100 MW		Large plants > 100 MW	
		Number	Capacity [GW]	Number	Capacity [GW]	Number	Capacity [GW]
Hard coal		67	23.8	12	0.8	55	23.0
Active power plants	Commissioned before 1990	40	11.3	10	0.6	30	10.7
	Commissioned after 1990	15	8.6	1	0.1	14	8.6
In the grid reserve		7	2.3	1	0.1	6	2.2
Scheduled for closure		5	1.5	0	0	5	1.5
Lignite		44	20.5	6	0.5	38	20.0
Active power plants	Commissioned before 1990	21	8.7	2	0.1	19	8.6
	Commissioned after 1990	15	9.0	4	0.3	11	8.7
Security reserve	Already transitioned	3	0.9	0	0	3	0.9
	To be transitioned	5	1.8	0	0	5	1.8
Total of lignite and hard coal		111	44.2	18	1.3	93	43.0

Sources: Own compilation based on BNetzA (2018a) and Tab. 1.1.2.

***Note:** Additionally, coal-fired power plants with an installed capacity of less than < 50 MW exist in Germany. These hard coal-fired power plants have a total output of 0.4 GW (15 power plant units), the corresponding lignite-fired power plants add up to 0.4 GW (15 power plant units). Due to rounding, some totals may not be accurate.

Fig. 1.1. 1. Locations of coal-fired power plants in Germany

Source: Own compilation based on BNetzA (2018a, 2018c) and Tab. 1.1.2

Lignite-fired power plants

Due to their integration with open-cast mines, lignite-fired power plants are highly concentrated in specific regions. In Germany, they are concentrated primarily in the Rhineland coalfields (10 GW). The Central German coalfields also feature 3 GW and the Lusatian coalfields have 7 GW of lignite capacity. In autumn 2016, lignite extraction in the Helmstedt coalfields ended after over 140 years. At 79 TWh_{el}, the Rhineland coalfields also generate more electricity than the Lusatian (49 TWh_{el}) and Central German coalfields (17 TWh_{el}) (data from 2015). As of the end of 2015, the lignite reserves in the approved lignite plans were 4.2 billion t (DIW Berlin et al. 2018). Furthermore, the economically attainable reserves, which have not been approved yet, add up to a further 36.3 billion t of lignite (Öko-Institut 2017b).

The lignite industry in Germany is spread over the Rhineland, Lusatian and Central German coalfields.

The lignite open-cast mines and power plants in the Rhineland coalfields are operated by RWE. In the Federal States of former East Germany, Czech company EPH (Energetický a průmyslový holding) operates LEAG (Lausitz Energie Bergbau AG), Mibrag (Mitteldeutsche Braunkohlengesellschaft mbH) and Saale Energie via various subsidiaries, which own all open-cast mines and most of the power plants (DIW Berlin 2017c).

The lignite-fired power plants are almost entirely owned by RWE and EPH. EnBW and Uniper only have holdings in Lippendorf and Schkopau.

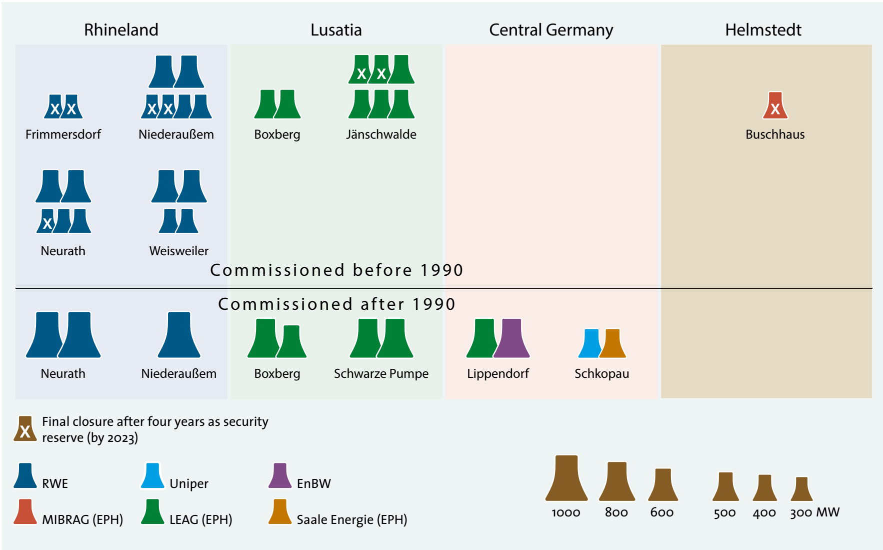
Lignite-fired power plants in Germany differ significantly in their age and efficiency structure (see also Fig. 1.1.2). The average age of lignite-fired power plants is roughly 35 years (UBA (2017a).

Roughly half of the lignite capacities was built before 1990, and has low efficiencies.

There is a clear divide between the former Eastern Federal States and those in the West. While all power plant blocks in North Rhine-Westphalia, with the exception of the three new blocks in Neurath and Niederaußem, were built before 1976, modernised plants have been in use in the former Eastern Federal States since the reunification. On average, the power plants in the former Eastern Federal States are therefore more modern and efficient than those in North Rhine-Westphalia. Modern power plants have efficiencies between approx. 43% and can also operate more flexibly than older power plants (UBA 2017a). In 1990, the average efficiencies were approx. 34% (UBA 2017e). Fig. 1.1.2 shows all lignite-fired power plants with an electrical capacity of at least 100 MW. The cumulative CO_2 emissions of power plants under 100 MW are to be evaluated as minor (see. Annex, Tab. 1).

Fig. 1.1.2: Structure of lignite coal-fired power plants in Germany

On average, lignite-fired power plants in former Eastern Federal States are more modern and efficient than those in North Rhine-Westphalia.



Source: Own compilation based on BNetzA (2018a); Öko-Institut (2017b)

Hard coal-fired power plants and extraction

The operators and locations of hard coal-fired power plants are more diverse than for lignite.

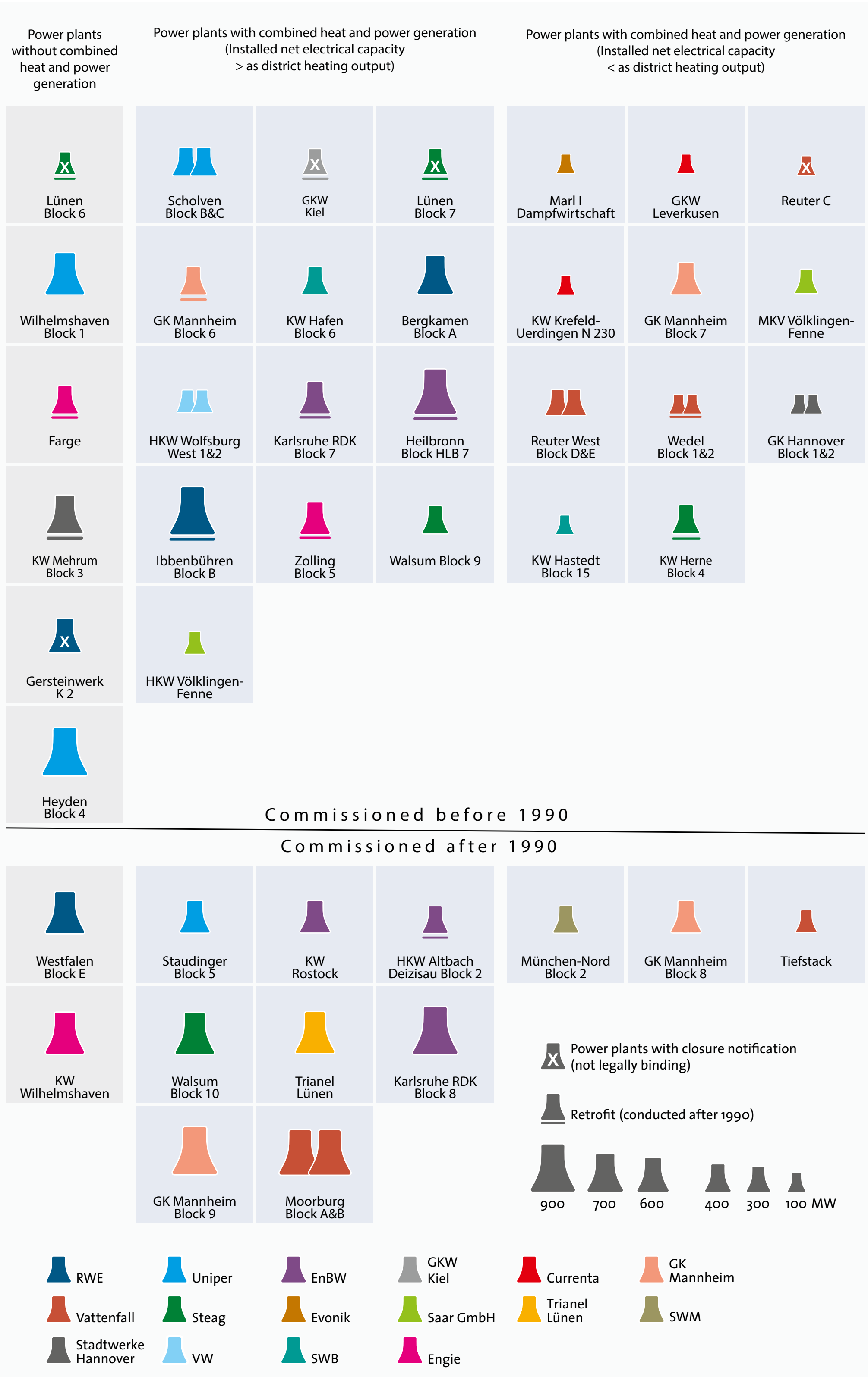
The locations of the hard coal-fired power plants are spread throughout Germany, and have many different operators. Having developed historically, they are concentrated in the former hard coal mining regions in North Rhine-Westphalia and the Saar coalfields and, due to deliveries of imported coal, along the river Rhine and on the North Sea coast.

As early as 2007, the national and state governments, and the mining companies decided to phase out hard coal mining for economic reasons at the end of 2018. At this time, about 30,000 employees were still working in eight coal mines (coal industry statistics 2017a, 2017c). The two remaining hard coal mines are Ibbenbüren and Prosper-Haniel (DIW Berlin et al. 2018). Germany has overall hard coal resources of roughly 83 million t, of which approx. 12 million t can be extracted by the end of 2018. In 2015, 55.5 million t of hard coal was imported. Roughly one third of imports come from Russia, followed by imports from the USA, Colombia, Australia, Poland and South Africa (UBA 2017a).

The average age of the hard coal-fired power plant fleet is approx. 30 years.

Hard coal-fired power plants in Germany differ significantly in their age and efficiency structure, too (see Fig. 1.1.3). The average age of hard coal-fired power plants is approx. 30 years (UBA 2017a). Older power plants like Wedel or Lünen have an efficiency of just 36%; by contrast, modern power plant blocks like block 9 in Mannheim achieve values of 46%.

Fig. 1.1.3: Structure of hard coal-fired power plants in Germany



The power plants are ordered by age from left to right and from top to bottom in each category, starting with the oldest at the top left. The date of initial construction, not the retrofit date is the determining factor.

Source: Own compilation based on BNetzA (2018a). The plants are broken down by categories based on the age and CHP use according to the BNetzA list, the district heating output according to the UBA power plant list and assumptions for scheduled closure as in the closure table 1.1.2. The retrofits described refer to essential repairs to the plants (e.g. boiler or turbine exchange); no sufficient public data is known for a more detailed distinction between the various retrofits, e.g. based on the percentage additional investment.

Utilisation of heat from combined heat and power generation plays an important role for hard coal-fired power plants.

Most hard coal-fired power plants are located near conurbations and produce heat in addition to electricity (known as combined heat and power, [CHP]; see Fig. 1.1.1 and Fig. 1.1.3). As a result, CHP plants can achieve a fuel utilisation rate of 85 to 90% (see Chapter 3.6). However, electricity is the more important output for most of the plants; the additional district heat capacity is lower than the installed electrical capacity.

Coal-fired power plant blocks under construction and in the planning

It is not clear whether and when new coal-fired power plants will be connected to the grid in Germany.

The Datteln 4 hard coal-fired power plant block (1.1 GW), which was originally to be commissioned in 2011, has not been connected to the grid yet. Construction was delayed due to many (environmental) objections, as well as technical problems caused by an innovative steel (T24), which was to permit higher temperatures and thus efficiencies. It is not clear when the block is to be connected to the grid; the current target is 2020.

In addition to this, a hard coal-fired power plant project is currently being planned for an industrial park in Stade (900 MW). According to the operator, the actual decision on whether it will be built will be made in 2019. Since the early 2010s, there have also been plans to build a new lignite-fired power plant with optimised plant technology (BoAplus) (1.2 GW) located in Niederaußem.

Closed coal-fired power plants and planned power plant closures

Since 2010, 10.6 GW of coal-fired power plant capacities were shut down by operators. In addition, lignite-fired power plants with a capacity of 900 MW were transitioned to the security reserve.

Under the current conditions on the electricity market with lower electricity prices, more and more operators are deciding to shut down their power plants before the end of the technically possible operating period has been reached. Since 2011, 51 coal blocks, with a total rated electrical capacity of 10,600 MW, have been shut down for good. In addition, 3 lignite blocks with 900 MW have been transitioned to the security reserve and four more coal blocks with another total of 300 MW have been shut down on a preliminary basis (BMWi 2018b).

By 2020, a total of 2.7 GW of lignite-fired power plants will initially be transitioned to the security reserve, and then taken from the market.
3.8 GW of hard coal-fired power plants have notified their intentions to shut down to the Federal Network Agency.

Within the next two years, another approx. 3.8 GW of hard coal-fired power plants could be disconnected from the grid. The closures have been announced to BNetzA, but can still be revoked by the operators or rejected also on a preliminary basis by BNetzA. In addition to this, a total of 2.7 GW of lignite-fired power plants are being gradually transitioned to what is known as the 'lignite security reserve' between 2016 and 2019 (see Chapter 5.3). This means that they cease regular production and are only kept on the grid as a reserve for a further four years. Tab. 1.1.2 lists the currently planned closures.

Lignite open-cast mine structures

In the Rhineland coalfields, all power plants and open-cast mines are connected. The only exception is the Weisweiler power plant, with the adjacent Inden open-cast mine.

A unique characteristic of the lignite industry is the link between open-cast mines and power plants. Coal from the open-cast mines is transported within the coalfields to the connected power plants via conveyor belts, railway lines, coal mixing and storage facilities. Various local interim storage sites guarantee continuous operation. However, due to the risk of self-combustion, the coal is not buffered/stored for extended periods.

The Rhineland coalfields (Fig. 1.1.4) comprises the Garzweiler and Hambach open-cast mines, which supply in particular the Neurath, Niederaußem and Frimmersdorf power plants (the last is part of the lignite security reserve) and smaller power plants like Fortuna-Nord, Frechen, Ville-Berrenrath, Goldenberg and Merkenich via railways (Gerbaulet et al. 2012). That makes the open-cast mining operations technically independent of continued operation of specific power plants. The Weisweiler power plant is supplied exclusively by the Inden open-cast mine (DIW Berlin et al. 2018).

Tab. 1.1.2: Scheduled* power plant closure and power plants in the grid reserve until 2020 incl. addition to the security reserve

Energy source	Location	Block	Closure	Net capacity (MW)	Age
Hard coal	Lünen	Lünen 6	31/12/2018	149	56
Hard coal	Lünen	Lünen 7	31/12/2018	324	49
Hard coal	Kiel		2019	323	48
Hard coal	Reuter	Reuter C	2019	124	49
Hard coal	Gersteinwerk	K2	2019	614	34
Hard coal	Weiher	Weiher III	Grid reserve, earliest closure 2019	655	42
Hard coal	Walheim	WAL1	Grid reserve until 31 March 2020 at the latest	96	54
Hard coal	Walheim	WAL2	Grid reserve until 31 March 2020 at the latest	148	51
Hard coal	Heilbronn	HLB 5	Grid reserve until 31 March 2020 at the latest	125	53
Hard coal	Heilbronn	HLB 6	Grid reserve until 31 March 2020 at the latest	125	52
Hard coal	Altbach/Deizisau	Alt HKW 1	Grid reserve until 31 March 2020 at the latest	433	33
Hard coal	Bexbach	BEX	Grid reserve, earliest closure 2019	726	35
Security reserve plants					
Lignite	Buschhaus		30/09/2020	352	33
Lignite	Frimmersdorf	P	30/09/2021	284	52
Lignite	Frimmersdorf	Q	30/09/2021	278	48
Lignite	Niederaußem	E	30/09/2022	295	48
Lignite	Niederaußem	F	30/09/2023	299	47
Lignite	Neurath	C	30/09/2022	292	45
Lignite	Jänschwalde	F	30/09/2022	465	29
Lignite	Jänschwalde	E	30/09/2023	465	31
			Total	**6572**	

Source: Own compilation based on BNetzA (2018d), (2018c); Steag (2018a); Uniper (2018); Mark-E (2018); Ruhrnachrichten (2018); Wuppertaler Rundschau (2018); S&P Global Platts (2018); Vattenfall (2015); Steag (2018b); Power plants > 50MW

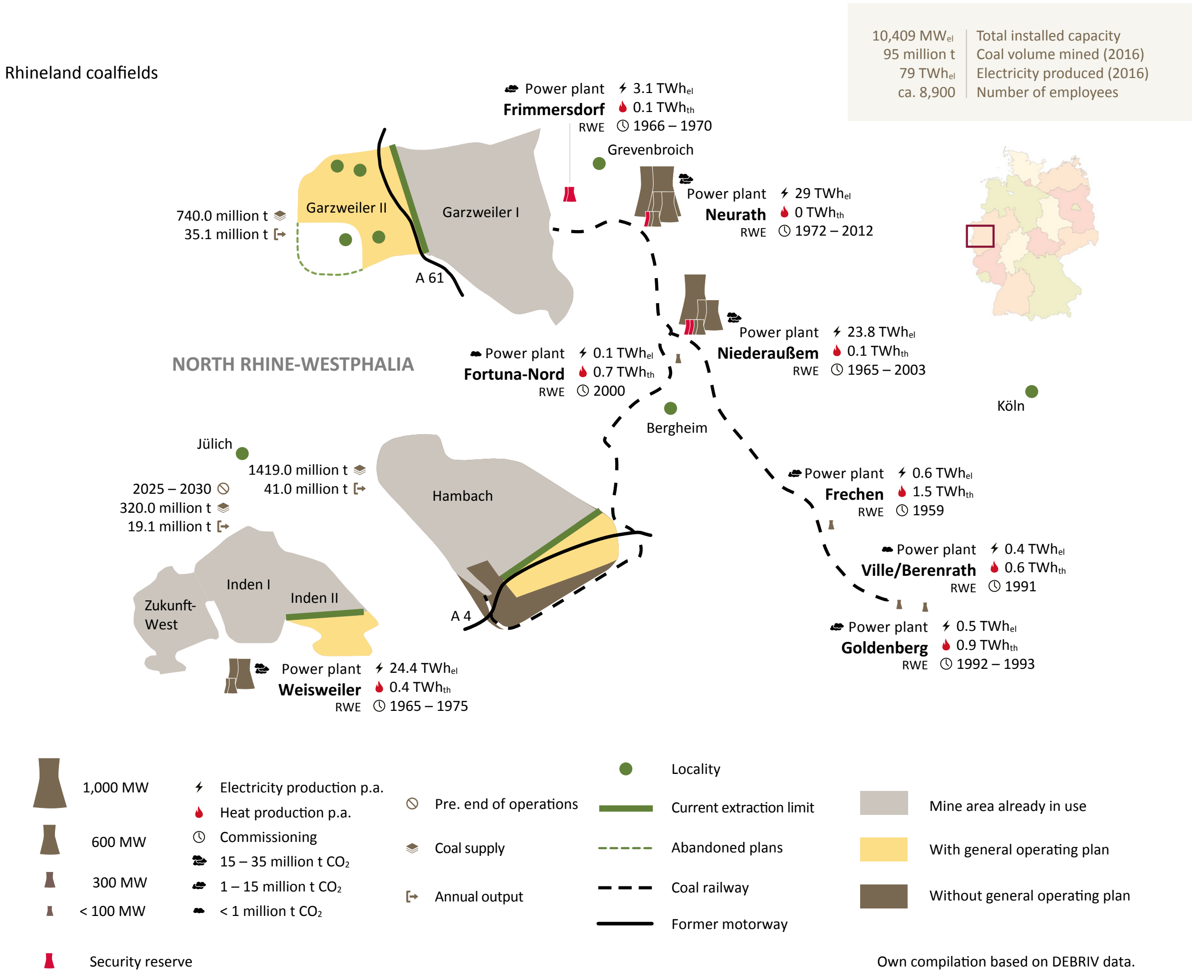
Notes:* Scheduled means that the operators have notified BNetzA of their intention to shut down. However, closure is not legally binding and can also be withdrawn by the operators. The following power plants still slated for closure in the BNetzA closure list have already been shut down according to local newspaper reports: Kraftwerk Werdohl-Elverlingsen (310 MW), HKW Elberfeld (Wuppertal; 85 MW), Kraftwerk Ensdorf (389 MW), HKW I in Duisburg (95 MW) (Westfalenpost 2018; Westdeutsche Zeitung 2018; WAZ 2018; Saarbrücker Zeitung 2017).

In the Lusatian coalfields (Fig. 1.1.5), operations will be reduced from the original five open-cast mines (Cottbus Nord, Jänschwalde, Welzow-Süd TF 2, Nochten 2, Reichwalde) to three by shutting down the open-cast mines Cottbus Nord in December 2015 and Jänschwalde in five years at the latest. All power plants are connected to the open-cast mines via a coal link railway. The Jänschwalde large-scale power plant is primarily supplied by the Jänschwalde and Welzow-Süd open-cast mines. The Schwarze Pumpe lignite-fired power plant is supplied by Welzow-Süd and with lesser quantities from Reichwalde and Nochten. Boxberg is supplied with coal both by Nochten and from Reichwalde (Gerbaulet et al. 2012).

In the Lusatian and Central German coalfields, all power plants and open-cast mines are connected.

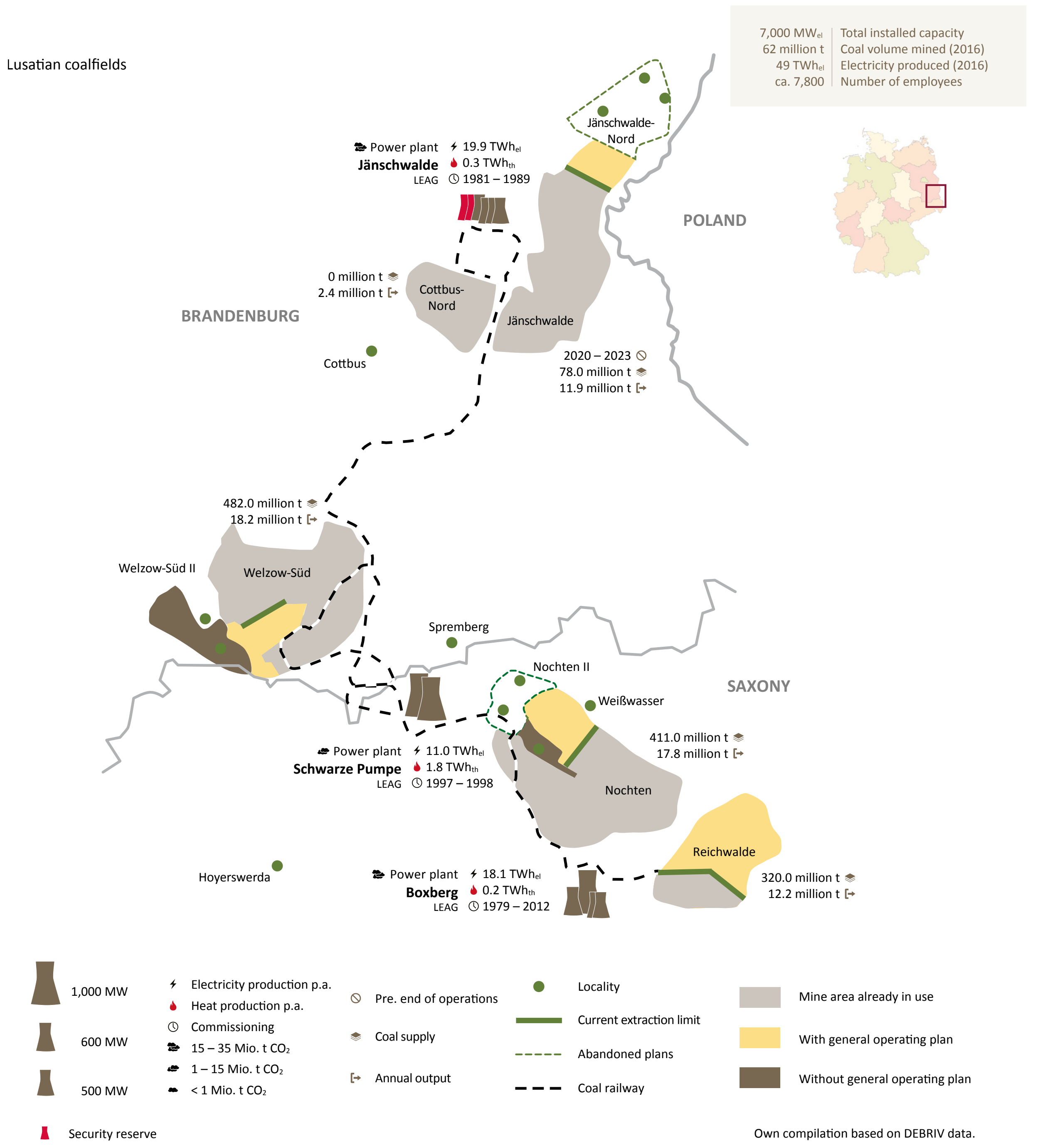
The Central German lignite coalfields (Fig. 1.1.6) consist of the Profen open-cast mine, which supplies the Schkopau power plant and smaller buyers in Deuben, Mumsdorf and Wählitz. The Vereinigtes-Schleenhain open-cast mine supplies the Lippendorf large-scale power plant. Both open-cast mines also supply smaller power plants in Chemnitz, Dessau and Könnern (Gerbaulet et al. 2012). There is also the smaller Amsdorf open-cast mine with the corresponding power plant, which extracts lignite to manufacture crude montan wax (DIW Berlin 2014a).

Fig. 1.1.4: Coal mining and power plants in the Rhineland coalfields (2017)



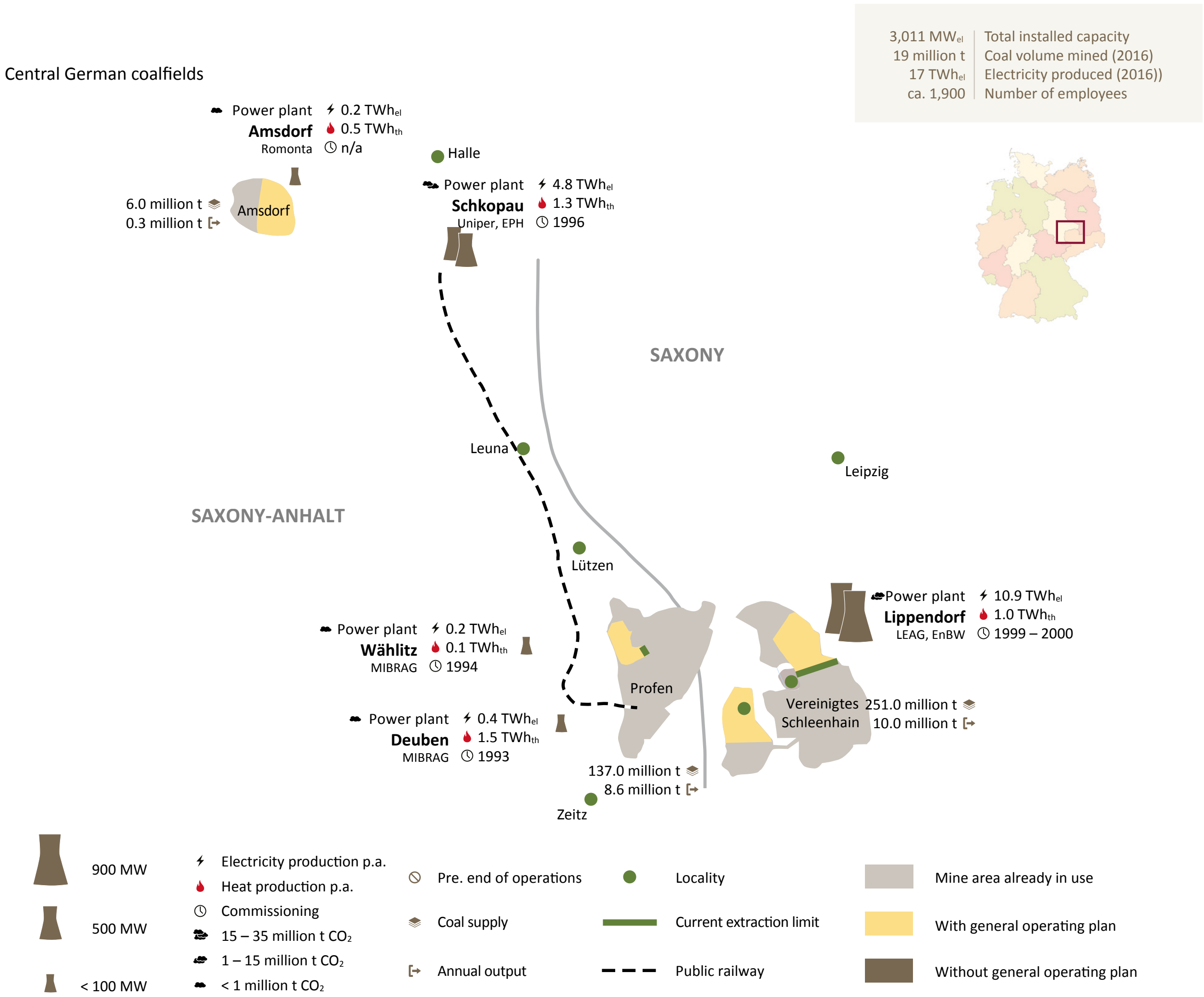
Own compilation based on DEBRIV data.

Fig. 1.1.5: Coal mining and power plants in the Lusatian coalfields (2017)



Own compilation based on DEBRIV data.

Fig. 1.1.6: Coal mining and power plants in the Central German coalfields (2017)



Own compilation based on DEBRIV data.

1.2 COST STRUCTURES OF COAL-FIRED POWER GENERATION AND OPEN-CAST MINES

» **In the competition between the fossil energy sources, lignite has significant cost advantages compared with hard coal-fired or natural gas-fired plants, if further environmental effects are ignored.**

» **Due to the current electricity wholesale prices, hard coal-fired power plants currently at most cover their variable costs. Even that is no longer guaranteed if the CO_2 price increases further.**

» **Operation of the open-cast mines burdens lignite-based power generation with a significant share of fixed costs. At the current price structures, the operating costs of the open-cast mines will no longer be covered in full starting from CO_2 prices of roughly 15 euros/t.**

Power generation from both hard coal and lignite is capital-intensive, but the cost structures differ significantly.

Cost structures of power generation from lignite

Lignite-fired power plants have very low variable costs. They include CO_2 costs, costs for auxiliary materials and supplies, such as the limestone used to treat flue gas or the production-dependent component of the recultivation costs (Öko-Institut 2017b). The investment costs of both the open-cast mines and most lignite-fired power plants have long been amortised.

Lignite-fired power plants have very low variable costs. The investment costs for lignite-fired power plants have already been largely amortised.

As part of the study „The German Lignite Industry", an index was developed to assess the economic outlook of the lignite coalfields ('LignIX', Öko-Institut (2017b)). The indicator incorporates both the variable costs and the costs of open-cast mines and power plants (personnel costs, maintenance and repairs, minor and major overhauls, insurance, fuel costs, costs of implementation and expansions of the mining equipment, costs of recultivation). Taking the expected wholesale electricity prices into consideration, profitability trends can be derived from this. According to these trends, most lignite-fired power plants can still cover their ongoing operating costs in 2018, thanks to the high capacity utilisation. In this, the operators benefit from the CO_2 emission certificates purchased for roughly 5 euros/t in previous years (Bloomberg 2018). However, if the variable costs increase, e.g. due to the current increase in the CO_2 certificate prices to over 20 euros/t, continued operation of power plant blocks may be uneconomical. Additional costs could result e.g. from technical power plant retrofits to extend the service life or to comply with the new thresholds for industrial emissions (see Chapter 5.1) and from developing new open-cast mine sections.

However, if the variable costs increase, e.g. due to the current increase in the CO_2 certificate prices to over 20 euros per tonne, continued operation of power plant blocks may be rendered uneconomical.

The domino effect

In some cases, the term 'domino effect' is used to describe the concern that an entire coalfield will become unprofitable when individual lignite-fired power plant blocks are decommissioned, and will therefore have to be shut down. This extreme assumption would mean that gradual phase-out trajectories could not be chosen, only a point in time when the entire coalfield would be shut down. However, as all power plants and open-cast mines are connected within the lignite coalfields, operation of individual power plants or open-cast mine sections remains possible, irrespective of whether operation of certain other power plants or open-cast mine sections continues. One exception to this is the Inden open-cast mine with the Weisweiler power plant, which is not connected to other open-cast mines in the Rhineland coalfields (see Fig. 1.1.4).

As the power plants and open-cast mines are interconnected within the coalfields, continued operation of individual power plants or open-cast mine sections is not necessarily endangered by the closure of individual other facilities.

At a CO_2 price of just approx. 15 euros/t, the open-cast mines' fixed operating costs would no longer be covered. From approx. 25 euros/t CO_2, the power plants' fixed costs could only barely be covered.

However, it is true that open-cast mine operation, which is very fixed cost-intensive, is only profitable at a minimum extraction quantity. The point at which an open-cast mine becomes unprofitable depends on a number of factors, and therefore cannot be generalised. Lignite open-cast mines and power plants are often operated jointly by an integrated company. Accordingly, operation of the open-cast mines becomes part of the fixed costs of lignite power generation. These fixed costs incurred irrespective of the utilisation of power plant capacity must be covered by contribution margins from electricity sales. In a study, Öko-Institut calculated that at current price structures with a CO_2 price of approx. 15 euros/t, the medium-term recoverable fixed operating costs of the open-cast mines (such as avoidable costs for relocations or large-scale open-cast mining equipment) would no longer be covered. From approx. 25 euros/t CO_2, even the short-term open-cast mining operating costs (e.g. fuel costs and other operating and auxiliary materials), as well as recoverable power plant fixed costs would only barely be covered (Öko-Institut 2018b). The CO_2 price at which closure decisions would then be made depends on the efficiency of individual power plant blocks and strategic decisions by operators, among other things.

Cost structures of power generation from hard coal

The hard coal industry is currently subject to significant economic pressure. In particular, hard coal-fired power plants have far higher fuel costs than lignite-fired power plants.

By contrast to lignite, the hard coal sector in Germany is already under considerable economic pressure today. While hard coal-fired power plants have lower capital costs than lignite-fired power plants, they have far higher fuel costs. Due to the resulting price disadvantage compared with lignite, hard coal-fired power plants ultimately have a significantly lower capacity utilisation. As a result, many hard coal-fired power plants are already making losses or can only cover their operating costs with additional revenues from the heating sector. As this economic outlook is unlikely to improve in the years to come either, many operators have already had to make big write-downs for newly constructed power plants (IEEFA 2017; Öko-Institut 2017b).

1.3 PRICING ON THE ELECTRICITY MARKET AND COMPETITION BETWEEN COAL AND NATURAL GAS

- **The merit order of providers on the German electricity market is based on their marginal costs (costs incurred for production of one additional kWh of electricity). It is typically topped by renewable energy sources, followed by nuclear power and fossil energy sources.**
- **The efficiency of the respective power plants and the international raw material and CO_2 prices influence the competition between the fossil energy sources lignite, hard coal, natural gas and oil.**
- **At CO_2 prices of 20 to 50 euros/t CO_2, lignite-fired power plants are currently competing with hard coal and natural gas-fired power plants.**
- **Efficient combined-cycle gas turbine power plants have comparable marginal costs with hard coal-fired power plants; by contrast, conventional gas-fired power plants are only used to cover demand peaks due to their far higher fuel costs.**
- **Due to their low marginal costs, continued expansion of renewable energy sources will lead to further decreases in electricity wholesale prices in the medium term.**

The operational sequence of power plants in the merit order

Pricing on the spot market is based on a system known as merit order. All participants on the electricity market offer electricity at least at their marginal costs. Marginal costs are defined as the costs incurred for one additional production unit, e.g. one additional kWh for electricity. To cover the hourly demand for electricity, power is purchased from generation plants in the order of their bids (starting with the lowest bid) – the merit order – until the demand for electricity is covered in full. The electricity wholesale price paid to all providers who sell their electricity at a given point in time, is based on the last bid awarded an order (so called marginal plant).

In order to meet the electricity demand, power is purchased from generation plants in the order of their bids, known as the merit order. The electricity wholesale price is calculated from the highest accepted bid at a given point of time.

The marginal costs of wind and solar power plants, which neither need fuel nor emit CO_2, have marginal costs of zero. In addition, renewable energy sources have a feed-in priority for preferential purchase, transmission and distribution of the electricity. All other costs above and beyond the direct production costs, e.g. investment costs or fixed costs of power plant operation are not part of the marginal costs, as they do not depend on the quantity of electricity produced. Accordingly, they do not form part of the bid. Environmental effects of power generation are only incorporated in the marginal costs if the operator must make direct payments for them. This is the case for CO_2 emissions in the form of EU emission trading certificates (see Chapter 5.1).

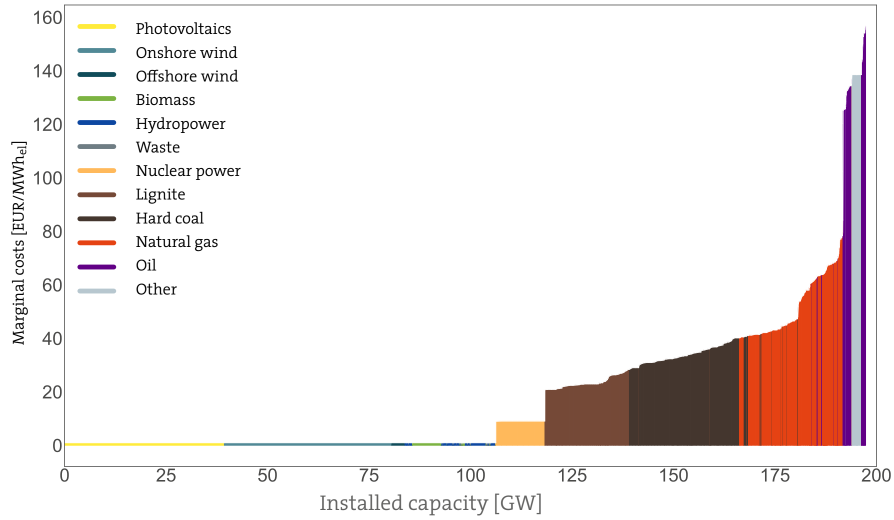
In exceptional cases, it can be economical for operators of conventional power plants to offer electricity at prices under the marginal costs, as the alternative of stopping the plant and starting it up again would lead to higher costs (higher plant wear, conflicting contractual commitments in the heat or system services sectors). This lack of flexibility of conventional power plants results in a conventional minimum generation in the electricity system, which has even led to negative electricity prices in the past (see Chapter 1.4 - Flexibility of coal and natural gas-fired power plants).

Additional costs for stopping and restarting coal-fired power plants can lead to negative prices.

In accordance with the prevailing marginal costs, the merit order is typically topped by renewable energy sources, followed by nuclear power and the fossil fuels (see Fig. 1.3.1). In recent years, the merit order has shifted away from conventional energy sources due to the growth of renewables. Now, the most expensive technologies are used less frequently. This 'merit order effect' has reduced the electricity wholesale price significantly.

Fig. 1.3.1: Merit Order in Germany 2015

Renewable energy sources top the merit order, followed by nuclear power and the fossil fuels lignite, hard coal and natural gas.



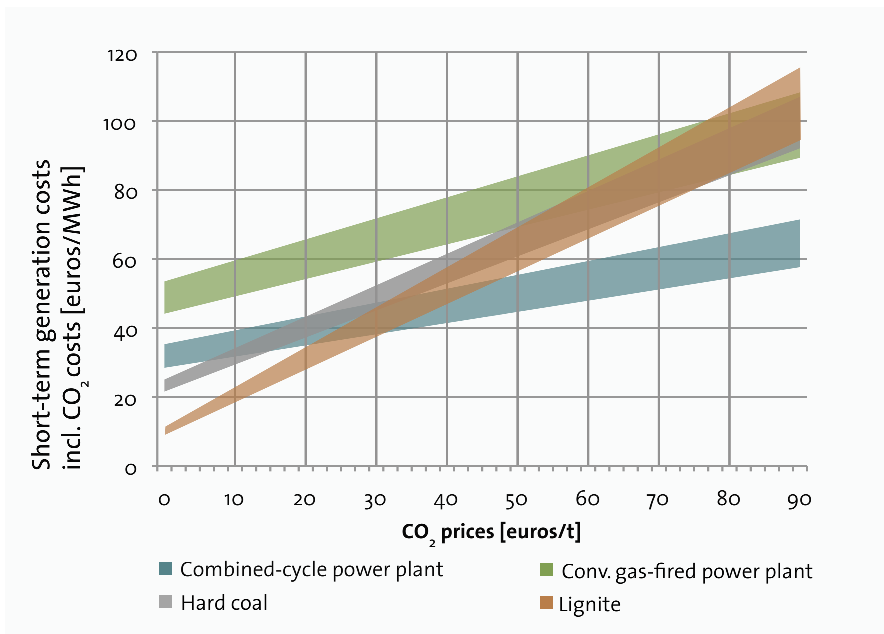
Quelle: DIW Berlin (2017b)

Competition between the fossil energy sources within the merit order

At the current CO_2 price in European emissions trading, modern gas-fired power plants overtake hard coal-fired power plants in the merit order.

The sequence of use of fossil fuels (lignite, hard coal, natural gas) depends in particular on German and international raw material prices, and the current CO_2 certificate price, in addition to the efficiency of a power plant. In recent years, more modern and efficient gas-fired power plants have already overtaken older, less efficient hard coal-fired power plants in the merit order (move to the left). Fig. 1.3.2 shows a schematic comparison of average short-term generation costs of power plants in the past three years.

Fig. 1.3.2: Short-term generation costs of hard coal, lignite, conventional gas and combined-cycle power plants



Notes: Efficiencies of between 35% and 43% were assumed for calculations of lignite, and 37% to 43% for hard coal. For combined-cycle power plants and conventional gas turbines, the efficiencies assumed are between 50% and 62% or 33% and 40%, respectively. The fuel prices used for gas and hard coal are the average prices published by the Federal Office for Economic Affairs and Export Control for the last three years (BAFA 2018b, 2018a). For lignite, a fuel price of 4 euros/MWh was assumed, and the emission factors for the fuels correspond to figures released by the Federal Environment Agency (UBA 2017d).

At a CO_2 price of less than 20 euros/t, and ignoring other negative environmental effects, lignite has the lowest costs. At CO_2 certificate prices of 20 to 50 euros/t CO_2, lignite's marginal costs compete with other fossil fuels. Already today – with a CO_2 price of roughly 20 euros (August 2018) – efficient combined-cycle gas power plants have lower costs than hard coal-fired power plants; conventional gas-fired power plants, on the other hand, are only called upon to cover demand peaks due to their far higher fuel costs. The increase in prices of CO_2 emissions to almost four times the level of the previous year (from just roughly 5.50 euros/t CO_2 in August 2017), the highest prices in 7 years, is also explained by the reforms of the Emissions Trading System. It can be assumed that power supply corporations like RWE have hedged the risks of rising CO_2 prices by purchasing CO_2 emission certificates at low prices for years in advance (Bloomberg 2018). Accordingly, the new emissions trading prices will not affect the merit order in the short term.

From CO_2 certificate prices of 20-50 euros/t of CO_2 and higher, there will also be increasing competition between lignite and gas-fired power plants.

It can be assumed that power supply corporations have hedged the risks of rising CO_2 prices by purchasing CO_2 emission certificates at low prices for years in advance.

Box 1.1: Capacity instruments

In addition to variable costs, power supply companies must also cover their fixed costs, which are incurred irrespective of their capacity utilisation. That applies for both conventional power plants and renewable energy sources. Fundamentally, different price models are conceivable for covering variable and fixed costs and to ensure sufficient capacities at all times (Beckers and Hoffrichter 2014; Matthes et al. 2015). As ideal types, the following two organisational models are distinguished:

- In the current 'energy-only' system, companies generate their revenues from electricity sales traded on the spot market. To date, renewable energy sources have been guaranteed sufficient revenue via the feed-in priority and other subsidy mechanisms. Conventional power plants must offer electricity at prices that can cover their total variable and fixed costs in the long term. Lignite-fired power plants and nuclear power plants have almost always been used in the merit order to date due to their currently relatively low marginal costs. Thanks to this high utilisation, they generate enough revenue over the year to cover their full costs (variable and fixed costs) in spite of fluctuating electricity wholesale prices. Peak load power plants, e.g. gas turbines with comparatively high marginal costs, are only called on for a few hours a year, where there is a bottleneck to cover the total electricity demand. In these hours, sufficiently high price peaks are required to enable the power plants to still cover their entire full costs.

- By contrast, the 'capacity instruments' system focuses on a two-stage revenue structure. Besides the revenue of the electricity quantities sold, some companies are also to be paid for secure provision of electricity generation capacity. This can be implemented by TSO-arranged tenders for provision of certain quantities of guaranteed capacity. In this system, the companies are paid to guarantee their ability to provide capacity to the TSO as required. The additional costs can be passed on to the end consumer via the electricity price.

Due to the high costs of mechanisms like these, the predictable subsidisation of excess capacities and foreseeable problems with administration, the German Federal Government has chosen the 'energy-only' market design (BMWi (2015), Germanwatch (2012); see also the critical take on this of the German Association of Energy and Water Industries (BDEW 2017)).

Capacity instruments target a two-stage revenue structure, where guaranteed provision of power generation capacity is paid for in addition to the electricity volumes sold.

The German Federal Government has chosen an energy-only market design. Reasons include high costs, administration problems and the expected support for excess capacities when introducing capacity instruments.

1.4 COST STRUCTURES OF COAL-FIRED POWER GENERATION AND OPEN-CAST MINES

- **The lack of technical flexibility of coal-fired power plants results in decreases of electricity prices, even including negative electricity prices and additional strain on the electricity grid, as renewable energy sources continue to grow.**
- **Measures to reduce and phase-out coal-fired power generation increase utilisation of less CO_2-intensive, more flexible gas-fired power plants.**
- **The slight resulting increase in the electricity wholesale price due to measures of this kind will stimulate additional essential investments in demand management, storage and efficiency technologies. Greater price spreads and occasional higher peak prices could serve as incentives for investments in power-to-X applications, synthetic fuels and different battery technologies, with just a minor increase in prices for consumers.**
- **A decrease in coal-fired power generation leads to a reduction in grid bottlenecks, as renewables are currently competing with conventional fuels for grid capacities.**
- **A reduction of the coal-fired power generation would decrease electricity exports, which also adversely affect gas-fired power plants in neighbouring European countries with their high percentage of coal- (in particular lignite-) fired power. Domestic coal-generated electricity would only be replaced by foreign coal and nuclear power to a minor extent.**

Flexibility of coal and natural gas-fired power plants

Due to the increasing volatility of power generation caused by the growth in fluctuating renewable energy sources, the flexibility requirements in the future electricity supply system are also rising.

Due to the increasing percentage of fluctuating renewable energy sources in the German and European electricity mix, the flexibility requirements in the future power supply system will increase (see Chapter 3.1). In principle, plants fired with solid fuels are significantly less flexible than plants fired with liquid or gaseous fuels. In particular, the flexibility of lignite-fired power plants is restricted by their slow start-up processes and their high minimum loads (Öko-Institut 2017b). As in the case of the efficiency of the plants, the year of construction also plays a significant role here (see Tab. 1.4.1).

As renewable energy sources become more abundant, the lack of technical flexibility of coal-fired power plants lowers electricity prices and puts additional strain on the grid.

The comparatively high technical inflexibility of coal-fired power plants prevents them reacting quickly to changes in generation of renewable electricity. In particular, it prevents deactivation of unrequired generation capacity (known as conventional minimum generation). This leads to price drops, even including negative electricity prices (in 2017 for 146 hours, and for 15 hours in 2011), and an additional strain on the electricity grids, and therefore to additional costs for the overall system (Consentec 2016).

The 'conventional generation base' comprises 19 to 24 GW, required for operational or commercial reasons (start-up times, minimum runtimes, wear) and heat-related feed-in due to combined heat and power generation.

In conventional minimum generation, roughly 70% of which is accounted for by lignite-fired and nuclear power plants, 'system-supporting minimum generation' and the 'conventional generation base' are distinguished. 'System-supporting minimum generation' includes the components required for the electricity system to provide positive and negative redispatch and balancing energy (for details on the terms, see the 'Alleviating grid bottlenecks' section below and Chapter 3.5) and is specified as 3 to 5 GW for Germany in 2015 by BNetzA (2017). On the other hand, the 'conventional generation base' adds a further 19 to 24 GW, required for operational reasons (long start-up times and minimum runtimes), commercial reasons (additional costs from stopping and starting plants) or heat-related feed-in from CHP plants (accounts for 7 to 8 GW).

There are many technical means to increase the flexibility of coal-fired power plants. However, flexible operation leads to higher costs and wear for the plants.

There are many technical means to increase the flexibility of power plants. Many coal-fired power plants have used them to improve their flexibility in recent years. Even if the operation of coal-fired power plants (esp. hard coal) can adapt more flexibly to renewable generation than in previous years, they remain far less flexible than gas-fired plants (Öko-Institut 2017b). Also, more flexible operation of coal-fired power plants

Tab. 1.4.1: Potential speed of capacity adjustment of fossil-based power plant types between minimum and full load

Power plant type	Potential speed of capacity adjustment between minimum and full load (as a % of the nominal output per minute)	Cold start capability*	Warm start capability*
Older lignite-fired power plants	1-2 %	8-10 hours	4-6 hours
Older hard coal-fired power plants	1.5-4 %	5-10 hours	2.5-3 hours
New lignite-fired power plants	2-6 %	5-8 hours	1.25-4 hours
New hard coal-fired power plants	3-6 %	3-6 hours	80 minutes – 2.5 hours
Open gas turbines	10-15 %	5-11 minutes	5-11 minutes
Combined-cycle power plants (natural gas-fired)	4-8 %	2-4 hours	30-90 minutes

Source: Prognos and Fichtner (2017)

***Note:** Cold start capability means that the power plant has been shut down for over 48 hours previously. The greater temperature differences place a greater thermal stress on power plant components, which is why the power plant must be ramped up more slowly. Warm start capability figures refer to power plants which have been shut down previously for less than 8 hours.

causes increased thermal loads and thus rising operating and maintenance costs, and reduce the service lives of individual components (Prognos and Fichtner 2017). It also reduces the efficiency, as the electrical efficiencies when operating at partial loads decrease (Öko-Institut 2017b). Major retrofits may entail significant investment costs (Glensk and Madlener 2016).

Higher market shares for flexible natural gas-fired power plants as partner to renewable energies

Due to the low electricity wholesale prices, gas-fired power plants were only operational on average for approx. 2,700 hours in 2017 (lignite-fired power plants ran almost two and a half times longer at over 6,600 hours; on average, hard coal-fired power plants ran for 3,600 hours). Under these conditions, it was difficult for gas-fired power plants (and also for hard coal-fired power plants) to earn the contribution margins for the fixed costs above and beyond the variable costs. As a result, many natural gas-fired power plants were shut down, or announced their intentions to shut down, in recent years (BNetzA 2018c). However, thanks to their comparatively greater flexibility and low CO_2 intensity, gas-fired power plants could be an ideal supplement to fluctuating renewable energy sources for a transitional period (see Chapter 3.3).

In recent years, it has often proved impossible to operate gas-fired power plants profitably.

Studies assume that a coal phase-out will increase utilisation of gas-fired power plants (ewi 2016; PwC 2016; enervis energy advisors 2015; DIW Berlin 2014a). The Cologne Institute of Energy Economics (ewi 2016) calculated that a coal phase-out would lead to additional revenue of approx. 2.4 billion euros for gas-fired power plants, and additional revenue of 5.1 billion euros for renewable energy sources.

It is to be expected that the coal phase-out will result in greater utilisation of gas-fired power plants.

Economic incentives for further technologies

Coal phase-out can incentivise the required investments in renewable energy sources, storage technologies, demand management options and energy efficiency measures.

In the short term, an accelerated coal phase-out could result in a slight increase in electricity wholesale prices (DIW Berlin 2014e; PwC 2016) (see Chapter 4.4). Potential migratory effects of energy-intensive industries out of Germany are unlikely due to the expected electricity wholesale prices (Germeshausen and Löschel 2015; Agora Energiewende 2014b; SRU 2017; DIW Berlin 2014c). A slight increase in the electricity wholesale price could stimulate urgently needed investments for the future electricity system. Besides lower-CO_2 power plant technologies, this could also include advancing storage technologies, demand management options and energy efficiency measures. For example, due among other things to the low price peaks or insufficient price spread, load management is virtually non-existent in the industrial sector, although there is a considerable technical potential for it, for example in the aluminium electrolysis/air fractionation industries, electric steel and paper/cardboard production (UBA 2015b). Investments in storage technologies outside of self-supply solutions are only incentivised if price spreads send the right messages. Higher electricity prices are required as an investment incentive in particular for the development and use of power-to-gas or synthetic fuels (Agora Energiewende 2014a; Agora Energiewende and Agora Verkehrswende 2018). Power-to-heat can also benefit from higher electricity prices via various battery technologies (Agora Energiewende 2017b). Higher prices can also offer incentives for greater energy efficiency, both for households and industrial consumers (DIW Berlin 2018a).

Alleviation of grid bottlenecks and grid expansion requirements

Grid bottlenecks arise in particular where major conventional plants like nuclear power plants or coal-fired power plants feed electricity into the grid in addition to renewable energies.

Electricity transport is subject to the laws of physics. For example, electricity always chooses the path of least resistance to the centres of consumption, which is in most cases the shortest route. This often leads to grid bottlenecks at locations where both significant renewable energy sources and major conventional plants like nuclear power plants or coal-fired power plants feed into the grid (BNetzA 2018b). TSOs must then take system stability measures like curtailing renewables (feed-in management) and redispatch. Redispatch means that power generation plants upstream of the grid bottleneck are curtailed and systems downstream of the grid bottleneck provide the supply. The resulting costs totalled roughly 1.4 billion euros in 2017 (BNetzA 2018b). An analysis by BMWi and BNetzA (2017) indicates that a reduction of coal-fired power generation could alleviate the grid situation in Germany, enhancing security of supply and saving costs for system services.

50Hertz assumes that an accelerated coal phase-out would lead to a 5% reduction in the need for grid expansion.

The lack of technical flexibility of existing conventional power plants exacerbates this problem, as power plants cannot be shut down completely. Grid operator 50Hertz, whose supply region includes both the Lusatian and the Central German coalfields, has therefore incorporated various sensitivities for the speed of the coal phase-out etc. for future grid expansion requirements. The results show that an accelerated lignite phase-out would lead to a 5% lower need for grid expansion without endangering security of suppy (50Hertz 2016).

Effects on the energy mix in neighbouring countries

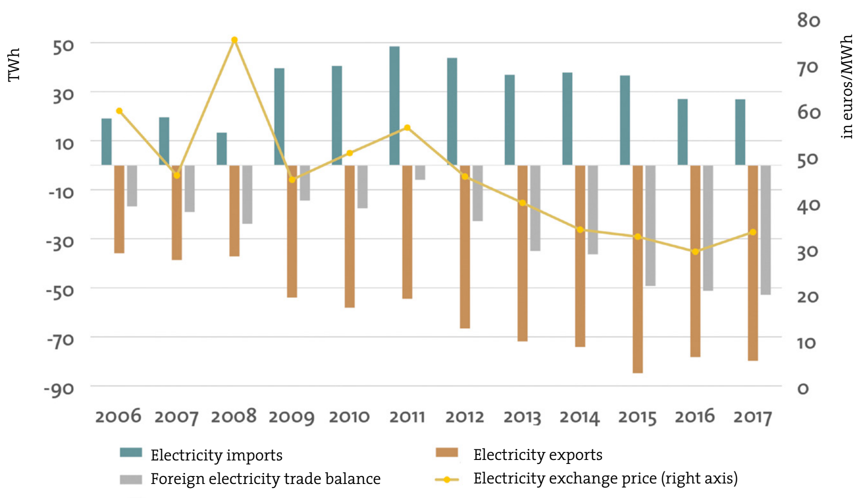
Germany's electricity exports have risen sharply in recent years and are now roughly 10% of domestic consumption.

In Germany, net electricity exports, i.e. the difference between exports and imports has increased continuously in recent years. In 2017 the figure was just under 60 TWh, or roughly 10% of the German power consumption (see also Fig. 1.4.1) (Fraunhofer ISE 2018a; Agora Energiewende 2018). The increase can be traced back to the comparatively low prices on the German electricity exchange (Prognos and Öko-Institut 2017). The average electricity export price in 2017 was 35.57 euros/MWh, while the import price was 38.31 euros/MWh (Fraunhofer ISE 2018a).

With their significant coal share, much of it lignite, German power exports put a strain on gas plants in neighbour countries.

With its significant percentage of coal power, especially lignite power (era 2017), German electricity exports also place a strain on Germany's European neighbours (energate 2017). This is forcing gas-fired power plants from the market, not only in Germany, but also in neighbouring countries like the Netherlands and Italy. These effects could be exacerbated further by upgraded electricity cables from Germany to Norway, the Netherlands, Belgium, Denmark and Austria (Agora Energiewende 2017c).

Fig. 1.4.1: Development of German electricity exports and imports and the exchange electricity price



Quelle: Eigene Darstellung basierend auf Fraunhofer ISE (2018a, 2018b)

Box 1.2: Effects of a reduction of coal-fired power generation in Germany on electricity imports

In the event of a reduction in coal-fired power plants, Germany would initially only reduce its exports of coal-based power, and not automatically import nuclear power from France or coal-based power from Poland (Energy Brainpool 2017; PwC 2016). Various studies have been submitted, indicating that even in the event of a complete coal phase-out by 2030 Germany would at most only become a minor net importer or could have an neutral electricity balance, (öko-Institut 2018b; Agora Energiewende 2017c; DIW Berlin 2015b). According to one analysis, Germany could even remain a net electricity exporter (Energy Brainpool 2017a).

Electricity imports are only worthwhile for buyer countries if domestic electricity production is more expensive. As a result, low-cost German coal-based electricity is currently replacing lower-emission gas-fired power plants in other countries in particular. In the event of a decrease in German coal-fired power generation, increases in electricity production from gas-fired power plants in other European countries are to be expected, and not from the nuclear and lignite-fired power plants, which are currently working to capacity. Model results show that a reduction of coal-fired power generation in Germany would not lead to an increase in the use of nuclear power in France, even in 2030, and only to a minimal increase in coal-fired power generation in neighbouring European countries. In Europe, the lower German coal-fired power generation would also lead to a significantly greater utilisation and far higher expansion of renewable energy sources (DIW Berlin 2018b).

A coal phase-out would reduce German electricity exports, but not necessarily increase imports of nuclear power from France or coal-based power from Poland.

1.5 MONITORING TO ENSURE SECURITY OF SUPPLY

» **The right to reserve approval for closure (assessment by the Federal Network Agency) and reserve capacities ensure that a sufficiently guaranteed capacity can be provided in Germany even in the event of extensive closures of coal-fired power plants.**

» **The transmission system operators are obliged to conduct an annual system analysis to study potential critical limit situations of the power supply system (extreme load, generation and grid assumptions).**

Germany has a comprehensive regulatory framework to guarantee security of supply and to ensure that power plant closures do not lead to security of supply shortfalls.

Monitoring of power plant closures

Intended closures of power plants must be announced to the Federal Network Agency with 12 months' notice. If the power plant is found to be system-relevant, it must be kept on standby. The operator is reimbursed for the resulting costs.

All intended power plant closures must be announced to the BNetzA 12 months before the planned closure date per Section 3 b of the Energy Industry Act (EnWG). The Federal Network Agency first forwards the closure application to the TSO, which assesses the system relevance of the power plant. If it is found to be system relevant, closure can be prevented; the power plant must then be kept on standby for an initial 24-month period. This period can be extended indefinitely by a further 24 months. The costs incurred for maintaining a state of standby are reimbursed to the operator (per Section 13 c of EnWG). These costs are charged on as part of the grid fees. Currently, 26 power plant blocks with a net nominal capacity of roughly 6.9 GW are classified as system relevant. At 13 power plant blocks and an overall capacity of 3.0 GW, most of these plants are natural gas-fired. Seven power plant blocks, with a capacity of 2.3 GW, are hard coal-fired. There are a further six power plant blocks which run on crude oil products, accounting for 1.6 GW.

Reserves

Various reserves and load management offer further security.

The regulatory framework also requires the establishment of various reserves and load management (EnGW Section 13 b, d, e, f and Section 11 Par. 3):

- The grid reserve is designed to provide sufficient flexible generation capacity for grid-supporting bottleneck management for the winter term. It includes both redispatch capacities and measures to maintain voltage or to restore the supply after a failure in Germany or other countries. The grid reserve aims in particular to rectify grid bottlenecks from north to south.
- Moreover, grid stability plants are to be provided to the TSOs from 2020 on, as special network operating equipment to rectify faults in the German transmission grid.
- Besides securing grid-side faults, the capacity reserve will provide support in unusual and unpredicted situations from 2019 on. For example, this would take effect if electricity generation and consumption cannot be balanced on the German power markets. In order to minimise the volume of the strategic reserves, the capacity reserve is dovetailed with the grid reserve at the request of the European Commission. Power plants can qualify for both security mechanisms simultaneously if they have a grid-supporting location.
- The TSOs can also contract switchable loads and reduce their electricity supply if necessary with payment, in order to react to generation or grid bottlenecks. Providers of switchable loads include industrial companies connected in the medium, high or ultra-high voltage grid. The compensation is worthwhile for companies whose production is not disrupted, or only disrupted to a minor extent,

by a temporary decrease or stoppage of their power procurement.

- In the event of supply-side bottlenecks due to extreme and prolonged predictable weather situations, the lignite security reserve, provided by lignite-fired power plants shut down on a preliminary basis, can be activated as the final security mechanism. In light of the current excess power plant capacities and the low flexibility of these plants, they are unlikely to be used in the security reserve phase (UBA (2017a), and Chapter 5.3).

The various reserves and load management options – excluding the lignite security reserve – have a total capacity of 11.3 GW, comprising the grid reserve (6.6 GW for winter 2018/19), grid-stabilising plants (1.2 GW from 2020 on), the capacity reserve (2 GW) and switchable loads (1.5 GW). The total capacity of the reserves can be decreased by max. 2 GW due to the combination of the grid and capacity reserve, where power plants qualify for both security mechanisms.

Germany has reserve capacities and demand management options of approx. 11.3 GW.

The lignite security reserve currently comprises 0.9 GW and will grow to max. 2.7 GW in 2019. It will then decrease until 2023 and be phased out. Given the low flexibility of lignite power plants, it is unlikely to be used.

Intervention options

In the event of a foreseeable shortfall, BNetzA and the TSOs have short- and medium-term options:

- Expansion of the capacity reserve per Section 13 e of EnWG
- Construction of power plants (e.g. gas turbines) as special grid equipment (implementable in the short-term, incorporated in Section 11 Par. 3 of EnWG)

If a shortfall is foreseeable, the Federal Network Agency has various options for sourcing secure capacity, such as expanding the capacity reserve or building gas-fired power plants.

By amending the Federal Requirement Plan Act (BBPlG), cross-border interconnectors to other European countries could also be expanded.

The extent of the individual security measures is based on an annual system analysis, in which the TSOs investigate potential critical limit situations of the power supply system. These analyses are based on various extreme load, generation and grid assumptions. The analysis is made for a short-term perspective of the upcoming winter period, i.e. the time of year with the highest electricity demand. It is also conducted for the long term for at least one more of the following four years under review, and confirmed by the BNetzA.

The Federal Network Agency and transmission system operators conduct regular system analyses to investigate critical limit situations in the power supply system. These analyses are based on extreme load, generation and grid assumptions.

2 CLIMATE CHANGE AND MITIGATION TARGETS

Summary

The energy transformation in Germany and worldwide is driven by man-made global climate change caused by greenhouse gas emissions (GHG) and the national and international climate policy targets that have been developed in response.

As well as describing the impact of climate change (Chapter 2.1), this Chapter also explains international climate policy targets and the concept of a limited carbon budget (Chapter 2.2) and outlines trends in the global use of coal (Chapter 2.3). Subsequently, it presents German targets and progress made so far in the field of climate change mitigation (Chapter 2.4) and derives the climate policy framework necessary to facilitate the reduction and phase-out of coal-fired power generation in Germany (Chapter 2.5).

GREENHOUSE GAS NEUTRALITY BY THE MIDDLE OF THE CENTURY

Evidence supports the fact that the intensity of the climate change we observe is due to human activity. Its consequences will directly or indirectly impact all areas of life and economic activity worldwide. The macroeconomic costs of unabated climate change significantly exceed the costs of timely climate change mitigation.

Under the Paris Climate Agreement, the rise in average global temperature is to be limited to well below 2 °C above pre-industrial levels and efforts are to be pursued to restrict the rise in temperature to 1.5 °C. To implement the Paris climate targets, the German Climate Action Plan has adopted the goal of general GHG neutrality by the middle of the century, i.e. energy-related GHG emissions are to be almost eliminated by 2050. The key GHG in this respect is CO_2.

Studies conducted on behalf of the Federation of German Industries (BDI) and others show that an 80% reduction of GHG emissions by 2050 would - at the very least - be cost-neutral for Germany. Alliances with international partners, resulting for instance in lower costs of new technologies, will be crucial if the 95% target is to be attained. However, already short- and medium-term climate change mitigation measures must be designed such that the 95% target by 2050 remains achievable.

TRANSFORMATION OF ENERGY SUPPLY AT NATIONAL AND GLOBAL LEVEL

While Germany was long seen as a pioneer in the field of global climate change mitigation, national GHG emissions have failed to go down in the last years. According to current forecasts, Germany is expected to miss the 2020 climate policy target (40% reduction of GHG emissions compared to 1990) by a margin of 8 percentage points. Coal-based power makes up a larger percentage in Germany than in the USA. Germany is by far the biggest consumer of lignite worldwide. By contrast, other countries are significantly reducing their use of coal. Over the last five years, the UK has cut the share of coal-based power from 39 to 2%. China, the biggest consumer of coal-based power worldwide, has also stopped the growth trend of the last few decades.

The speed and extent to which Germany can reduce its dependence on coal is of central importance for global advances in climate change mitigation, because many countries are closely observing Germany's energy transition. If this affluent country and technology leader fails to demonstrate how the conversion to a high percentage of renewable energy is possible, faith in the feasibility of the Paris climate targets could be shaken. In consequence, the ambition of climate change mitigation efforts could be weakened in many countries.

MEDIUM TERM - THE 2030 TARGET

The German climate policy target for 2030 provides for a minimum total GHG emission reduction of 55% compared to the year 1990. Under the German Climate Action Plan, the 2030 target is broken down by sector, with the energy industry slated for a minimum reduction contribution of 61 to 62%.

In terms of power generation, the required savings must essentially be delivered through a reduction of coal-based power. Using less natural gas in the short- to mid-term would not be appropriate, since gas is less CO_2-intensive and gas power plants are more flexible than coal-fired plants when it comes to responding to fluctuations in solar and wind power generation. Hence, the percentage of gas in the electricity mix is expected to rise until 2030. Against this background, the conclusion is that annual coal-fired power generation must decline by at least 60% by 2030 compared to today to ensure that the 2030 target can be reached. Under scenarios aiming for a 95% reduction of GHG emissions by 2050 - the Federal Government's upper target range for the year 2050 -, coal-fired power generation would have to drop by approx. 70 to 85% by 2030.

CLOSURE OF THE LAST COAL-FIRED POWER PLANT AND SHORT-TERM REDUCTION CONTRIBUTIONS

The debate about possible phase-out trajectories for coal-based energy must also account for the fact that, from a climate physical perspective, there is a substantial difference between earlier and later closures of power plants. Because the key parameter is the emissions cumulated over the years. This means that ambitious short-term reductions allow a certain leeway for keeping the last power plants on the grid for a longer period. Then again, the longer the delay in the reduction measures, the steeper the reduction will have to be.

Consequently, the 'climate policy gap' arising from the failure to reach the 2020 target must be closed as soon as possible. According to the current trend, the 2020 target would be missed by 8 percentage points, which corresponds to approx. 100 million t of CO_2. Through reduced coal-fired power generation the energy industry has a higher potential to save significant amounts of CO_2 in a relatively short time compared to other sectors.

2.1 IMPACT OF CLIMATE CHANGE IN GERMANY AND WORLDWIDE

- » **Our climate is already changing: Average global temperatures have risen by more than 1°C over pre-industrial levels. Evidence supports the fact that the intensity of the climate change we are observing is due to human activity.**
- » **Global effects include extreme weather events, such as heavy rainfall, storms, heat waves or droughts. Sea levels are rising and the oceans are acidifying.**
- » **These trends have a host of negative effects on ecosystems, human health, infrastructure, cities, agriculture, tourism and energy production. Not restricted to the global south, they are also making themselves felt in Germany.**
- » **Furthermore, Germany and Europe may also be affected by indirect consequences of climate change as food crises may reinforce international conflicts and lead to increased migration, while extreme local weather events may affect global trade.**
- » **The macroeconomic costs of unchecked climate change significantly exceed the costs of timely climate change mitigation.**

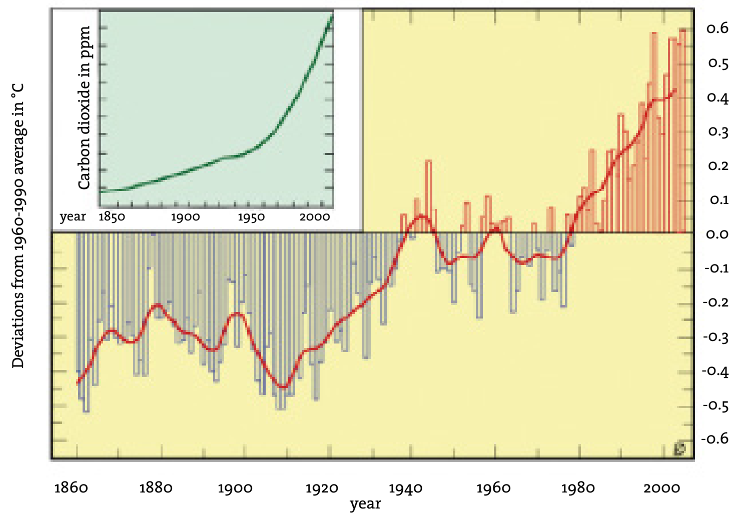
Man-made climate change is undisputed fact

Climate change is caused by man-made greenhouse gas effects triggered by higher GHG emissions.

The earth's climate has always been dominated by long-term variations. In the course of millions of years, periods of warmer average temperatures alternated with periods of colder average temperatures. A range of different phenomena precipitates these natural fluctuations, for instance different degrees of solar activity, natural disasters such as erupting volcanoes or changes in the oceans' heat circulation. However, the rise in GHG in the atmosphere and the associated warming of average global temperatures in the last 100 years cannot be explained with natural causes alone. Current climate change is demonstrably man-made and results from the growing greenhouse gas effects triggered by GHG emissions since the beginning of the age of industrialisation (IPCC 2014). With very few exceptions, all climate experts agree on this point, with the level of agreement rising in line with the scientists' expertise (Cook et al. 2016).

Fig. 2.1.1: Surface air temperature - global average annual values from 1860 to 2005.

There is a clear link between CO_2 levels in the atmosphere and the rise in average global air temperatures.



Source: (Kasang o. J.) based on IPCC (2007)

Fig. 2.1.1 juxtaposes the global average annual temperature with the average temperature over a 30-year period (using the years 1960 to 1990 as base period). Aside from the absolute value, the change in the average global temperature is also highly relevant in terms of global warming and its impact. Disregarding temporary fluctuations in individual years, average annual temperatures in the past 100 years show a distinct upward trend and hence a development that coincides with the trend in GHG emissions (small illustration, bottom left).

At approx. 1.1 °C above pre-industrial levels, 2016 was the warmest year since temperature records began (Jones 2017). The 20 warmest years since records began all occurred in the period after 1990 (UBA 2018d). In general, land temperatures have risen faster than sea temperatures. In some individual regions, global warming substantially exceeds the world's average. For instance, in the past 100 years temperatures in the Arctic rose at double the rate of the global average (UBA 2013b).

At 1.1 °C above pre-industrial levels, 2016 was the warmest year since records began. The 20 warmest years since records began all occurred in the period after 1990.

Impacts of climate change

Since climatic conditions are crucial in determining where and how human civilisations and ecosystems develop, climate change will completely transform life on earth. This is not just a case of gradual changes in temperature, it is a fundamental upheaval of basic climatic structures (Schleussner et al. 2016) - specifically of established atmospheric conditions which are a central prerequisite for predictable food production. The consequences of climate change will directly or indirectly impact all areas of life and economic activity. Among the direct impacts are:

Climate change is not just a case of gradual changes in temperature, it is a fundamental overthrow of basic climatic structures, especially of established weather conditions, which are a central prerequisite for predictable food production.

- Extreme weather events: It is already clear that global warming has led to more extreme weather events, including heat waves and frequent storms as well as longer droughts and heavy rainfall.
- Health: Heat affects the circulatory system, especially among older people and those with chronic illnesses, and can have lethal consequences. Changes in climate zones also allow disease carriers, e.g. malaria mosquitoes, to proliferate in regions where they previously did not exist (Stöver 2015).
- Water supply: A temperature increase of over 1.5 °C will have drastic consequences, not least for the Mediterranean region. It is now assumed that a temperature increase of 1.5 °C or above will result in a 10% to 20% drop in precipitation (Iglesias et al. 2006), which will have a massive impact on the availability of water in the entire Mediterranean region.
- Sea levels: If global warming rises between 1.5 °C and 2 °C, sea levels are expected to rise by a further 10 cm to 50 cm by 2100 compared to the year 2000. Any rise in sea levels of up to one meter will have a direct impact on the Maldives, the Nile delta in Egypt, the city of Shanghai and numerous island states (Schröter 2013; Germanwatch 2002). However, many other densely populated coastal areas will also be affected, for instance in the north-east of the USA and parts of Asia (Munich RE n.d.).
- Urban areas and infrastructure: More than half of the global population lives in cities which are often situated on rivers or coasts. The hurricanes which have swept the USA in the past few years have clearly shown that rising sea levels and extreme weather conditions pose a direct danger to populations, urban infrastructure and companies alike (Mooney 2017). However, even cities which are not located directly on the coast will have to deal with climate impacts, especially in the form of consistent heat (Rosenzweig et al. 2015).
- Agriculture: Vegetation periods will shift as a consequence of climate change. Extreme weather conditions can jeopardise entire harvests. Some food producing regions, for instance the southern Mediterranean, will no longer be usable for this purpose. Migrating pests can lead to lower yields and increased use of pesticides which, in turn, may have a negative impact on health.

- Tourism: Climate change is expected to result in drastically different climatic conditions in many regions. This will have significantly negative effects on the economic performance of tourism-dominated regions.
- Energy production: With big power plants requiring large amounts of cooling water, which typically comes from rivers, extended heat periods threaten the security of supply provided by fossil and nuclear power plants. The river water used for this purpose must not exceed a certain maximum temperature.

Climate change effects are not increasing at a linear rate. Higher temperatures can trigger irreversible developments.

Generally, the impact of climate change increases disproportionally with rising temperatures rather than on a linear basis. On top of this, certain effects are irreversible and trigger developments that cannot be contained (so-called 'tipping points'), for instance the release of methane in thawing permafrost regions (PIK 2007).

Aside from the direct consequences arising from changes in climatic conditions, there are also a number of indirect effects, for instance:

- Conflicts, possibly wars, triggered by competition for food and water (Anton 2017),
- Migration caused by food scarcities, fights for water resources and climate disasters (Pinzler 2017),
- Economic crises and adverse effects on global trade due to recurring weather disasters (Jahn 2015; van Asselt 2017; Darby 2015).

The majority of climatic changes and adverse effects are expected to occur in the global south. At the same time, the countries which are most likely to be affected have the lowest economic and technological capability to adjust. However, in Germany too, the effects of climate change are already noticeable, for instance in the increased frequency of heat waves, storms, flooding through heavy rainfall or droughts. Even if certain consequences do not directly affect Europe, significant economic and social impacts on Europe and Germany can be expected due to progressive globalisation (economy, migration).

Cost of climate change

The cost associated with climate change significantly exceed the cost of climate change mitigation.

The more pronounced the impact of climate change, the higher the macroeconomic cost. Sir Nicholas Stern, former chief economist at the World Bank, put the cost of global warming in a range of 2°C to 3°C at 5% to 20% of global GDP. The cost of doing nothing is thus significantly higher than the cost of effective climate change which Stern estimated to be 1% of GDP per year (Stern 2006). The longer we hold back on combating climate change and implementing adjustment measures for consequences that can no longer be avoided, the higher the cost will be. In contrast, early climate change mitigation measures can even result in economic benefits for Germany (Fraunhofer ISI et al. 2012).

2.2 INTERNATIONAL CLIMATE POLICY TARGETS AND AVAILABLE CARBON BUDGET CONCEPT

» **According to the Paris Climate Agreement, greenhouse gas emissions must be reduced to zero by the second half of this century at the latest.**

» **In terms of climate change mitigation, the key factor is not the greenhouse gas emissions at a certain point in time but the total emissions quantity over a period (carbon budget approach).**

Paris climate policy targets

Under the 2015 Paris Climate Agreement, "the increase in the global average temperature [is to be held] well below 2 °C above pre-industrial levels and efforts [are to be pursued] to limit the temperature increase to 1.5 °C above pre-industrial levels" (UNFCCC 2015, Art. 2).

To implement the Paris climate policy targets, 169 countries had adopted Nationally Determined Contributions (NDCs) as per March 2018 and submitted them to the UNFCCC (UNFCCC 2018). The current NDCs are expected to result in a global rise of temperatures of over 3 °C (CAT 2018). Pursuant to estimates of the UN Environment Programme, global GHG emissions would have to be cut by a further 22 to 38% beyond the countries' current NDCs by 2030 if the Paris climate policy targets are to be reached.

According to the scenarios researched by the Intergovernmental Panel on Climate Change (IPCC), maximum warming of 2 °C is unachievable unless global (net) GHG emissions are reduced to zero before 2100 (IPCC 2014). Compliance with the 1.5 °C target requires the complete elimination of global emissions between 2055 and 2075. As well as many 2 °C scenarios, most scenarios compatible with the 1.5 °C target assume that the second half of the century will see 'negative emissions' (Rogelj et al. 2018). So-called negative emissions are technically feasible and could be achieved through direct air capture or capture and storage (CCS) of CO_2 emissions from GHG-neutral sources (bioenergy with carbon capture and storage). However, the respective technological processes are either not yet commercially available, associated with high costs or leading to conflicts of use (e.g. food production) (Wuppertal Institut, Fraunhofer ISI and IZES 2018; Heck et al. 2018; Smith et al. 2016).

Greenhouse gas emissions must decline to zero in the second half of the century if the Paris climate policy targets are to be reached.

Aside from these long-term targets, it will also be necessary to reduce global emissions in the short-term to ensure that the total available carbon budget is not exceeded. Global energy-related CO_2 emissions must reach their peak between 2020 and 2030 and decline thereafter (Rogelj et al. 2018; IEA 2017d, 78; UNEP 2017; IPCC 2014).

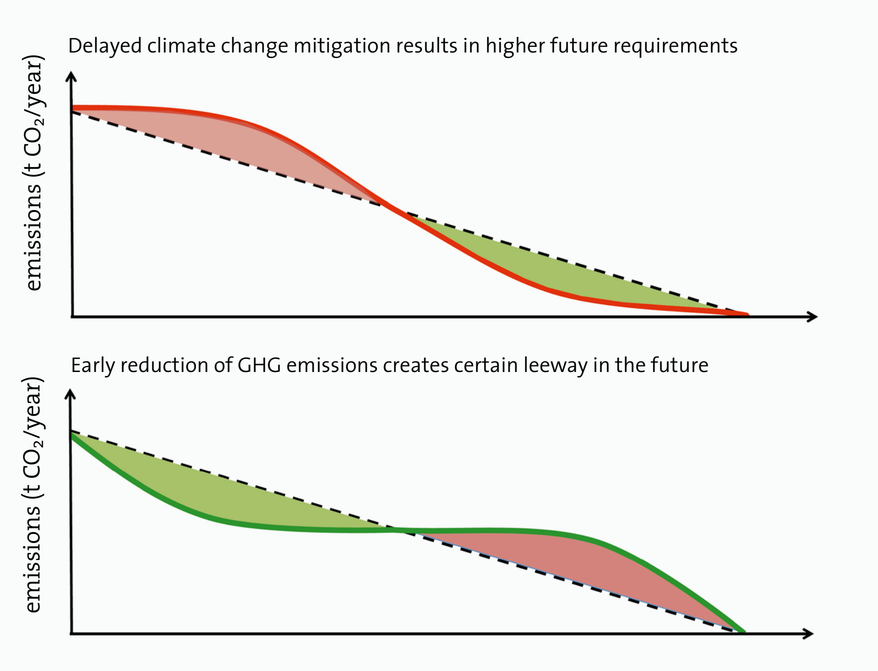
Carbon budget

Climate policy targets are frequently formulated in the form of reduction targets for a specific date. Germany, for instance has adopted the aim of reducing its GHG emissions by a minimum of 55% by 2030 compared to the year 1990. From a political perspective, this is a logical approach to formulating targets since it is easy to communicate and verify an 'x% reduction by 20xx'. However, from a climate physical perspective, such a target is insufficient. The decisive factor that determines the degree of global warming is not the GHG emissions at a certain point in time but the cumulated emissions over a period. Many climate experts therefore talk about a maximum available 'carbon budget'.

The decisive factor that determines the degree of global warming is not the emissions at a certain point in time but the cumulative emissions over a period.

The carbon budget concept clearly shows that low-key climate change mitigation today will require much more significant reductions in GHG emissions tomorrow (see first curve in Fig. 2.2.1). Ambitious measures taken at an early stage, on the other hand, can create leeway for less drastic reduction trajectories in the future (see second curve in Fig. 2.2.1).

Fig. 2.2.1: Emissions budget – cumulated emissions per period are the key climate impact factor



Source: Own compilation based on SRU (2017)

To comply with the 2 °C target, the world may emit another 785 Gt of CO_2 until 2100. Current global CO_2 emissions amount to approx. 35 Gt of CO_2 per year.

According to the IPCC, global CO_2 emissions between 1870 and 2100 may not exceed approx. 2,900 Gt if we want to keep global warming below 2 °C. By 2011, global CO_2 emissions had already exceeded 1,900 Gt (IPCC 2014) and a further 215 Gt were emitted between 2012 and 2017 (own calculation based on the Global Carbon Project 2017; World Bank 2018). To comply with the 2 °C target, cumulative emissions between 2018 and 2100 must be lower than 785 Gt of CO_2. If we aim for 1.5 °C, the carbon budget is as low as 180 Gt of CO_2 (based on Rogelj et al. 2018). Given the fact that global CO_2 emissions currently amount to approx. 35 Gt per year, an immediate reduction of emissions is evidently required.

Coal-fired power plants are responsible for 45% of global greenhouse gas emissions.

In 2015, the world's coal-fired power plants accounted for 14.5 Gt of CO_2, i.e. 45%, of global energy-related CO_2 emissions (IEA 2017a, 2018d). If all coal-fired power plants currently in existence, under construction or planned were in operation until the end of their technical lifetime, they would emit a total of approx. 234 Gt of CO_2 (CoalSwarm, Sierra Club and Greenpeace 2017). Hence, the climate policy targets will not be reached unless CO_2 emissions from coal-fired power plants are substantially reduced.

2.3 GLOBAL TRENDS IN COAL-FIRED POWER GENERATION

» **Following a long phase of expansion, the coal sector is now going through a trend reversal. China, the biggest coal consumer worldwide, has broken the growth trend of the last few decades.**

» **With the exception of Germany and Spain, all western European countries have either completed or are preparing their phase-out of coal. Over the last five years, the UK has cut the share of coal-based power from 39% to 2%.**

» **Coal-based power makes up a larger percentage in Germany than in the USA. Germany is by far the biggest consumer of lignite worldwide.**

Coal growth has peaked

Following close to two decades of substantial growth, the global coal sector has seen a trend reversal since 2015. In the years 2015, 2016 and 2017, coal mining recorded the biggest decline since 1971. Demand for coal has dropped consistently by 2% year-on-year and the number of newly constructed power plants has decreased significantly (IEA 2017c). China, Europe and the USA are mainly responsible for this development. In 2016, coal production in the USA dropped by an estimated 17% from the previous year (IEA 2017c) while India and China together abandoned over 100 planned power plant projects in 2016 (CoalSwarm, Sierra Club and Greenpeace 2017). Worldwide, the number of new power plant construction projects decreased by 29% year-on-year in the past two years. At the same time, growing numbers of power plants were shut down in the last decade (CoalSwarm, Sierra Club and Greenpeace 2017).

Global demand for coal is seeing a significant decline.

Future growth in the demand for coal, which was still considered a certainty just a few years ago, is now in doubt: In its contribution to the Paris Agreement, China, the biggest coal consumer worldwide, has undertaken to reach the peak of its coal-fired power plants emissions by 2030. However, the International Energy Agency (IEA) assumes that China has already reached its coal consumption peak (IEA 2016; see also Green and Stern 2017).

The International Energy Agency assumes that China has already reached its coal consumption peak.

In the USA, the future of coal is also uncertain: Although the Trump government has promised the coal industry its full support, natural gas is increasingly challenging the competitiveness of coal-fired power (IEA 2017c). The share of coal in the US electricity mix has dropped from 53% in 2000 to 34% in 2015 (IEA 2018c).

The share of coal in the US electricity mix has dropped from 53% in 2000 to 34% in 2015.

Even India and South-East Asia, for a long time the great hope of coal exporters, no longer offer any certainty when it comes to further growth in coal demand. The reasons are the rapidly declining cost of renewable energy and protests against air pollution (IEA 2017d).

In the period 1990 to 2007, the EU generated approx. 1,000 TWh of coal-based power a year. Between 2007 and 2015, this figure declined to 826 TWh (IEA 2018b). Hence, the share of coal in total power generation has dropped from 30% to 26%. Eastern and western European countries show substantial discrepancies: With the exception of Germany and Spain, all western European countries have already phased out coal production and use or are phasing it out within the next ten years (UNEP 2017). Most notably, the UK has cut the share of coal-based power from 39% (2012) to 2% (2017) in just a few years (CoalSwarm, Sierra Club and Greenpeace 2017). In May 2018, the Dutch government announced that the use of coal in power generation would be prohibited within the coming decade and that two of its five coal-fired power plants would be closed by 2024 unless they converted to different fuels (Meijer 2018).

The UK has cut its high coal percentage from 39% (2012) to 2% (2017) in five years.

Die Netherlands will close down all coal-fired power plants by 2030.

By contrast, the majority of central and eastern European countries persist with their domestic coal production (UNEP 2017).

If the current trends continue, the annual number of closures of coal-fired power plants will exceed the number of new constructions as of 2022, kicking off an overall decline in the number of global coal-fired power plants (CoalSwarm, Sierra Club and Greenpeace 2017).

Powering Past Coal Alliance

35 countries and regions have joined the Powering Past Coal Alliance and have committed to phasing out coal by 2030 or earlier.

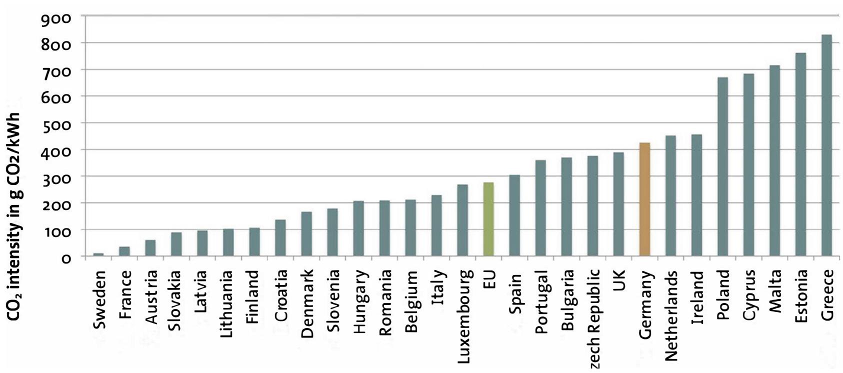
Under the leadership of the UK and Canada, the Powering Past Coal Alliance was established in 2017 with the aim of swiftly advancing global phase-out programmes and substantially limiting global warming. According to the Alliance, to achieve this objective, all OECD countries must phase out coal-fired power generation by 2030 and all non-OECD states by 2050. By December 2017, the initiative had brought together over 35 countries and regions all of which have committed to phasing out coal by 2030 or earlier. On top of this, 24 companies and organisations have joined the Alliance who have pledged to discontinue all investments in coal-fired power plants operating without carbon capture and storage (CCS). Aside from the UK and Canada, members also include Mexico, New Zealand, several US states and European countries consisting of Austria, Belgium, Denmark, Finland, France, Ireland, Italy, Latvia, Lichtenstein, Lithuania, Luxembourg, the Netherlands, Portugal, Sweden and Switzerland (Powering Past Coal Alliance 2017). Although coal already plays a minor role in many member countries, there are some (for instance the Netherlands or the UK) in which coal was previously a significant part of the electricity mix.

Coal use in Germany in international comparison

As shown in Fig. 2.3.1, at 425 g of CO_2/kWh, the CO_2 intensity of electricity generation in Germany is significantly higher than the average of the EU countries (276 g CO_2/kWh). Only five EU states (Bulgaria, Estonia, Greece, Poland, Czech Republic) have a higher share of coal-based electricity (IEA 2018b; World Bank 2018). The large proportion of lignite, which is particularly CO_2-intensive, plays a significant role. At 20% of global production, Germany is the world's biggest lignite consumer by far (see Fig. 2.3.2). The quantity of lignite produced in Germany is approx. 2.5 times that of other big coal-producing countries, such as Russia, Australia, Poland and the USA.

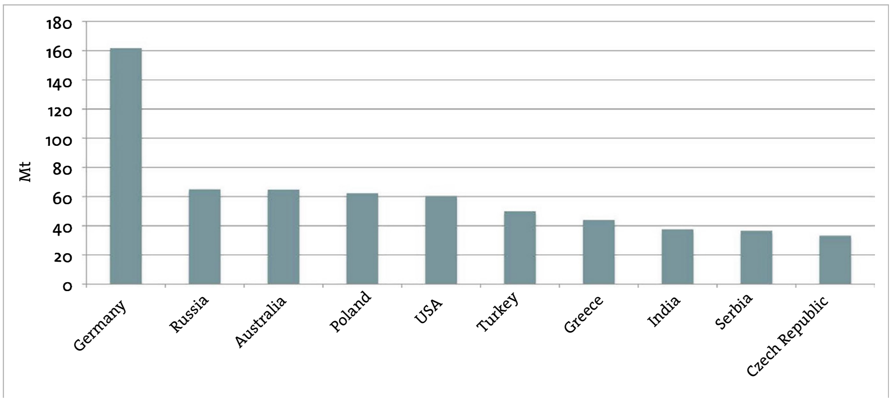
Fig. 2.3.1: CO_2 intensity of power generation in EU countries

The CO_2 intensity of electricity generation in Germany exceeds the European average.



Source: EEA (2016)

Fig. 2.3.2: Global use of lignite – the ten countries with the highest use of lignite in Mt per year, 2015



Germany is the largest consumer of lignite worldwide.

Source: Own compilation based on IEA (2018)

Box 2.1: Germany - a climate pioneer?

Germany was long seen as a pioneer in the field of global climate change mitigation. Subsidisation of renewable energy in Germany (and other progressive countries) has resulted in a massive decline in technology costs that has facilitated the global spread of wind and solar energy. The term Energiewende has become a technical term the world over.

However, in recent years, the international perception has changed. The word 'pioneer' is not being used anymore (Vahlenkamp et al. 2018). Although Germany was long seen as a champion of climate change mitigation, it has been criticised for failing to reduce its GHG emissions in recent years. At around 37%, Germany has a higher share of coal-based electricity than for instance the USA at 34% (World Bank 2018; IEA 2018a). Although Germany receives relatively good marks for a number of indicators on McKinsey's Energy Transition Index, in terms of overall ranking, it now occupies 12th place among the European states under review. In global comparison, Germany lags far behind on the 'energy system structure' indicator where it comes 110th out of 114 countries. The main reason is Germany's substantial share of coal-based electricity which leads to a high CO_2 intensity of its electricity mix (see Fig. 2.3.1).

With all eyes on the German energy transition, the international impact of Germany's climate change mitigation efforts is far greater than its actual CO_2 savings. If Germany, an affluent and highly industrialised country, fails to implement further measures to reduce GHGs and reach its climate policy targets – so the argument goes – how are other, especially economically weaker, countries expected to manage?

A successful energy transition in Germany can advance global climate change mitigation.

Climate change mitigation in Germany thus plays a crucial role in demonstrating the technological, energy structural and economic feasibility of transforming a country's energy system and thereby contributes to a reduction in global emissions beyond the country's borders.

2.4 IMPLEMENTATION OF CLIMATE POLICY TARGETS IN GERMANY

- **Since 1990, Germany has reduced greenhouse gas emissions by close to 28%.**
- **However, the decline in GHG emissions has stalled since 2014. It is expected that Germany will significantly fail the 2020 target of 40%.**
- **To implement the Paris climate policy targets, the Federal Government's Climate Action Plan calls for greenhouse gas neutrality in Germany by 2050.**
- **Short to medium-term climate change mitigation measures must be designed so as to ensure that the long-term 95% emission reduction by 2050 remains feasible.**
- **The energy sector plays a crucial role in achieving short and medium-term climate policy targets. Unless the electricity supply is decarbonised, other sectors cannot follow suit.**

German climate policy targets

Based on international climate protection commitments, Germany adopted its first national climate policy target as early as 1995 and decided in 2007 to reduce GHG emissions by at least 40% by the year 2020 (compared to 1990). Since then, Germany has underpinned its efforts to mitigate climate change by a series of targets and concrete measures (BMUB 2007; Bundesregierung 2010). In 2016, the German Climate Action Plan adopted the concept of GHG neutrality by the middle of the century (BMUB 2016). Furthermore, specific targets for 2030 were adopted for individual sectors (energy, industry, buildings, transport and agriculture). The target for the energy industry is a 61% to 62% reduction compared to 1990.

Tab. 2.4.1: Germany's Climate Action Plan 2050 (reference year: 1990)

	2020	2030	2050
German climate policy targets	Minimum 40% reduction	Minimum 55% reduction	80 to 95% reduction

Source: BMUB (2016)

Tab. 2.4.2: 2030 emission reduction targets by sector according to Climate Action Plan 2050

Sectors	Percentage reduction by 2030 (compared to 1990)
Energy industry	61 to 62%
Buildings	66 to 67%
Transport	40 to 42%
Industry	49 to 51%
Agriculture	31 to 34%
Sub-total	54 to 56%
Other	87%
Total	55 to 56%

Source: BMUB (2016)

Climate change mitigation record

Over the past decades, Germany has achieved much in the field of climate change mitigation. However, in the last few years, progress has stalled. In 2017, GHG emissions amounted to approx. 905 million t of CO_2 equivalent, which corresponds to a 28% reduction compared to 1990. However, since 2014, GHG emissions have not really gone down (see Fig. 2.4.1).

To reach the 2020 target of a 40% reduction in emissions compared to 1990, the Federal Government adopted the 'Climate Action Plan 2020' in December 2014 (BMUB 2014). However, despite the measures defined therein, Germany is expected to fail its 2020 climate policy target. According to the Federal Government's current Climate Action Report, Germany will miss the target by approx. 8 percentage points (BMU 2018). This corresponds to a shortfall of approx. 100 million t of CO_2 a year.

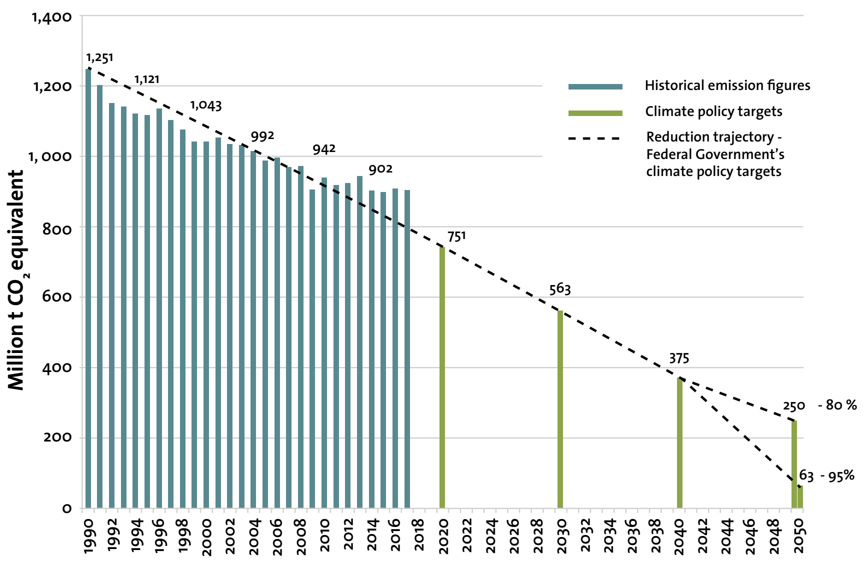
Emissions in Germany have declined only marginally since 2014. Germany is expected to fail the 2020 climate policy target by 8 percentage points (32% instead of 40%).

From a climate change mitigation perspective, the key factor is the cumulative total emissions over a period rather than the emissions in a specific target year (budget approach, see Chapter 2.2). Hence, once the 2020 target has been missed, it is not sufficient to aim for the next target in 2030. On the contrary, Germany will have to implement extensive short-term measures to return as soon as possible to the original target trajectory.

German climate policy targets in relation to Paris

A more stringent implementation of the GHG neutrality concept by the middle of the century depends on a 95% reduction of GHG emissions by 2050 and hence alignment with the upper margin of the target range defined by the Federal Government in its 2010 'Energy Concept' for GHG emission reductions. The 55% reduction trajectory for GHG emissions by 2030 and the 70% reduction by 2040 as described by the Federal Government's interim targets will not result in a 95% reduction of GHGs in 2050 (see Fig. 2.4.1). To reach this objective, the reduction target for 2030 would have to be closer to 58 or 59%. Given this background, there have been calls for an adjustment of interim targets (DENA 2018).

Fig. 2.4.1: Trend in GHG emissions in Germany from 1990 to 2016 and reduction trajectory along climate policy targets until 2050.



The 2020, 2030 and 2040 German climate policy targets do not result in a linear trajectory towards a 95% reduction in 2050.

Source: Own compilation based on historical data (UBA 2018g) and climate policy targets for 2020, 2030, 2040 and 2050 (BMWi 2017c)

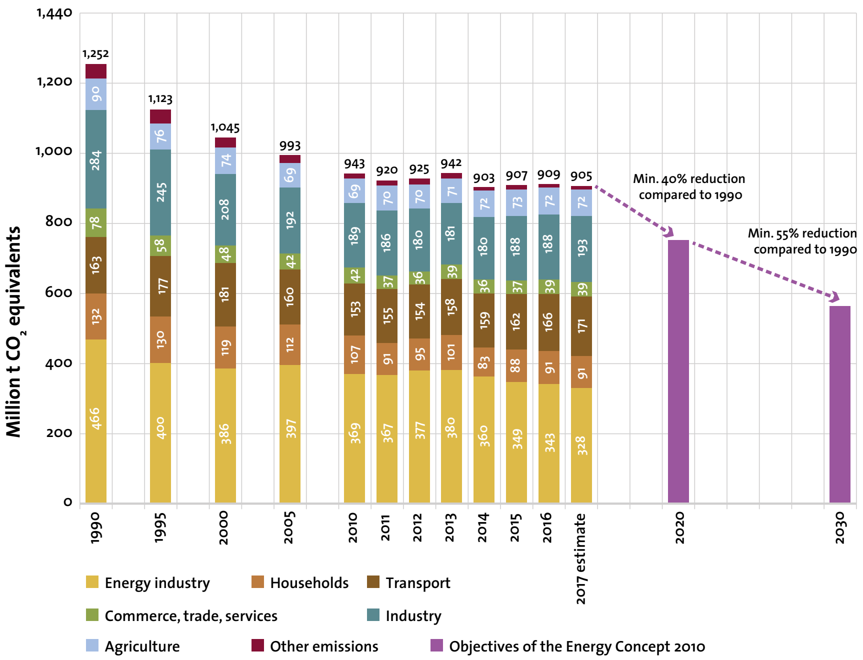
An 80% reduction of greenhouse gas emissions by 2050 is, at the least, cost-neutral from a macroeconomic perspective. For the 95% target to be achieved international alliances will be crucial, in order to reduce costs of new technologies.

According to current studies conducted, among others, on behalf of the Federation of German Industries (BDI), compliance with the current German climate policy targets along the 80% trajectory would be at least cost-neutral for the economy and may even have a positive impact due to the associated innovation and investment momentum (BCG and Prognos 2018). Climate alliances with international partners, which would for instance result in lower combined costs of new technologies, will be crucial if the much more ambitious 95% target is to be attained. However, in any event the short and medium-term climate change mitigation measures must be designed such that the 95% target can be reached by 2050.

Trends in greenhouse gas emissions by sector

A breakdown of GHG emissions by sector (see Fig. 2.4.2) shows that the energy sector produces the largest quantities by far at 36%, followed by industry (21%), transport (19%), households (10%), agriculture (8%), commerce, trade and services (5%) and finally waste and wastewater (1%).

Tab. 2.4.2: Trend in GHG emissions in Germany from 1990 to 2016 by sector and climate policy targets for 2020/2030.



Source: UBA (2017h)

To date, German greenhouse gas emissions have been cut by approx. 30% compared to 1990 in the energy sector as a whole and by 22% in the area of electricity generation.

Although the industry and buildings sectors have recorded the highest cuts, progress has stalled in recent years.

GHG emissions in the transport sector are now higher than in 1990.

The sectors have followed heterogeneous trends since 1990:

- Although GHG emissions have declined by 30% in the energy sector as a whole, emissions associated with electricity generation only decreased by 22% (UBA 2018e).
- In the fields of industry (-32%) and buildings (-38%), reductions come closest to the overall 40% target by 2020, with industry having implemented numerous successful structural changes after the German reunification. However, in the last few years, emissions have stagnated in these sectors.
- By contrast, the transport sector did not record any reduction at all – emissions have even gone up by 5% since 1990. Any technological progress made in this sector in the last few decades has been offset by increased demand (both in terms of traffic volume and engine power of cars).

Reduction potentials in the different sectors

If the current energy policy framework remains unchanged, Germany is likely to fail its 2050 climate policy target. According to various analyses, instead of GHG neutrality, the expected GHG reduction by 2050 will range between 61 and 65% (compared to 1990) (BCG and Prognos 2018; Prognos, EWI and GWS 2014).

Hence, available reduction potentials must be exploited in all sectors. Barriers to implementation hold back progress in a number of sectors, especially in the short-term (Prognos, EWI and GWS 2014): In the industrial sector, for instance, new technologies and processes (e.g. hydrogen-based steel production) must be developed and implemented in line with the market. With climate change mitigation ultimately depending on changes in consumers' eating and consumption habits, technological solutions are limited in the fields of agriculture and land use.

All sectors must make considerable reduction contributions in order to reach the targets under the German Climate Action Plan.

By contrast, in the field of energy generation, emissions can be reduced in the short-term. A consistent rise in the share of renewable energy sources in Germany's energy supply is feasible (see Chapter 3.2). Close to 60% of the country's coal-fired power plants are over 30 years old, and almost one third were commissioned more than 40 years ago (see Chapter 1.1). On top of this, Germany has generated substantial surplus energy for many years now. In 2017, the country's export surplus of 55 TWh was equivalent to almost one-tenth of its gross power consumption. In the medium to long-term, the use of (by then low-carbon) electricity in the transport, buildings and industrial sectors will also result in a further reduction of GHG emissions (sector coupling, see Chapter 3.1). However, this approach specifically depends on a timely reduction of lignite and hard coal-fired power generation to achieve a significant contribution to climate change mitigation (BCG and Prognos 2018). The rising trend in electricity consumption due new consumers (e.g. electromobility) cannot result in net GHG emissions reductions unless there is a further reduction in the CO_2 intensity of electricity generation (via a substantial increase of renewables in the electricity mix).

The electricity sector can reduce emissions in the short term and can play a key role in the decarbonisation of all other sectors via sector coupling.

2.5 PATHWAYS TOWARDS A REDUCTION OF COAL-FIRED POWER GENERATION IN GERMANY

» **A complete phase-out of coal-fired power generation is necessary to achieve the aim of greenhouse gas neutrality.**

» **By 2030, emissions caused by coal-fired power generation must decline by around 60% to 85% compared to 2017.**

» **A reduction of the share of coal in Germany's electricity mix can contribute to a mitigation of the 'climate policy gap' caused by the breach of the 2020 target in a relatively short period of time.**

» **A swift reduction of coal-based power allows for the longer operation of fewer power plants while maintaining the carbon budget.**

An assessment of the coal sector's contribution to the achievement of Germany's climate policy targets throws up three central questions that have been addressed (in the same order) in the appointment resolution of the Commission on Growth, Structural Change and Employment:

- To what degree does coal-fired power generation have to be reduced by 2030 to ensure compliance with the German climate policy targets?
- By which year does coal-fired power generation have to be phased out entirely?
- What potential short-term contribution can the reduction of coal-fired power generation make to the 2020 climate policy target?

To answer these questions, the following aspects will have to be reviewed for each of the above time frames: technological feasibility in connection with security of supply (see Chapter 3), transition costs in connection with electricity prices, employment and structural change (see Chapter 4) and choice of implementation tools (see Chapter 5). This section primarily focuses on the target aspects arising from Germany's climate policy targets.

Box 2.2: Carbon sequestration/carbon capture and storage (CCS)

Carbon capture and storage is not a feasible option for German coal-fired power plants.

Among the technological options suitable to reduce emissions from fossil energy sources is the sequestration and storage of CO_2 (carbon capture and storage - CCS), for instance in deep geological formations. Some 15 years ago, Europe had high hopes for this process and launched several research and pilot projects, among other countries in Germany. Although the relevant technologies were proven to be feasible, a number of barriers prevent their large-scale use. These barriers include the relatively low degree of maturity of individual key technologies, the fact that overall CO_2 abatement costs are relatively high and the limits to the storage of large quantities of CO_2 (Wuppertal Institut 2010; Wuppertal Institut, Fraunhofer IS, and IZES 2018; Oei and Mendelevitch 2016). Germany faces another significant hurdle, namely lack of acceptance among the population. Given this background, it must be assumed that CCS technology will not be a feasible option for German coal-fired power plants (Wuppertal Institut, Fraunhofer ISI and IZES 2018; Hirschhausen et al. 2012).

This assessment should not be confused with the debate about the use of CSS in other sectors, such as reducing GHG emissions in industry e.g. in steel or cement production (acatech 2017), and should be distinguished from strategies aimed at achieving negative emissions worldwide through CCS of biomass or direct air capture of CO_2 (see Chapter 2.2).

Coal-fired power generation - 2030 reduction target

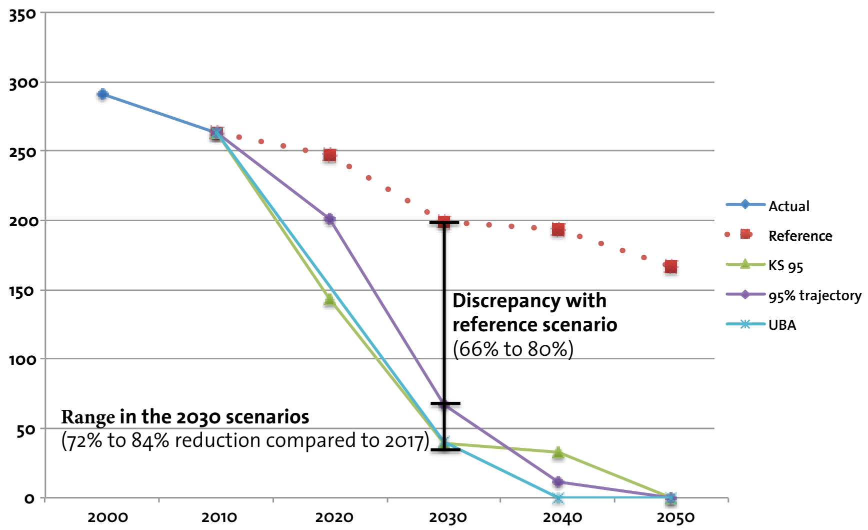
According to the German Climate Action Plan, GHG emissions in the overall energy sector (predominantly electricity production, but also including combined heat and power and fugitive emissions of the energy sector) are to be cut by 61 to 62% by 2030 compared to 1990 levels. Assuming that Germany must achieve the emission reduction in the field of electricity generation solely via a reduction of GHG emissions caused by lignite and hard coal, while GHG emissions caused by natural gas may even rise for some time (see Chapter 3.3) and the overall quantity of electricity generated remains constant, the GHG emissions arising from coal-fired power generation must be cut by at least 60% by 2030 compared to the year 2017. If we also assume a rise in electricity consumption, GHG emissions from coal-fired power generation must decline even further.

To achieve the energy sector target under the German Climate Action Plan, coal-fired power generation must be reduced by 60% by the year 2030.

However, the 2030 sector target under the German Climate Action Plan lags behind the reduction necessary to achieve GHG neutrality by 2050: Fig. 2.5.1 provides an overview of coal-based electricity quantities in climate change mitigation scenarios describing a 95% reduction of emissions by 2050 which are, therefore, compatible with the Paris Agreement and the objective of extensive GHG neutrality by the middle of the century. According to these scenarios, coal-based electricity generation must be cut by around 72 to 84% by 2030 compared to 2017. A reference scenario (Fraunhofer ISI, Consentec GmbH and ifeu 2017) compares this with Germany's current trajectory, underlining the urgent need for action.

To achieve the aim of climate neutrality by the middle of the century, coal-fired power generation must be reduced by 72% to 84% by the year 2030.

Fig. 2.5.1: Trend in gross power generation from lignite and hard coal (in TWh)



Source: Wuppertal Institute diagram based on 'Actual' (AG Energiebilanzen 2018a), 'Reference scenario' (Fraunhofer ISI, Consentec GmbH and ifeu 2017), '95% trajectory' (BCG and Prognos 2018), 'KS 95' (Öko-Institut and Fraunhofer ISI 2015), 'UBA' (UBA 2017c)

Note: Some scenarios only include net power generation figures. For comparative purposes in this diagram, the figures were converted to gross power generation based on the assumption of a simplified average internal power consumption of 10% for coal-fired plants.

Phase-out of coal-fired power generation

The long-term aim of climate neutrality cannot be achieved unless emissions in the electricity sector decline towards zero. In this context, it would be expedient if gas-fired power plants, which are associated with lower CO_2 emissions and more flexible operations, should run longer than coal-fired power plants, which are more CO_2-intensive and less flexible (see Chapter 3.3). From a climate mitigation perspective, the overall emission reductions over the whole period are decisive (see Chapter 2.2). Early emission reductions can therefore form the basis for an extension of the carbon budget available in terms of coal-fired power plants / electricity generation as a whole in order to keep individual power plants on the grid for longer periods and thus guarantee security of supply. On the other hand, the later coal-fired power generation is reduced, the steeper the required subsequent decline in coal-based generation.

The majority of the scenarios that are compatible with the Paris climate policy targets involve a complete coal phase-out between 2030 and 2040.

At the same time, the energy and climate mitigation scenarios at hand provide a reference point in regard of the period in which coal-fired power generation should be (extensively) phased out if Germany is to reach its climate policy targets. The scenarios with a 95% reduction in GHG emissions by 2050 are based on an 86% to 100% cut in coal-fired power generation by 2040 (UBA 2017c; BCG and Prognos 2018; Öko-Institut and Fraunhofer ISI 2015). In addition, a number of studies have directly derived statements on the future use of coal in Germany and Europe from the Paris climate policy targets (see Tab. 2.5.1). Depending on the assumed maximum admissible global warming (below 1.5°C, below 1.75°C or below 2°C) and the specific assumptions regarding the distribution of the remaining carbon budgets among different countries and individual sectors, the majority of the scenarios require a full phase-out of coal-fired power generation between 2030 and 2040.

Tab. 2.5.1: Data relating to coal phase-out in various climate scenarios compatible with the Paris Climate Agreement

	Study	Assumption of climate policy target - maximum warming	Impact on coal-fired power generation
In Germany	(Prognos und Öko-Institut 2017)	Below 2°	Coal phased out by 2035
In Germany	GreenEE scenario (UBA 2017a)	95% reduction in 2050	Coal phased out by 2040
In Germany	95% climate trajectory (BCG and Prognos 2018)	95% reduction in 2050	96% reduction of coal-based power by 2040 compared to 2017
In Germany	Climate change mitigation scenario – KS 95 (Öko-Institut and Fraunhofer ISI 2015)	95% reduction in 2050	87% reduction of coal-based power by 2040 compared to 2017
In Europe	Below 2 Degrees Szenario der Internationalen Energieagentur (IEA 2017c)	Below 1.75°	Coal phased out by 2030
In Europe	Sustainable Development Szenario des World Energy Outlooks 2017 (IEA 2017d)	Below 2°	86% reduction of coal-based power by 2040 compared to 2016
In Europe	(Climate Analytics 2017)	1.5° to 2°	Coal phased out by 2030

Short-term greenhouse gas reduction potential

At present, Germany is expected to fail the 2020 reduction target by 8 percentage points (approx. 100 million t of CO_2 equ.) (see Chapter 2.4). The 'available carbon budget' concept (see Chapter 2.2) calls for the swift and extensive closure of this 'climate policy gap'.

The reduction of coal in electricity generation can make a substantial contribution to the closure of the German 'climate policy gap' by the year 2020.

Reducing the share of coal in Germany's electricity mix can contribute to a mitigation of the climate policy gap. In contrast to other sectors, this area could save significant amounts of CO_2 in a relatively short time (see Chapter 2.4). The last few years have seen the publication of a number of studies on this subject which assume that the coal sector has a short-term reduction potential of around 50 to 80 million t which can be contributed to the 2020 climate policy target (Prognos und Öko-Institut 2017; Agora Energiewende 2017c; Öko-Institut 2018b). With respect to the associated impacts on the energy industry and the regional economies, we refer to Chapters 1 and 4.

3 TECHNICAL FEASIBILITY OF A COAL-FREE ENERGY SUPPLY

Summary

The energy sector is undergoing fundamental changes worldwide, not just in Germany, in pursuit of a greenhouse gas-neutral power supply. This process focuses on avoiding fossil energy sources, transitioning the system to renewable energy sources and making more efficient use of energy. In Germany and Europe, other trends are influencing the restructuring of the energy sector: liberalisation and Europeanisation of the electricity market, digitalisation and break-up of sector borders, specifically the use of electricity in the heat and transportation sector. All of that has an immense impact on generation and distribution of energy.

All analyses of German climate targets show that their implementation is technically feasible and economically viable, including coal and nuclear phase-outs. What is more, coal and nuclear phase-outs are vital to the success of the energy transition. The technologies required for the upcoming phase-out of coal-fired power generation are already available, or their development is sufficiently advanced that they will be available in the relevant energy transition phase. Chapter 3 presents the key aspects for an energy supply without coal: increased flexibility and sector coupling (Chapter 3.1), expansion of renewables (Chapter 3.2.), natural gas as a bridge technology (Chapter 3.3) and storage (Chapter 3.4). Furthermore, it also covers the implications of a reduction and phase-out of coal as an energy source for a secure electricity and heat supply (Chapters 3.5 and 3.6).

THE ENERGY SYSTEM OF TOMORROW

The transition to a climate-friendly power supply entails a fundamental system transition. Accordingly, there will be fewer and fewer base load power plants using fossil energy sources or uranium. Instead, fluctuating renewable energy sources can and will deliver energy, guarantee supply reliability and provide system services. For this purpose, the electricity system as a whole must become more flexible on the generation and demand side. Implementation includes grid expansion and extensive digitalisation of local distribution networks (e.g. transformer stations), expansion of load management (demand-side management) and storage, as well as – for a transition period – increased flexibility in the remaining conventional power plants. Another way to increase flexibility and simultaneously reduce CO_2 emissions is to increase use of electricity in the heat and transportation sector, for example through electromobility or heat pumps for buildings and industrial applications (sector coupling).

EXPANSION OF RENEWABLE ENERGY SOURCES

In the electricity sector in Germany, the percentage of renewables increased from 6.5% in 2000 to 36.4% in 2017. At the same time, the costs of solar and wind power have decreased dramatically in recent years. Accordingly, the electricity production costs for wind and solar electricity today are roughly the same or even lower than new fossil-fired power plants. It is important that we do not ease up in this area, but continue to develop the technology-specific expansion trajectories for wind and photovoltaics (PV) at the pace stipulated in the coalition agreement of the current German government, which sets a target of reaching 65% of renewable electricity by 2030.

THE ROLE OF NATURAL GAS AND SYNTHETIC GAS

Even where coal-fired power plants have been retrofitted to increase flexibility in recent years, gas-fired power plants are technically better suited than coal-fired power plants to deliver electricity flexibly, and can do so at significantly lower specific CO_2 emissions. As a result, natural gas-fired power plants are an important factor in security of supply during the energy system transformation.

However, achieving the objective of a greenhouse gas-neutral power supply by the middle of the century means that ultimately also fossil-based natural gas must be replaced with renewable energy sources. In the long term, applications for which natural gas is used today could continue with

synthetic CO_2-neutral gas (generated from renewable electricity). However, it must be considered that high energy conversion losses restrict synthetic gas use.

Temporarily, higher utilisation of existing gas-fired power plants may make up for decreasing percentages of coal-based electricity and heat. Construction of new plants must be kept to a minimum, as these new gas-fired power plants will primarily serve just as backup capacities in future, or be retained to cover peak loads for the corresponding short runtimes.

SIGNIFICANCE OF STORAGE TECHNOLOGIES

Development of electricity storage facilities is an important factor to the overall success of the energy transition. However, it is not a limiting factor in how quickly coal-fired power generation can be reduced. Electricity storage is just one of several components to balance supply and demand. With a long-term perspective, there is a need for research and development, especially for storage systems that can store high quantities of energy for very long periods. However, options like sector coupling, electricity-based combined heat and power (CHP) and demand-side management (including heat storage systems) are available today and sufficient to balance increasing flexibility demands at the current stage of the transition process. The availability of electricity storage is therefore not a limiting factor for the coal phase-out.

SECURITY OF SUPPLY AS PART OF A TRANSFORMATION OF THE ELECTRICITY SECTOR

A secure, disruption-free power supply is crucial for Germany's economic competitiveness, and must not be compromised, even as decarbonisation increases during the energy transition. A wide range of technologies is already available today to ensure this is the case. Both the guaranteed capacity and other system services currently provided by conventional power plants can be delivered by a mix of renewable energy sources, reserve plants and gas-fired power plants, short- and long-term storage facilities and flexible loads within the European electricity system.

TRANSFORMATION IN THE COAL-FIRED HEATING SECTOR

As part of the power supply transition, heat supply security must also be taken into consideration, as some fossil-fired power plants also generate heat for households or the industrial sector in addition to electricity. There are alternatives for all of these applications, for example substitution with other energy sources (natural gas, waste), use of industrial waste heat and reduction in consumption via increased energy efficiency. However, substitution measures of this kind are longer-term projects, taking several years to plan and implement. In spite of this, a secure heat supply is not a barrier to a timely reduction of coal-fired power, as there are enough coal-fired power plants that do not supply heat, or only do so to a minimal extent. Where alternative heat supply must be built, it may be necessary to keep hard coal-fired power plants operational for a transitional period and with minimal load. In large-scale lignite-fired power plants, multiple blocks are often operated at the same location. When older power plant blocks are shut down, newer blocks can take over the heating supply function on a transitional basis.

3.1 THE ENERGY SYSTEM OF TOMORROW

- **The entire energy industry is faced with a fundamental transformation. To achieve the climate objectives, Germany's power supply must be derived entirely from renewable energy sources. Sun and wind will be the primary energy sources for electricity generation.**
- **In addition, a significant increase in energy efficiency is necessary to reduce energy consumption and make the transition to 100% renewables viable.**
- **In the medium term, electricity will also be increasingly important in heating provision and transportation (sector coupling). Sector coupling will only lead to emission decreases if CO_2 emissions from electricity production are reduced rapidly.**
- **The current challenge is integration of renewable energies into an increasingly flexible electricity system. The technologies required in the short and medium term (such as demand-side management, grid expansion and short-term storage in particular) are available.**
- **Digitalisation will make new business models possible and necessary.**

Core elements of the energy system 'of tomorrow'

For climate change mitigation reasons, the energy system must be transformed.

A fundamental technological restructuring of our energy system is inevitable for climate change mitigation reasons. There are several studies on how the future energy system could and should be structured. A central statement of all studies is that a 95% reduction of greenhouse gases by 2050 is technologically feasible (e.g. BCG and Prognos 2018; DENA 2018; BMUB 2016). At the same time energy efficiency must be increased sustainably in all sectors, to implement the energy transition with optimised costs (BMWi 2017b).

A 95% reduction of greenhouse gases by 2050 is technologically feasible.

The transition to renewable energy sources entails a fundamental system change in the power supply.

The switch to a power supply primarily based on renewable energy sources entails a fundamental system change. In the long term, there will no longer be any base load power plants using fossil energy sources or uranium in continuous operation. Instead, a variety of renewable energy sources will provide electricity at different times and in different volumes. Where the power supply was previously characterised by the fact that the (electricity) supply always had to follow the volatile demand (load), the transformation of the power supply to renewable energy sources is expected to lead to increasing volatility on the supply side.

Phases of the transformation

Based on the increasing percentage of renewable energies in the energy system, three phases of the transformation can be derived (see Fig. 3.1.1). In the first phase, which has now been completed, the focus was on innovation and cost reduction in renewables.

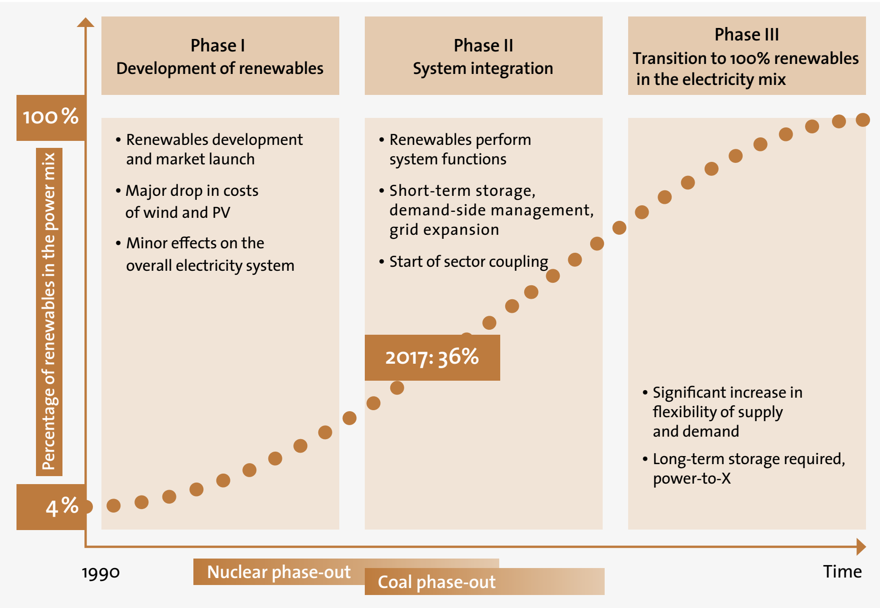
The current challenge is to integrate renewable energy sources better into the system. It means also that electricity consumption and generation must become more flexible.

We are currently in the second phase, which is primarily about integrating renewable energy sources better into the system. With an increasing share of volatile supply from wind and PV, the remaining fossil-based energy generation in particular must become more flexible. Where it is expedient and viable, an increase in flexibility of demand also helps integrate renewables into the overall system. The focus is not only on technological issues, but also on issues of the electricity market design and the general political conditions. The technologies required in this phase are either already available, or being developed with foreseeable market maturities.

Long-term storage will not be required until renewables reach a very high share of the supply.

Long-term storage facilities will not be needed until the renewable energy sources account for a high percentage of electricity generation (phase III). Relevant technologies are still in development (see Chapter 3.4 for details).

Fig. 3.1.1: Phases of the energy transition - Transformation of the energy system and expansion of renewable energy sources



Source: Own compilation based on (acatech 2017; Henning et al. 2014)

Increasing flexibility of electricity consumption

The challenges arising from an increasingly fluctuating supply from renewables must be met via a combination of various technologies and approaches on the consumption and generation side. On the generation side, diversification of the renewable plant locations and a corresponding expansion of the electricity grids are necessary. On the consumption side, there are various ways to achieve an increasing flexibility of the electricity sector: This includes in particular demand-side management, comprehensive digitalisation of local distribution grids (e.g. transformer stations), increasing European integration of the electricity markets, and – for a transitional period – increased flexibility in the remaining conventional power plants. The expansion of electricity storage facilities is another option (of many) to balance supply and demand (Krzikalla, Achner and Brühl 2013; acatech, Akademienunion and Leopoldina 2015).

A range of technologies and approaches to make the electricity system more flexible are available already today.

There is great potential for demand-side management, especially in industrial companies (Arnold et al. 2016). According to various studies, the potential for short-term reduction of current consumption (positive load shift potential) here is between 0.5 GW and 2 GW and between 0.7 and 4.4 GW for additional consumers in times of high supply availability (Krzikalla, Achner, and Brühl 2013). As part of the spread of 'intelligent' electricity applications, the household sector also offers a growing load shift potential, e.g. in washing machines, dryers, refrigerators and freezers (Krzikalla, Achner, and Brühl 2013). According to the Dena Grid Study II, a maximum positive load shift potential for the household sector of 6.7 GW and a maximum negative potential of 35.3 GW can be achieved (DENA 2010). This gives industry in Germany an opportunity to develop new business models and technological innovations, which could also be suitable for export markets (Energieagentur NRW 2016).

There is a high demand side management potential in various sectors.

Sector coupling

A central element of the energy system of tomorrow will be a far stronger dovetailing of the energy demanding sectors. In the past, the demand sectors electricity, heat, transportation and industry were generally considered separately. Accordingly, specific technical solutions and political frameworks were largely developed separately.

The use of electricity for mobility and heat (sector coupling) makes a reduction of CO_2 emissions possible.

By contrast, cross-sectoral solutions are required for an efficient, flexible and robust energy system of the future. Sophisticated sector coupling makes the following possible:

- Transitioning mobility and heat to renewable energy sources, to reduce the CO_2 emissions in these fields and
- Creating additional flexibility by opening additional applications for wind and solar power, especially in the areas of mobility and heat, including cost-effective storage options (especially as part of electromobility).

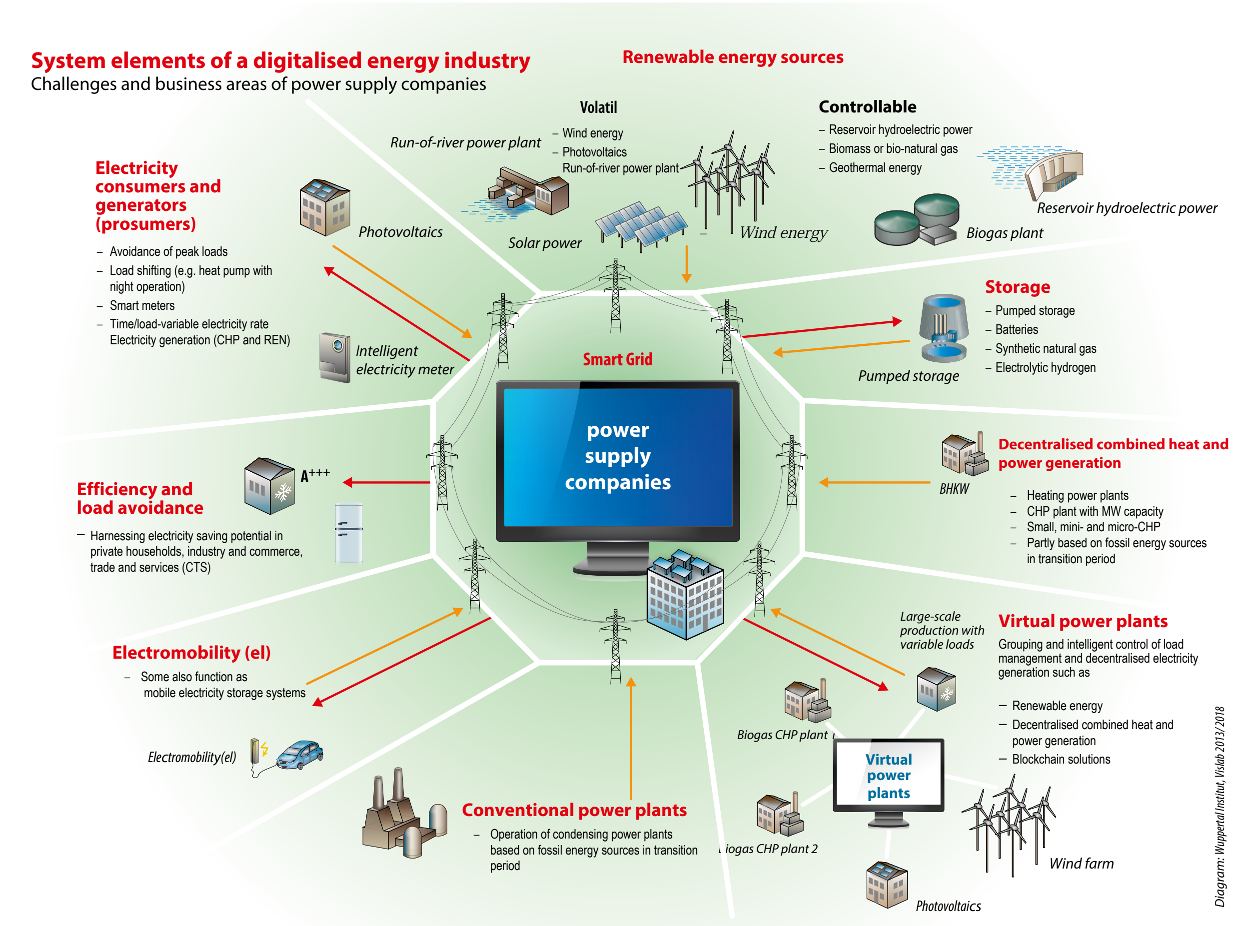
Energy efficiency must be improved to minimise the increase in electricity consumption.

It will take innovation in various fields to implement sector coupling (for example electromobility), and entail investments in new infrastructure (e.g. charging stations for electric vehicles). For the electricity sector, sector coupling is a paradigm shift in many cases, for example if our energy system is increasingly dominated by decentralised units, interconnected via intelligent control systems (e.g. charging and discharging cycles of electric vehicles) and no longer by large central units.

The CO_2 intensity of electricity must decrease, for sector coupling to support CO_2 emission reductions.

This increasing networking of sectors via the key energy source electricity – based on its versatility – will also lead to an increase in electricity demand (BCG and Prognos 2018; Prognos and Öko-Institut 2017). This must be counteracted by increasing energy efficiency, to minimise the additional energy demand. The CO_2 intensity of power generation must also decrease. That is why reducing and phasing out coal-fired power generation are requirements for a successful sector coupling.

Fig. 3.1.2: System elements of a digitalised energy industry



Source: Wuppertal Institut (2018)

Digitalisation and decentralisation in the energy sector

Already today power supply companies are developing from classic power suppliers to comprehensive energy managers and service providers (see Fig. 3.1.2). The requirement to provide CO_2-free energy is just one driver in this transformation process, calling for sector coupling and increasing the demand for flexibility. The increasing digitalisation of the economy and society, and increasing European integration of the electricity markets are just as important. Smart system services will be developed for grid monitoring and economically optimised operation of various generation systems. In addition, rising decentralisation will blur the lines between power supply companies and energy consumers. So called 'prosumers' will be both consumers and and producers of electricity simultaneously.

In this environment of a more digitalised and sector-spanning energy industry, there are many opportunities for companies. Ecologically and economically sustainable service concepts in which customers are actively involved can expand the range of roles taken on by power supply companies. By contrast, operating (large-scale) power plants, which has been the 'classic' business model to date for many power supply companies, will become less and less important, and has to be replaced with other innovative business models.

The scope of activities in the energy industry will grow – creating opportunities for companies.

3.2 EXPANSION OF RENEWABLE ENERGY SOURCES AND ELECTRICITY GRIDS

- **Renewable energy sources now meet more than one third of the German energy requirements.**
- **Germany has sufficient potential to continue to increase power generation from renewable energy sources in the decades to come, and to replace electricity from both nuclear power and coal-fired power plants entirely.**
- **A power supply based largely or fully on renewable energy sources is technically and economically feasible until 2050 and, according to studies, will be no more expensive than a fossil-based system.**
- **The power generation costs for renewable energy sources have decreased significantly in the past 20 years and are now at the same level as fossil fuels.**
- **Achievement of the Federal Government's medium to long-term climate targets requires increased construction of additional renewable plants in accordance with the expansion targets set forth in the Coalition Agreement (65% renewables in the electricity sector by 2030).**
- **Delays in grid expansion are not a limiting factor for phasing out coal.**

Expansion potential

By 2050, Germany's electricity demand can be covered fully by renewable energy.

Today, there is a broad scientific consensus that it will be technically and economically viable to meet the electricity requirements primarily via domestic renewable energy by 2050. That remains true even if there is an increase in electricity demand due to greater use of electricity (e.g. via electromobility and heat pumps) in the medium to long term (see Fig. 3.2.1). Whereas renewables accounted for just 6.5% of gross electricity consumption in 2000 at 38 TWh, this figure had risen to 218 TWh and 36.4% in 2017 (AG Energiebilanzen 2018a). The net electricity output from all energy sources in Germany is currently 566 TWh (AG Energiebilanzen 2018b). According to various studies (BMVI 2015; UBA 2013a; Scholz 2010; UBA 2017c; BCG and Prognos 2018), the annual power generation from renewable energy sources could be increased to at least 700 to 800 TWh, with the greatest potential for expansion in onshore and offshore wind energy and PV.

The greatest potential for expanding renewable energy is in wind energy and photovoltaic systems.

Energy and climate scenarios

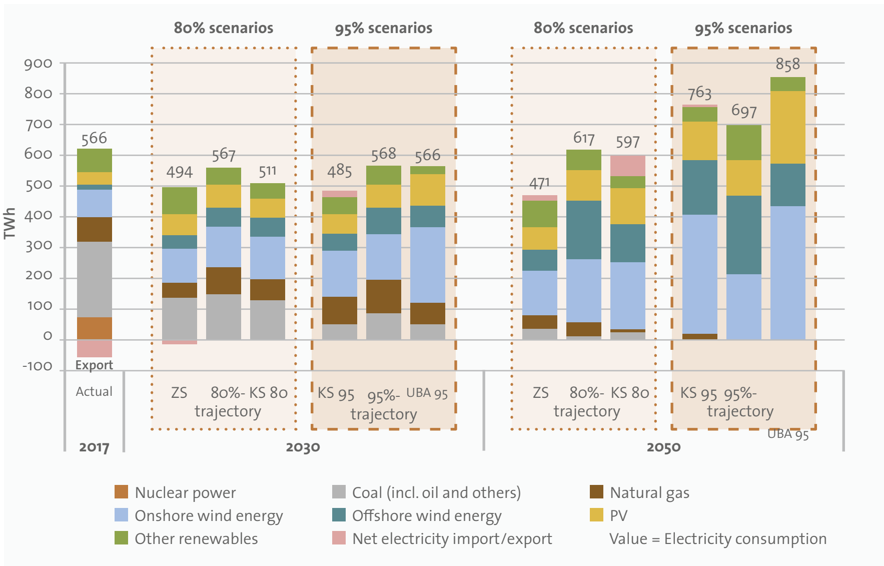
Further expansion of renewable energy sources can compensate diminishing contributions of both nuclear and fossil-based power generation.

According to various studies (BCG and Prognos 2018; UBA 2017c; Öko-Institut and Fraunhofer ISI 2015), further expansion of renewable energy sources by 2030 will not only compensate for the power generation lost in the nuclear power phase-out, it will also compensate for fossil-based power generation. Figure 3.2.1 shows that the diminishing power generation from nuclear, lignite and hard coal-fired power plants, could be offset in particular with a further expansion in wind and solar energy by 2030. All scenarios require that the efficiency potential is tapped. In some of the scenarios, this even leads to a decrease in electricity demand.

Increasing flexibility of electricity consumption and peak load gas-fired power plants play an important role for future security of supply.

All scenarios were based on detailed electricity system models with hourly breakdowns, so that they describe development trajectories with a high degree of security of supply. According to the scenarios, the challenge related to ensuring a constant and reliable power supply associated with high percentages of fluctuating renewable energies can be resolved in particular by increasing demand flexibility, expansion and/or modification of the transmission and distribution grids and use of back-up natural gas or synthetic (from renewable electricity) methane-based power plants (which only run for a few hours a year). The system services currently still provided by coal-fired power plants can be replaced in the future, by renewable energy among other sources (see Chapter 3.5).

Fig.3.2.1: Net electricity production and consumption by energy source in 2017 and by various scenarios in 2030 and 2050 (in TWh, without pumped storage electricity, incl. net import)



Source: Compilation: Wuppertal Institute based on 'Actual' (AG Energiebilanzen 2018a), 'ZS' (Prognos, EWI, and GWS 2014), '80% or 95% trajectory' (BCG and Prognos 2018), 'KS80 or KS95 (Öko-Institut and Fraunhofer ISI 2015), 'UBA 95' (UBA 2017c)

Adaptation of installation rate for renewables

In future, further dynamic expansion of renewables will be necessary.

A transformation of the electricity system, which is in line with the long-term climate targets of the Federal Government, will require a further dynamic expansion of renewable energy sources in the decades to come. The aim corresponds with target of 65% renewables in the electricity sector by 2030, put forth by the current German government in its coalition agreement. Accordingly, the specific expansion trajectories for wind and PV must be adapted.

Renewable energy sources and grid expansion

Transition of the power supply and construction of new renewable plants creates new challenges for the grid infrastructure. Among other things, this applies for transporting electricity from the main generation areas in the north to the consumption centres in the south, and increasingly decentralised feed-in of renewable electricity into the distribution grids.

As early as 2009, the passing of the German Power Grid Expansion Act (EnLAG) placed the focus on accelerating the grid expansion at the ultra-high voltage level. The grid development plan, managed by the Federal Network Agency (BNetzA), was introduced to plan new routes. In 2011, the 'Grid Expansion Acceleration Act for the Transmission System' (NABEG) was passed to speed up the planning and approval processes. In addition, the Federal Demand Planning Act provided binding specifications for the energy industry need and priority (expansion) demand for specific projects.

The overall length of the cables resulting from EnLAG is currently roughly 1,800 km. Taking into account the second quarter of 2018, a total of roughly 1,150 km has been approved, and roughly 800 km of those has been constructed, equivalent to just under 45% of the overall length. The total length of the additional 43 projects nationwide under the Federal Demand Planning Act is roughly 5,900 km. Of those, roughly 3,050 km is categorised as grid reinforcement/optimisation, and around 2,800 km as new routes. Overall, roughly 600 km has been approved as of the end of the second quarter of 2018, and roughly 150 km has been built. BNetzA expects 'Südlink' and 'Südostlink', the major north-south lines, to be completed in 2025.

Delays in grid expansion are not an obstacle to phasing out coal.

While grid expansion has suffered from delays to date, in particular in the crucial north-south lines, at the same time, grid expansion is not a limiting factor for further construction of additional renewable plants and phasing-out of coal. The goal of a renewable energy percentage of 65% in the electricity sector by 2030 is already being incorporated in the current grid development plan: In the 2030 scenario framework approved by the Federal Network Agency in June 2018, as of 2019, this renewable target was assumed for all scenarios, and thus forms the basis for future grid expansion requirements. In the Coalition Agreement (2018 Coalition Agreement between CDU, CSU and SPD), stronger regional management of the renewable energy expansion was agreed to improve synchronisation of the expansion of renewable energy sources and grid expansion. In addition to this, approval procedures are to be accelerated and simplified and short-term reinforcement and optimisation measures are to be used to a greater extent. The Federal Ministry for Economic Affairs and Energy has already announced its intention to submit an amendment with corresponding measures.

Development of electricity production costs

In the long term, a power supply based on renewable energy will cost less than using fossil fuels.

Existing studies (including Fraunhofer IWES 2014; Agora Energiewende and Öko-Institut 2017) assume that, given appropriate general conditions, a power supply based fully or largely on renewable energy sources will cost (even ignoring external costs) slightly less by the middle of the century than a power supply based largely on fossil energy sources.

Power generation costs from wind and solar power are currently equal to or even below those of new coal and gas-fired power plants.

The investment trend in the past 20 years, stimulated among other things by the German Renewable Energy Sources Act (EEG), has triggered significant learning effects and economies of scale, thus playing a key role in reducing the specific investment costs and therefore also the electricity production costs, in particular of PV and wind turbines. The electricity production costs of new onshore wind turbines (4.0 to 8.2 ct/kWh) and ground-mounted PV systems (3.7 to 6.8 ct/kWh) in Germany are at a similar level to new lignite-fired power plants (4.6 to 8 ct/kWh), and, in good to medium locations, even lower than new hard coal-fired power plants (6.3 to 9.9 ct/kWh) and new natural gas-fired combined-cycle power plants (7.8 to 10.0 ct/kWh) (ISE 2018). The costs specified here for fossil-based power plants in 2018 assume an average emission trading certificate price of 5.3 euros/t CO_2 (ISE 2018).

These cost considerations do not include external costs (health problems and environmental damage), which would generally tilt the balance further in favour of renewable energy sources. The cost comparison also does not take into consideration the system costs caused for example by electricity grids and measures to ensure a continuous and reliable power supply in the overall system (Samadi 2017). These system costs are higher on average for high proportions of fluctuating renewables, but cannot be attributed precisely to individual generation technologies.

In future, further decreases in technology costs are expected for PV systems and wind turbines. Now that EEG 2017 requires tenders for wind turbines and PV systems with capacities of over 750 kW and for new biomass systems, cost reductions due to competitions can be expected. In addition, after the last reform of the European Emissions Trading System, the CO_2 certificate prices have increased and will probably continue to rise in future (see Chapter 5.1 on the development of certificate prices). That will further tilt the competitive conditions in favour of renewables in future.

3.3 THE ROLE OF NATURAL GAS AND SYNTHETIC GAS

- **Natural gas-fired power plants cause far lower CO_2 emissions, are more adjustable and less costly to build than coal-fired power plants. In a transitional period away from coal, gas can take on an important role in securing electricity supply.**
- **During the next decade power generation from gas-fired power plants will increase temporarily to partially offset phased-out or reduced power generation from nuclear and coal-fired power plants.**
- **In the medium term, gas power plant capacity will increasingly serve as rarely used 'back-up' power plants.**
- **In a greenhouse gas-neutral energy system in line with the climate targets, fossil-based natural gas can no longer be used. After 2040, CO_2-neutral gas generated synthetically from renewable electricity could at most replace individual applications currently implemented with natural gas due to the high conversion losses and corresponding high costs.**

Lower emissions as a benefit of natural gas-based power generation compared to coal

In Germany, natural gas is currently primarily used to provide space and process heat, and to generate electricity. Natural gas-based gross power generation has more than doubled between 1990 and 2017, from 36 TWh to 87 TWh (AG Energiebilanzen 2018a). In 2017, this was equivalent to just over 13% of overall German gross electricity generation. At 27 GW, the natural gas-based power plant capacity installed in Germany is roughly equivalent to the scale of the installed capacity of hard coal-fired power plants.

The CO_2 emissions from power generation from natural gas are far lower than those from coal.

From an ecological perspective, natural gas is significantly less harmful than coal. In particular, its adverse climatic impact is lower: The CO_2 emissions of one kilowatt hour of electricity from natural gas-fired power plants (391 g/kWh) are less than half the emissions from hard coal-fired power plants (863 g/kWh), and only roughly one third of those from lignite-fired power plants (1,151 g/kWh) (UBA 2017d). Even taking the greenhouse gas emissions associated with providing the energy sources into account (i.e. the emissions from the upstream chain), natural gas retains a clear advantage over coal (Lambertz et al. 2012; Heath et al. 2014). Only natural gas extracted by means of fracking releases relatively high quantities of harmful methane into the atmosphere, leading to an overall climate impact that can be almost as poor as coal-fired power plants. Emissions of harmful substances like sulphur dioxide, nitrogen oxide and mercury are also far lower in natural gas-fired power plants (per kilowatt hour generated) than in coal-fired power plants (de Gouw et al. 2014).

Gas-fired power plants are suitable as balancing power plants

Gas-fired power plants can be operated more flexible allowing for a greater range / quicker change in power supply and have lower specific investment costs than coal-fired power plants.
As a result, they are well suited to taking on responsibilities for security of supply.

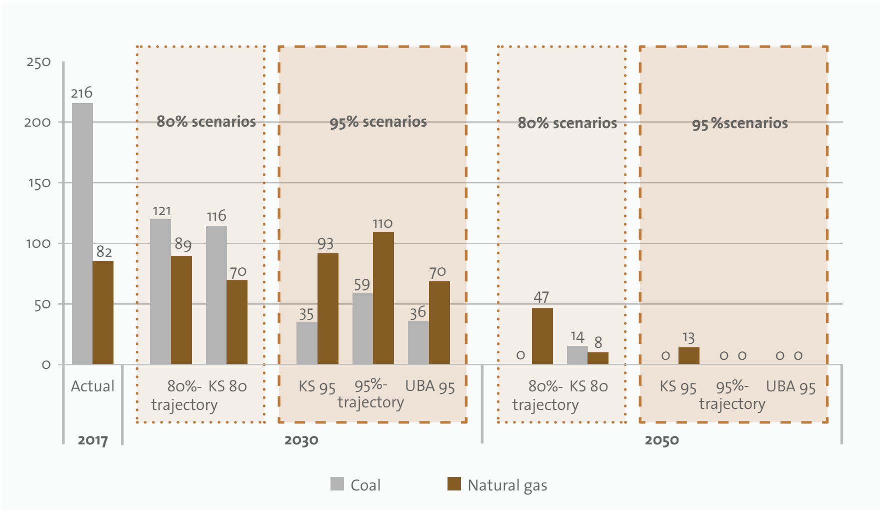
Gas-fired power plants have multiple properties that make them ideal for providing a variety of energy system services. Accordingly they are well suited to compensating for fluctuating electricity generated by wind and solar power plants, and can therefore make an important contribution to securing the power supply (see Chapter 3.5). For example, gas-fired power plants are technically more suited to quickly respond to changes in electricity demand compared to coal-fired power plants (see Chapter 1.4, Tab. 1.4.1). The specific investment costs are also lower than those of coal-fired power plants. As a result, gas-fired power plants are more economical at low capacity utilisation levels. This means that, from a technical and economical perspective, gas-fired power plants are well qualified to take on responsibilities for security of supply.

Up until 2030 natural gas will increase its role in the electricity mix, however, in the long term its share will shrink.

Accordingly, studies on the implementation of the climate targets for the period until 2030 prescribe a rapid decrease in coal-fired power generation, while electricity generation from natural gas increases slightly in most scenarios (see Fig. 3.3.1).

Between 2030 and 2050, these studies assume a decrease in the volume of electricity produced with natural gas. While the CO_2 emissions of natural gas are lower than coal, even natural gas must be replaced with CO_2-free energy sources to achieve the long-term goal of greenhouse gas neutrality. Accordingly, natural gas is only a relatively short bridge to a greenhouse gas-neutral future.

Fig. 3.3.1: Net electricity production from coal and natural gas in 2017 and by various scenarios in 2030 and 2050 (in TWh)



Source: Compilation: Wuppertal Institute based on 'Actual' (AG Energiebilanzen 2018a), '80% or 95% trajectory' (BCG and Prognos 2018), 'KS80 or KS95 (Öko-Institut and Fraunhofer ISI 2015), 'UBA 95' (UBA 2017c)

The decrease in power generation from natural gas between 2030 and 2050 is not accompanied with a corresponding decrease in the installed gas power plant capacity, as the natural gas capacities are still required as a back-up.

However, the significant decrease in natural gas-based power generation between 2030 and 2050 prescribed in the scenarios is not accompanied to the same extent with a decrease of installed gas power plant capacity, as even in the middle of the century, natural gas capacities will still be required as a 'back up' to ensure secure and continuous power generation in times of very low PV and wind feed-in due to the weather. Still, the full-load hours of gas-fired power plants must decrease continuously after 2030 at the latest, to ensure that the CO_2 emissions decrease in accordance with the climate targets.

Synthetic gas

Synthetic gas can be produced in a climate-neutral manner, but the process results in relatively high energy conversion losses.

In the long term, from roughly 2040, an increasing volume of synthetic gas could be used for power generation instead of natural gas. This gas could be produced domestically or abroad based on hydrogen produced with renewable energy and added CO_2 (known as 'Power-to-Gas', PtG) and is potentially climate neutral – depending on the source of CO_2 used. However, the relatively high energy conversion losses during the generation process must be noted (DBI Gastechnologisches Institut et al. 2017). They restrict production, at least on the basis of domestic renewable energy sources. The corresponding technologies are currently still under development, so that there are still significant uncertainties regarding the costs.

Synthetic gas could be used in particular where electrification is difficult (e.g. for aircraft, ships, lorries). It is also advantageous that the existing gas infrastructure (grids and storage) can still be used. However, different scenarios include very different percentages of synthetic gas (and synthetic fuels overall) (see for example DENA 2018). In summary, it can be noted that PtG will have a place in the energy sector of the future, in particular due to its storage capabilities. However, it cannot be assumed that it will replace natural gas on a wide scale due to the high conversion losses alone.

3.4 SIGNIFICANCE OF STORAGE TECHNOLOGIES

- » **Storage technologies that allow electricity to be stored and fed into the grid when required will become increasingly important in the future.**
- » **For short-term applications, storage technologies are already very technologically mature and their costs are decreasing rapidly.**
- » **With a long-term perspective, development is required, in particular for seasonal storage facilities, which can store high volumes of energy for extended periods.**
- » **However, in the medium term, other options for increasing flexibility, such as sector coupling, electricity-driven combined heat and power and demand-side management (also using heat storage facilities), will be even more cost-effective than electricity storage facilities.**
- » **The availability of electricity storage is therefore not a limiting factor for implementation of the coal phase-out.**

Grid-connected electricity storage facilities vs. flexible electricity consumers and non-grid-connected energy storage facilities

Grid-connected electricity storage systems make controlled electricity feed-in back to the electricity grid possible.

To assess which role storage plays in the transformation process, a distinction must be made between grid-connected electricity storage systems and flexible electricity consumers. The key characteristic of a grid-connected electricity storage system is that electricity can be fed-in and in particular withdrawn again. This distinguishes grid-connected electricity storage systems from items like batteries for laptops, mobile phones etc., which do not feed electricity back into the electricity grid. Examples of established technologies for grid-connected electricity storage systems include pumped storage power plants, batteries (e.g. rechargeable batteries in electric vehicles), flywheels etc.

There are a series of energy storage facilities in contact with the electricity system - but which cannot feed electricity into the grid. Heat storage facilities are one example. Since storing heat is often cheaper and more efficient than storing electricity, heat storage can be used to increase the flexibility of electricity demand, e.g. for industrial production processes. Another example are Power-to-X systems that are currently being developed. They produce fuels (e.g. hydrogen) synthetically using electricity (see Chapter 3.3). Here too, there is the option to shift production to times when solar and wind power are in plentiful supply and demand is low. While the synthetically produced energy source can be converted back into electricity subsequently, use in other sectors is more economical. Producing these energy sources based on electricity from fossil fuel-fired power plants only leads to additional CO_2 emissions due to the high conversion losses. Furthermore, it must be noted that depending on the technology used, some energy storage facilities can entail significant energy losses.

Storage demand and options

The majority of the electricity storage capacity is currently provided via pumped storage power plants. The details on the storage capacity vary between 6 and 11 GW, with a storage volume of approx. 40 GWh due to the different evaluations (BCG and Prognos 2018; Deutscher Bundestag 2017).

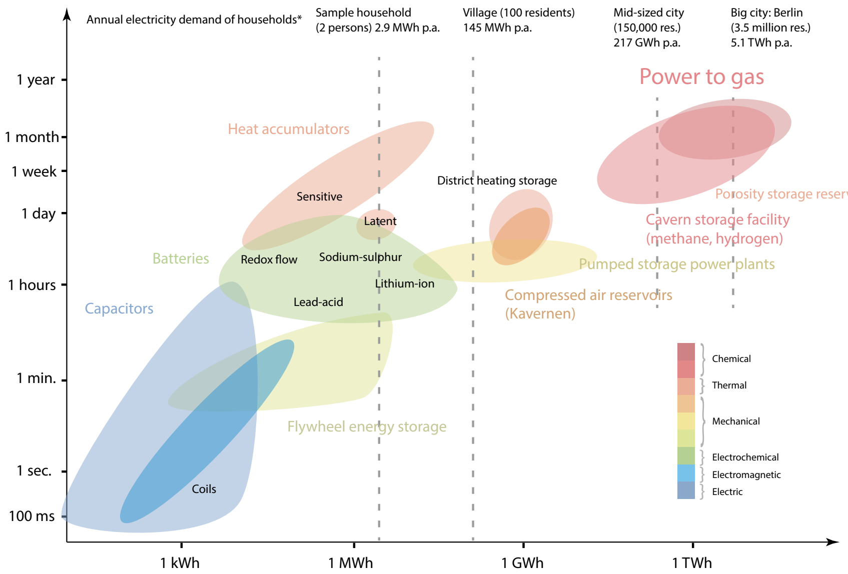
Due to the future increase in fluctuating renewable energy sources, the storage requirement will also increase to balance supply and demand. There are very different applications, from short-term storage facilities, which store electricity for less than a second for grid stabilisation, right up to seasonal storage facilities, which must be able to store large volumes of energy cost-effectively and with only minimal losses over long storage times (see Chapter 3.4.1).

Many short-term storage systems are already technologically very mature. Development is required in particular for seasonal storage.

Without being able to go into details on specifics and development statuses here, it can be said that research and development is required in particular for seasonal storage, while many short-term storage systems are already very technologically mature (Wuppertal Institut, Fraunhofer ISI and IZES 2018; VDI 2017; Fraunhofer 2015).

Fig. 3.4.1: Comparison of various energy storage systems: Storage capacity and retrieval period

Source: Own compilation based on Sterner and Stadler 2017



* excluding industry and CTS; electricity demand per person: 1.45 MWh p.a. The data clouds indicate the capacity ranges of existing plants in Germany.

Seasonal storage systems will not be required until renewable energy sources account for a very high percentage of the electricity mix.

A significant demand for seasonal storage is projected in most studies only at a later stage of the transition for an energy system that is primarily supplied with electricity from renewable sources (VDI 2017; Agora Energiewende 2014; acatech, Akademienunion and Leopoldina 2015). Until then, the rising demand for increasing flexibility can be met via cost-effective options like increasing flexibility of electricity consumption (incl. heat storage facilities), grid expansion, short-term electricity storage and gas-fired power plants (see Chapter 3.1). Seasonal storage systems (e.g. Power-to-X) will not be necessary until a phase-out of natural gas-based power generation takes place. Accordingly, the availability of electricity storage systems is not a limiting factor for the phase-out of coal.

Until 2040, a 60% decrease in the costs for short-term storage systems is to be expected, e.g. for electric vehicles and photovoltaic systems in households.

In the medium to long term, the greatest potential for battery storage systems is expected to come from electric vehicles and household PV systems (acatech, Akademienunion and Leopoldina 2015). The costs there have decreased significantly in recent years and the International Energy Agency (IEA) assumes costs will fall by a further 60% by 2040 (IEA 2017c). Battery storage technologies for PV systems are already competitive today provided they are used to optimise the percentage of own use.

3.5 SECURITY OF SUPPLY IN THE POWER SECTOR

» **Security of supply has various dimensions: The priority is on the guaranteed capacity available in accordance with the load requested and the grid and system stability (which must be secured via the so-called system services, among other things).**

» **Due to existing surplus capacities, further steps can be taken in Germany to reduce coal-fired power generation, even as nuclear power is phased out simultaneously. Sufficient guaranteed existing capacity can be provided via a combination of renewable energies, reserve and gas-fired power plants, short and long-term storage systems, flexible loads and exchanges with other countries.**

» **The system services currently provided by coal-fired power plants can be taken over by other technologies available today (gas-fired power plants, renewable energy sources, storage facilities).**

A secure and interruption-free power supply is a key success factor for Germany's economic competitiveness. Security of supply is broken down into various dimensions: The priority is availability of a sufficient, secure capacity in the long term. At the same time, major system parameters (voltage, frequency) must also be kept stable at short term in their respective nominal range (grid and system stability). This must be distinguished from active grid management via redispatch, i.e. short-term adjustment of power plant operations compared to the original plan (see Chapter 1.4).

Security of supply includes both guaranteed capacity and other short-term system services.

Methodological approaches for calculating the guaranteed capacity

In the entire electricity system it must be ensured at all times with a high degree of probability that every load that occurs can be covered with corresponding generation capacity. Classically, this is proven via capacity balances, which include the following elements:

There are different methodological approaches to calculate the guaranteed capacity.

- Conventional thermal power plants available,
- Pumped storage power plants,
- Renewables-based power plants,
- Grid reserve and security reserve power plants,
- Unusable power plants, plants being overhauled and in downtime,
- Ways to reduce contracted loads,
- Reserve of power plant capacity for system services.

Depending on the methodological approach, the capacity balance may also include other elements:

- Guaranteed capacity via rooting in an overall European system,
- Power plants from the reserve that can be reactivated,
- Standby generating systems (emergency power systems),
- Market-based load adjustment,
- Decentralised storage.

For a longer-term consideration, the future demand and generation capacity development due to new plants and closures will be incorporated in any form of capacity balance.

Development of guaranteed capacity and scope for additional power plant closures

Of the 216 GW of power plant capacity in Germany, 118 GW contribute to the guaranteed capacity.

The issue of future security of supply requires forecasting based on the power plants currently in existence. In 2017, roughly 216 GW of net power plant capacity was installed (BNetzA 2018a; UBA 2018a). Of that capacity, roughly 118 GW was attributable to power plants that can in principle make a substantial contribution to the guaranteed capacity. For future considerations, assumptions must be made on decommissioning of power plants and installation of new power plants. In this respect, the closure of the last nuclear power plants at the end of 2022 and the phase-out of the lignite security reserve in October 2023 (together 12.2 GW) must be taken into account. In addition, a currently unknown number of power plants will be shut down for economic reasons. By 2020/2023, this will be offset by construction of roughly 2 to 4 GW of power plant capacity (BNetzA 2018a).

Accordingly, to assess the question of how quickly coal fired power plants can be closed down without endangering security of supply, the year 2023 is an important milestone. However, the answers are very different based on the different methodological approaches mentioned above.

2023 is an important milestone for the assessment of security of supply, as the last nuclear power plants will have been taken off the grid at that point.

The transmission system operator's (TSO) approach led to the following result for the current year: For 2018, the TSOs assume a guaranteed capacity of 87 GW. The maximum load including the power plant capacity required to provide system services and the load reduction possible today is estimated to be roughly 82 to 84 GW for 2018. For the longer term, the TSOs conclude that the guaranteed capacity will decrease continuously and be at the same level as the maximum load in 2020 (50Hertz et al. 2017). The closure of the last nuclear power plants by 2022 would therefore lead to a gap in coverage of the guaranteed capacity without additional measures. However, this consideration ignores several of the options for delivering guaranteed capacity mentioned above, or makes very conservative estimates for them. For example, the availabilities of conventional and renewable power plants assumed in the TSOs' analysis represent more of a lower limit for the probable availabilities (BNetzA 2018).

The German Association of German Energy and Water Industries (BDEW) also concludes that there will be a coverage gap in 2023. For 2025, it is assumed that roughly 75 GW of conventional power plant capacity will be operational, roughly 15 GW less than in 2018. According to calculations by BDEW, the available conventional capacity will therefore be below the maximum load of over 80 GW (BDEW 2018). However, this estimate ignores both the availability of generation units other than conventional thermal plants, like waste combustion plants, pumped storage power plants, biomass and run-of-river power plants etc., which currently make up an installed capacity of over 11.8 GW, and switchable loads.

There are various estimates on the guaranteed capacity to be expected in 2023 (if no further measures were undertaken).

Agora Energiewende uses the TSOs' capacity balance, but taking additional capacity contractable in other countries into consideration and assuming higher availability probabilities of the energy converters, it concludes that in 2023, in spite of the planned decommissioning of the last nuclear power plants and the phase-out of the lignite security reserve (see Chapter 5.3) totalling 12.2 GW, there will still be a surplus capacity of guaranteed capacity of 10 to 15 GW. In this, Agora Energiewende takes the implementation of market-based demand-side management potential into consideration (Agora Energiewende 2017c).

Studies on periods extending beyond 2023 reveal ways to provide sufficient guaranteed capacity even with a transformation of the energy system in accordance with the climate targets. They use detailed fundamental models of the European energy market and power plant availability and calculate power plant use broken down by the hour. General assumptions in these studies are, that renewable energy sources will be expanded, storage facilities based on existing technologies will be installed and demand-side management and a strong integration in the European electricity market will be implemented. Construction of gas-fired power plants will only be required to a very limited extent, primarily exclusively as back-up power plants (due to the low capital costs but high production costs) (Prognos and Öko-Institut 2017; IZES 2015; Öko-Institut 2017c; Energy Brainpool 2017a). To assess the options for plant closures as well as to determine the need for construction of gas-fired power plants, the geographical distribution of the power plants must be considered to account for grid stability issues.

Very few additional gas-fired power plants, will have to be built (exclusively as backup power plants).

Beyond the issue of the technical capacities in place for supply security covered here, we refer explicitly to Chapter 1.5, which presents the institutional processes with which Germany ensures that power plant closures do not endanger security of supply.

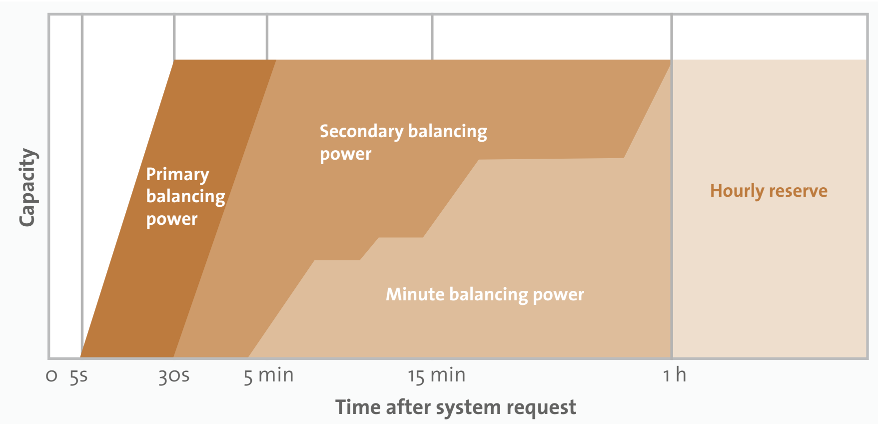
Provision of system services

Above and beyond this, system services are essential for ensuring that the electricity system is stable and robust. They ensure frequency and voltage stability and help to restore supply after a power failure. Coverage of electricity demand is also ensured via a phased regulation mechanism. Fig. 3.5.1 shows the system services tendered on the market. Besides these, there are other system services which are provided implicitly today or ensured via specific contracts with the TSOs. Among others, they include the momentary reserve, reactive power management, black start capability and the provision of short-circuit currents (see Box 3.1).

These system services are currently provided almost exclusively by conventional power plants. As coal-fired power generation is phased out, these system services can be provided increasingly by technologies already available today (gas-fired power plants, renewables, storage facilities).

The system services provided today by coal-fired power plants can be taken over by other technologies which are available (gas-fired power plants, renewables, storage facilities).

Fig. 3.5.1: Grid requirements of power plants for primary and secondary balancing power and minute and hourly reserves



Source: Own compilation based on (Görner 2016)

Box 3.1: System services

Primary balancing power:	Capacity buffer determined based on market needs, provided by all TSOs active on the electricity grid, which must be available in full after 30 seconds at the latest and for up to 5 minutes.
Secondary balancing power: :	Capacity buffer determined based on market needs, provided by all TSOs affected by a fault, which must be available in full after 5 minutes at the latest.
Minute reserve: :	Capacity determined based on market needs to be provided in full within 15 minutes.
Hourly reserve: :	Not a product on the balancing energy market. If a balance deviation cannot be rectified by its originator within 60 minutes, the originator of the deviation itself is responsible for compensating it via intraday trading on the spot market or via OTC (over the counter) trading.
Momentary reserve:	Reserve available in the generators of conventional power plants immediately when a fault occurs due to the inertia of rotating masses in the system.
Reactive power management:	In order to guarantee security of supply, specific voltages must also be maintained throughout the entire grid. This is implemented via reactive power management, currently provided primarily via conventional power plants (synchronous generators).
Short-circuit currents: :	In the event of a short circuit of a cable or transformer, it is automatically disconnected from the grid via permanently installed protective devices. For these protective devices to trigger, a short-circuit current must flow between the grid and the fault location, which is now automatically provided from the synchronous generators of the thermal power plants. Reduction of the conventional power plant capacity will decrease the short circuit level in principle. However, the grid expansion to be implemented in the next few years will reduce the need for short-circuit current. In the medium term, no need for action to provide additional short-circuit current is seen (BNetzA 2015).

3.6 TRANSFORMATION IN THE COAL-FIRED HEATING SECTOR

» **As part of a phase-out of coal-fired power generation, also heat supply security must be taken into consideration.**

» **Via combined heat and power generation (CHP), coal-fired power plants produce 3.5% of all heat demanded in Germany. This heat includes both to heat buildings and in industrial production processes.**

» **Some of the larger power plant blocks typical in the coal sector do not provide any or very little heat (exceptions include the lignite-fired power plants Schwarze Pumpe, Schkopau, Lippendorf). As a result, it is comparatively easy to replace the heat production of larger power plant blocks (where applicable) or to only shut down the blocks that do not contribute to the supply of heat.**

» **In the medium term, coal-based heating supply can be eliminated entirely. Technological alternatives are available to replace coal-based combined heat and power (substitution with natural gas or waste, or use of industrial waste heat). A period of 4 to 5 years must be expected for approval procedures, tenders and construction of alternative plants. The climate targets ultimately require a transition to greenhouse gas-neutral heat generation from renewable energy.**

Provision of heat by coal-fired power plants

Many coal-fired power plants are CHP plants. That means that the waste heat produced when generating electricity is harnessed, for example for space and water heating, or for production processes (e.g. process steam). This combination increases the degree of utilisation of the primary energy used. When phasing out coal capacities, the fact that many coal-fired power plants also provide heat must be taken into consideration.

When phasing out coal capacities, the fact that many coal-fired power plants also provide heat must be taken into consideration.

However, overall, coal plays a relatively minor role as a source of energy for heating (see Tab. 3.6.1). Coal-based CHP plants account for 3.5% of the total heat used. Of the overall CHP heat generation totalling 224 TWh in 2016, only 31.4 TWh was attributable to hard coal and 18 TWh to lignite, with the rest provided largely by natural gas and biomass. In the CHP heating market, coal accounted for only 22%. However, there is a structural dependency for consumers in certain regions (e.g. via connection to heating networks). While replacement is fundamentally possible here, a suitable lead time is generally required.

Coal plays a relatively minor role for heating supply in Germany. Coal-based CHP plants account for just 3.5% of the total heat used.

When considering heat supply, three power plant categories can be distinguished (see Tab. 3.6.1):

I. Lignite and hard coal-fired power plants that do not provide heat

The installed capacity of hard coal-fired power plants that do not provide heat is currently 4.9 GW. Of those, 0.7 GW are already scheduled for closure (final closure notifications for the Gernsteinwerk and Lünen 6 blocks have been submitted to BNetzA) (BNetzA 2018c). This means that in 2020, the installed capacity of hard coal-fired power plants without CHP will be roughly 4.2 GW. Of those, 2.7 GW were built before 1990. 1.5 GW are produced by newer power plants which have only been commissioned in the past few years (see also the description in Chapter 1.1, Fig. 1.1.3). The installed capacity of lignite-fired power plants that do not provide heat is currently 7 GW. Of that, a generation capacity of 0.9 GW will be transitioned to the lignite security reserve by 2020.

Currently, 4.9 GW of hard coal-fired power plants are used to produce electricity only (without heat).

In 2020, lignite power plants without heat provision are expected to have an installed capacity of 6.1 GW.

II. Large-scale lignite and hard coal-fired power plants

Many large-scale power plants provide heat to a limited extent. Only three power plants (Schwarze Pumpe, Schkopau, Lippendorf) are operated with significant heat use percentages.

Many large-scale power plants (> 200 MW) are primarily used to produce electricity and provide heat only to a limited extent (see Tab. 3.6.1). Multiple blocks are often operated at the same location. When deactivating older power plant blocks, the remaining newer power plant blocks could take over heating supply. Where alternative plants must be built, one option could be that power plants continue to run at a reduced rate for a transitional period as required to maintain the heating supply. The capacity of these large-scale hard coal-fired power plants with minor CHP output is 6 GW. Of that, 3.5 GW are generated by plants commissioned after 1990 and 2.5 GW by plants commissioned before 1990. In most large-scale lignite-fired power plants, usable CHP heat accounts for less than 3% of the electricity production energy volume. Only three power plants have higher heat use percentages: At Schwarze Pumpe and Schkopau, they are 21% and 14% respectively (primarily industrial heat use) and 8% for Lippendorf (heat fed into district heating networks) (Öko-Institut 2017b).

III. Small lignite and hard coal-fired power plants primarily used for heat production

Two thirds of coal-fired heat production is restricted to smaller power plants with capacities < 200 MW.

Most of the heat produced with coal is provided by small CHP plants (< 200 MW). These are frequently municipal plants that feed into local heating networks and are primarily operated for heat production. Their total electrical output is just 3.9 GW.

Tab. 3.6.1: Capacity of coal-fired power plants, CHP plants and heat provision

Energy source	Electrical capacity (GW_{el})	Of which CHP plants (GW_{el})	2016 heat production (TWh_{th})
Lignite	20.0	12.9	18.0
Of which > 200 MW	18.9	11.9	5.8
Of which ≤ 200 MW	1.0	1.0	12.2
Hard coal	21.9	17.0	31.4
Of which > 200 MW	18.8	14.1	11.5
Of which ≤ 200 MW	3.1	2.9	19.9

Sources: a Data on electrical capacity based on the list of power plants in the annex (capacity of the plants in operation at the end of 2017) and also power plants with a capacity < 50 MW (+ 0.4 GW for the hard coal-fired power plants and + 0.4 GW for the lignite-fired power plants) b Data on heat production: Block-specific data based on Öko-Institut (2018), scaled based on Umweltbundesamt (2018);

Transformation of the heating supply from coal-based CHP

There are technical alternatives to coal-fired CHP.

There are technical alternatives to coal-fired CHP. For example, they include substitution with other energy sources (natural gas, waste, waste heat), ideally in combination with a reduction in consumption via increased energy efficiency. In some cases, other generation facilities at the same location could take over heating supply. A period of 4 to 5 years must be expected for approval procedures, tenders and construction of alternative plants. In the medium to long term, it must be noted that the climate targets ultimately require a transition to fully greenhouse gas-neutral heat generation, e.g. utilising waste heat and renewable energy sources.

A period of 4 to 5 years must be expected for approval procedures, tenders and construction of alternative plants.

Many operators already plan to replace existing CHP power plants with newer, lower-CO_2 plants by 2022.

Currently, the CHP Act offers significant incentives to replace older coal-based CHP plants. It subsidises new CHP plants, which are to be commissioned by 31/12/2022 and which are based on the use of natural gas, liquid fuels, biomass or waste. A bonus is also paid for replacement of coal-fired power plants. Many operators plan to replace existing CHP power plants with newer, lower-CO_2 plants by 2022 (e.g. in Kiel, Cottbus, Chemnitz, Herne). For example, the Jänschwalde power plant will soon no longer be required to supply heat to the city of Cottbus, as the municipal utility company is currently building an alternative plant. Some cities have already started processes for a full phase-out of coal-fired power generation (e.g. Munich, Berlin).

The alternative plants constructed will depend on regional factors. Flexible gas motors are to be installed in Kiel, Cottbus and Chemnitz. In Herne, Steag plans to build a natural gas-based combined-cycle power plant. In Hanover, a district heating pipeline is to be built to harness waste heat from a waste incinerator. This has already been implemented in Wuppertal, and the old coal-fired heating power plant has been decommissioned. In Munich, a long-term transition of the district heat provision to geothermal energy is planned.

Box 3.2: Wuppertal: energy switch in CHP heat supply

Until recently, the city of Wuppertal had two separate district heating networks. One of these networks was supplied from the Elberfeld coal-fired power plant and not only delivered heat for many households, it also supplied the Bayer chemical plants. The power plant has been in existence since 1900, and was modified multiple times. It was run on natural gas between 1969 and 1989. The current coal-fired block built in 1989 has now reached the end of its technical lifetime and is to be shut down. In order to continue to operate the district heating network, a 3.2 km long connection pipeline to the municipal waste incinerator was built. It was officially commissioned on 7 July 2018 and cost the municipal utility company roughly 40 million euros. That marked the end of the 120-year era of coal-fired power generation in Wuppertal. The municipal utility company assumes that the overall measures will reduce annual CO_2 emissions by 450,000 t.

4 STRUCTURAL CHANGE AND TRANSFORMATION COSTS

Summary

An accelerated coal phase-out initiated by politics entails transformation costs, but also leads to significant benefits, that far outweigh these costs. In order to illustrate the challenges of a coal phase-out for regional economies, Chapter 4.1 gives an overview of the regional economy in the lignite regions. Chapter 4.2 then considers the employment effects of the phase-out of lignite and hard coal-based power generation. Chapter 4.3 shows options for successful structural change. Chapter 4.4 presents the costs and benefits of a coal phase-out, including the temporary increase in electricity wholesale prices on one hand and the avoided open-cast mine expansions on the other. Chapter 4.5 looks at the renaturation costs for open-cast mines.

REGIONAL ECONOMY IN THE LIGNITE REGIONS

The lignite industry is concentrated in the Rhineland coalfields (North Rhine-Westphalia), the Lusatian coalfields (Brandenburg and Saxony) and the Central German coalfields (Saxony and Saxony-Anhalt). It dominates the structure of some districts. They include in particular the Rhein-Erft-Kreis (district) and the Rhein-Kreis Neuss in the Rhineland, the Spree-Neiße and Görlitz districts in Lusatia and the district of Leipzig, the Burgenlandkreis and Saalekreis in Central Germany.

If we not only look at the coalfields, but on the broader, economically interconnected regions, we see that the relative economic significance of lignite in the Rhineland and in Central Germany is comparatively rather low. In both regions, there is a diversified industry and a well-developed infrastructure, which is why they can cope more easily with a coal phase-out. By contrast, lignite plays a relatively important role in structurally weaker Lusatia. Irrespective of the coal phase-out, the demographical changes in all regions, in particular in rurally-dominated regions, lead to a decrease in the workforce and a specialist shortfall.

EMPLOYMENT EFFECTS OF THE COAL PHASE-OUT

In recent centuries, the employment figures in both the lignite and hard coal industry have decreased significantly, and will also continue to decline due to market factors in the years to come. This process can be speeded up with a politically induced coal phase-out. Currently, there are still roughly 18,500 people employed directly in the lignite-fired power plants and open-cast mines; another 4,000 to 8,000 persons work in the hard coal-fired power plants. If we include the indirect and induced employment, i.e. employment at suppliers to the coal industry or the use of employees' wages and salaries for consumption purposes, add a further 11,000 persons in the coalfields for the lignite sector. Nationwide, this figure is increased by a further 22,000 persons. 4,800 - 9,600 indirect and induced employees are assumed for the hard coal sector.

As indirect and induced jobs due to a decrease in coal-fired power generation will be partially compensated by other economic developments, they do not necessarily have to be lost. For example, in recent years, roughly 100,000 new jobs were created in the renewables sector in the Federal States most affected by the coal phase-out. As a result, adding the direct, indirect and induced workplace effects overestimates the employment effect of the pending coal phase-out.

A coal phase-out does not mean unemployment for everyone who works in the coal industry. Roughly two thirds of the direct employees in the lignite industry in 2018 are already over 46 years old. As a result, much of the employment decline can be compensated by regular retirement. Employment opportunities in recultivation of open-cast mines have an additional absorbing effect. Accordingly, the coal phase-out can be implemented with minimal adverse effects on the current generation of employees. For future generations, the structural changes must be actively shaped to create new future-proof jobs in the regions.

OPPORTUNITES FOR A SUCCESSFUL STRUCTURAL CHANGE

The negative consequences of the coal phase-out can be reduced with a targeted structural policy. A successful structural change requires both measures for younger current employees in the coal industry who cannot retire for age reasons, and in particular investments into future-proofing the lignite regions beyond the coal industry.

For a successful structural change, a package of measures that specifically addresses science and soft location factors in addition to classic structural support for the economy and infrastructure expansion would be ideal. Positive employment prospects, for example through the energy transition, can more than compensate the lost jobs in the regions.

Financing for the measures is to be integrated in the existing funding structure (e.g. EU funds) and supplement them appropriately. A structural change fund financed from national government resources is conceivable for this.

COSTS AND BENEFITS OF THE COAL PHASE-OUT

Gradual decommissioning of all coal-fired power plants could lead to a slight electricity wholesale price increase. Assuming that the capacity utilisation of the gas-fired power plants will be increased anyway in the following years, an additional coal phase-out will only lead to a minor additional increase in electricity wholesale prices. The exact level of the rise depends among other things on the development of the raw material prices and other market developments. As increasing electricity wholesale prices automatically reduce the shared contributions under the German Renewable Energy Sources Act (EEG), the electricity price effects of a coal phase-out for domestic customers and companies which are not exempt from the EEG shared contribution will be compensated appreciably. Potential redundancy plan costs for coal industry employees who cannot retire for age reasons are another cost item. In addition, some municipalities will have to expect trade tax shortfalls.

On the other hand, an accelerated coal phase-out leads to a series of positive effects: Besides the importance for climate change mitigation, there will be no need to tap new open-cast mines or mine sections and thus relocate some towns and destroy further landscapes. Another benefit is reduced environmental and health costs via reduced emissions of greenhouse gases and air pollutants like mercury, sulphur dioxide, nitrogen oxides and particulate matter. The electricity wholesale price for a kilowatt hour of coal-based electricity currently covers less than one quarter of these external costs.

ENSURING RENATURATION OF OPEN-CAST MINES

Operators of lignite mines are legally obliged to bear the follow-up costs of lignite mining, and form corresponding provisions in their balance sheets. However, figures on the level and timing of follow-on costs are based on company-internal calculations. Most of the costs are not incurred until the open-cast mine closes. This results in the risk that the current provision system will not be expedient, in particular in the context of an accelerated coal phase-out. In order to ensure that the follow-up costs are actually borne by the lignite companies and not the general public, various measures like a public law fund are being discussed.

4.1 REGIONAL ECONOMY IN THE LIGNITE REGIONS

- **The Rhineland and Central German lignite coalfields are well positioned to cope with structural change thanks to the economic structure in the regions around the coalfields.**
- **By contrast, conditions in the structurally weaker and more rural Lusatian coalfields and the surrounding regions are more difficult. Compared with the other coalfields, they have fewer other industrial sectors, and the infrastructure is mediocre.**
- **Irrespective of the coal phase-out, demographic changes are resulting in a declining workforce and a shortage of skilled workers in all regions.**

The coal phase-out is a challenge for regional economies in the lignite regions.

In the lignite coalfields and regions in particular, the coal phase-out will be challenging for the regional economy. Lignite coalfields are defined as districts with active open-cast mines and/or power plants with net capacities of over 50 MW. Lignite regions also include districts linked to lignite coalfields via significant flows of commuters (DIW Berlin et al. in press; see Fig. 4.1.1 on regional demarcation of coalfields).

There are three lignite coalfields in Germany: The Rhineland coalfields in North Rhine-Westphalia, the Lusatian coalfields in Brandenburg and Saxony and the Central German coalfields in Saxony and Saxony-Anhalt (see Fig. 4.1.1). The Rhineland coalfields are the largest lignite coalfields in Germany by lignite extraction volume and the number of employees in the lignite industry, followed by the Lusatian coalfields and – by a clear margin – the Central German coalfields.

Since 1990, the extraction quantities and employment figures in all three lignite coalfields have decreased. The decrease in the Lusatian and Central German coalfields was particularly significant.

The extraction volumes and employment figures in all three lignite coalfields have been decreasing since 1990 (see Fig. 4.1.2). The decreases in the Lusatian and Central German coalfields were particularly significant after the economic and currency union in 1990. As this process also caused structural upheaval, there is greater scepticism on the pending coal phase-out in Eastern German Federal States. In addition, irrespective of the coal phase-out, demographical changes in all regions are leading to a reduction in the available workforce and a shortage of skilled workers.

Rhineland coalfields: Good conditions for economic realignment

The Rhineland coalfields comprise the four districts on the left bank of the river Rhine and the city of Cologne.

The Rhineland coalfields comprise the Rhein-Kreis Neuss district, the city of Cologne, the district of Düren, the Rhein-Erft district and the district of Euskirchen (see Fig. 4.1.1). Besides the Rhineland coalfields, the superordinate lignite region of Rhineland comprise the cities of Düsseldorf, Krefeld, Mönchengladbach and Leverkusen, the Aachen metropolitan region and the district of Mettmann, the district of Viersen, the district of Heinsberg and the Rheinisch-Bergisch district.

Within the Rhineland coalfields, lignite is structurally dominant in particular for the Rhein-Erft district and the Rhein-Kreis Neuss district. The Niederaußem, Fortuna Nord, Frechen, Ville-Berrenrath and Goldenberg large-scale power plants are concentrated in the Rhein-Erft district. It also includes part of the Hambach open-cast mine. The Rhein-Kreis Neuss district is home to the Garzweiler open-cast mine and the Frimmersdorf and Neurath large-scale power plants. In both districts, the mining, energy and water supply sector (MEWS) accounted for the highest percentages of gross value added in 2015, at 13% and 11%, in the districts associated with the coalfields (own calculations based on VGRdL (2017)).

In economic terms, lignite is relatively insignificant to the Rhineland lignite region.

In the Rhineland lignite region, the relative economic significance of lignite is rather low. Relative to the net power generation, it contributes 0.6% to value creation (DIW Berlin et al. (2018), see Tab. 4.1.1).

In 2017, fewer than 10,000 persons, or roughly 0.3% of the entire working population, were employed directly in the lignite industry in the Rhineland lignite region. As an estimate, it can be assumed that the lignite industry generates another 0.6 jobs in indirect employment within lignite regions (RWI 2017; Öko-Institut 2017b) (see Chapter 4.2).

The Rhineland lignite region has an above-average per capita gross domestic product (GDP) and a highly developed service sector (see Tab. 4.1.1). However, compared with national figures, there is a slightly above-average unemployment rate that has hardly decreased since 2002 (DIW Berlin et al. in press).

The Rhineland lignite region's gross domestic product is above-average.

The Rhineland lignite region has a diversified industry. For example, this includes energy-intensive industries like aluminium and chemicals, logistics and technology as well as agriculture and the food sector. The region is characterised by strong innovation potential, as evidenced by an active start-up scene and the presence of many major corporations' research and development departments (Regionomica 2013; SRU 2017). The Rhineland also has a strong infrastructure. Almost two thirds of the North Rhine-Westphalia's 72 higher education institutions and many technology and energy research institutions are located here (DIW Berlin u. a. 2018). The region is also well connected to North Rhine-Westphalia's transportation network, i.e. to the densest network of roads and the second longest rail network in Germany, to major European waterways and two international major airports. The Rhineland is also home to major conurbations (like Aachen, Cologne and Düsseldorf), and is close to the Ruhrgebiet region.

The Rhineland lignite region has a diversified industry, high innovation potential and a strong infrastructure.

Overall, it can be assumed that the Rhineland lignite region will cope comparably well with a coal phase-out. On one hand, the lignite industry only makes a limited contribution to the region's economic output in spite of its absolute size. On the other hand, there are numerous other industrial sectors, urban areas and research centres, which can be used to economically re-align the Rhineland coalfields towards future-proof sectors like renewable energy sources and energy efficiency.

The Rhineland lignite region is in a good position to cope with the coal phase-out.

Lusatian coalfields: The lignite industry provides a significant portion of economic output

The Lusatian coalfields consist of the city of Cottbus and the Elbe-Elster, Oberspreewald-Lausitz, Spree-Neiße and Görlitz districts; the Lusatia lignite region comprises the Bautzen district in addition to the Lusatian coalfields (see Fig. 4.1.1).

The Lusatian coalfields cover parts of Brandenburg and Saxony.

The lignite industry is of structural significance in particular for the Spree-Neiße (Brandenburg) and Görlitz (Saxony) districts. In the Spree-Neiße district, the MEWS sector accounted for 44% of the gross value added in 2015; in the Görlitz district, it reached just over 16% (internal calculations based on VGRdL (2017)). The Spree-Neiße district contains the Jänschwalde open-cast mine and part of the Welzow-Süd open-cast mine. It is also home to part of the Cottbus-Nord open-cast mine, which was shut down at the end of 2015. In addition, the Spree-Neiße district is home to the Jänschwalde and Schwarze Pumpe large-scale power plants. The Görlitz district is home to the Nochten, Reichwalde and Boxberg large-scale power plants.

Lignite has a relatively high economic significance for the overall rather structurally weak, homogeneous and rural Lusatia lignite region; however this is not tantamount to an industrial monoculture.

In the structurally weaker and more rural Lusatia lignite region, the lignite industry plays a relatively important role. The lignite industry's gross value added share in Lusatia in 2014 was just under 4%. Also, roughly 8,000 direct employees worked in the Lusatian lignite industry in 2017, though that is just 1.8% of the total working population in the region. If you add indirect employees per the 1:0.6 ratio in RWI (2017), this increases the percentage of employees to roughly 2.9%. While there are relatively few other dominating industrial sectors besides lignite in the Lusatia region, it would be inaccurate to call it an industrial monostructure (Markwardt et al. 2016).

The per capita GDP in the Lusatia lignite region is far below the national average (see Tab. 4.1.1). The Lusatia lignite region is characterised by the manufacturing industry and population ageing to a greater extent than Germany as a whole.

The GDP in Lusatia is far below the national average.

The high percentage of over-50-year-olds in Lusatia is due in particular to extensive emigration of young people in the 1990s (DIW Berlin et al. in press; Markwardt et al. 2016). The unemployment rate in Lusatia is almost twice the national average. It decreased at an above-average rate between 2002 and 2014, which can be traced back to the decline in the working population (DIW Berlin et al. in press; Markwardt et al. 2016).

The region has just two higher education institutions and relatively poor transport connections and infrastructure.

Infrastructure in Lusatia is limited: The region only has two higher education institutions, both of which specialise in engineering and natural sciences. Lusatia has neither a relevant airport nor a good connection to fast trains and road networks (DIW Berlin et al. in press).

Accordingly, the conditions for structural change are more difficult in the Lusatia lignite region than in the two other lignite coalfields.

Central German coalfields: Germany's smallest lignite coalfields well positioned for economic realignment

The smallest lignite region, Central Germany, covers parts of Saxony and Saxony-Anhalt.

The Central German coalfields comprise the cities of Chemnitz and Leipzig and the district of Leipzig, the Burgenlandkreis district, the Mansfeld-Südharz district and the Saalekreis district (see Fig. 4.1.1). Outside the Central German coalfields, the Central German lignite region also comprises the city of Halle (Saale), the Erzgebirgskreis district and the districts of Mittelsachsen, Zwickau and Nordsachsen. The lignite industry is structurally relatively insignificant within the Central German coalfields for the Leipzig district (Saxony) and for the Burgenlandkreis and Saalekreis (Saxony-Anhalt) districts. In 2015, the MEWS sector accounted for almost 13% of gross value added in the Leipzig district; the figure in the Burgenlandkreis and Saalekreis districts was roughly 10% (own calculations based on VGRdL 2017). The Leipzig district is home to the Vereinigtes Schleenhain open-cast mine, part of the Profen open-cast mine and the Lippendorf large-scale power plant. The Burgenlandkreis district contains the Lützen open-cast mine, part of the Profen open-cast mine and the Wählitz and Deuben industrial power plants. The Saalekreis district is home to the Schkopau large-scale power plant.

Lignite is of restricted importance for the Central German lignite region.

Both in absolute and relative terms, lignite is of restricted importance for the Central German lignite region. In 2014, the lignite industry only accounted for just over 0.4% of the gross value added of the region (see Tab. 4.1.1). In 2017, the lignite industry in Central Germany also employed just over 2,000 people, equivalent to just under 0.2% of all of the region's working population. If jobs indirectly dependent on lignite are added, the percentage of the workforce increases to roughly 0.3% (see RWI (2017)).

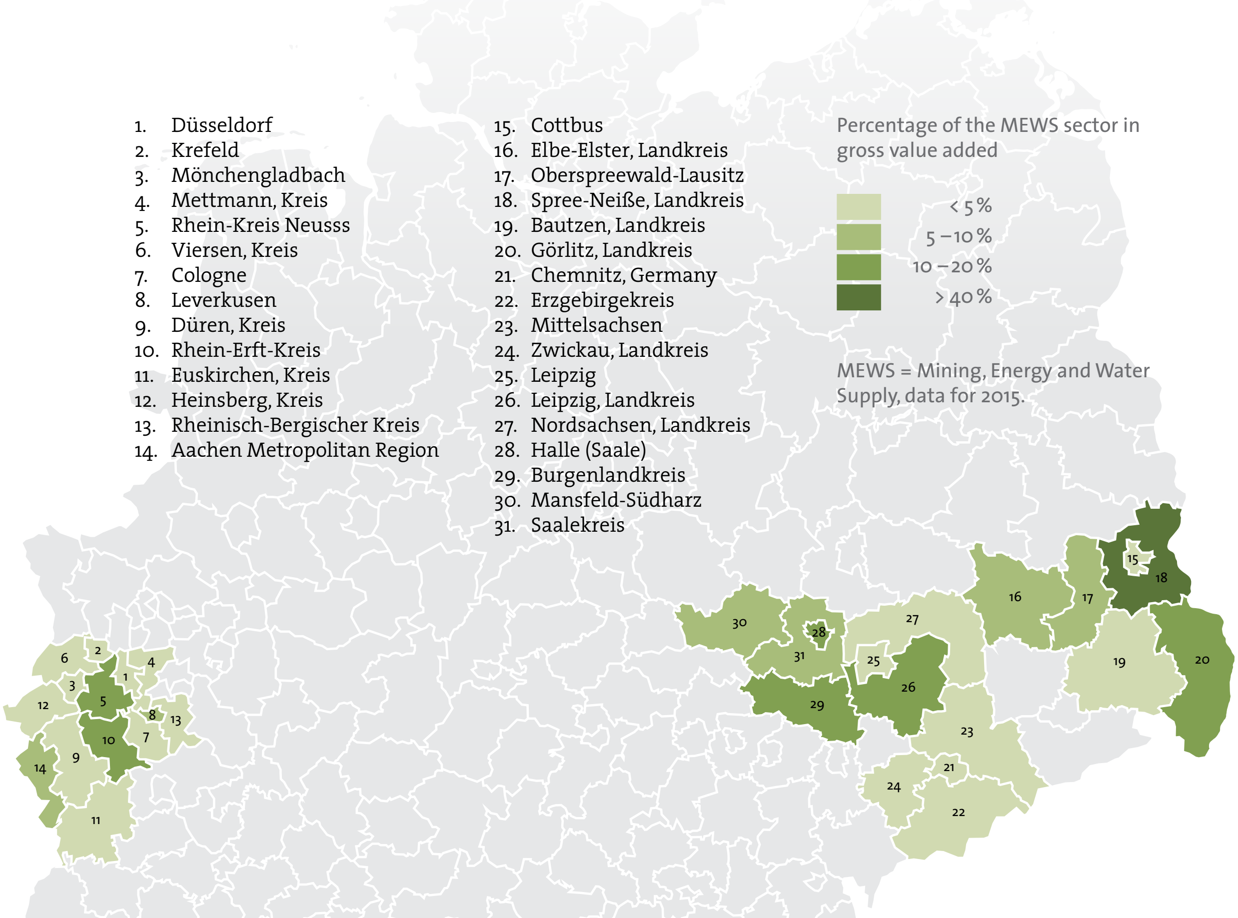
The per capita gross domestic product in the Central German lignite region is slightly higher than in Lusatia, but far below the national average.

The per capita GDP in Central Germany is slightly higher than in Lusatia, but far below the national average (see Tab. 4.1.1). Services and the manufacturing industry are of similar significance for the region as for Germany as a whole. Even though it is lower than in Lusatia, the percentage of over 50-year-olds in Central Germany is above the nationwide average. Here too, emigration of young people is the main reason (DIW Berlin et al. in press). In Central Germany, the unemployment rate is significantly higher than the national average. In the last years, it decreased at an above-average rate due to the decline in the working population (DIW Berlin et al. in press).

Thanks to the diversified industry and the good infrastructure, the Central German lignite region will cope relatively well with a coal phase-out.

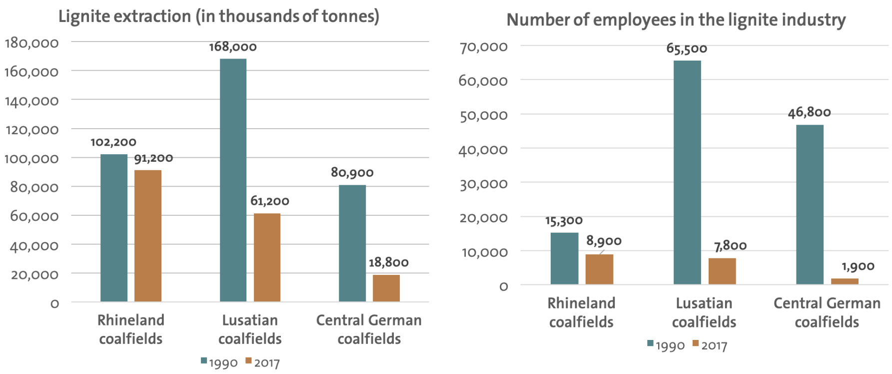
Due to the central location near Leipzig, and the area's chemical and automotive industry, the economy in Central Germany is far more diversified than in Lusatia (SRU 2017). Central Germany also has a far better infrastructure. In addition to twelve higher education institutions, there are many research institutions in the energy, buildings and environmental technology sector there. With Leipzig/Halle airport, Central Germany also has Germany's second-largest freight airport, and one of the most modern transshipment points for express air freight. In summary, it can be assumed that Central Germany will cope relatively well with a coal phase-out due to the number of alternatives available.

Fig. 4.1.1: Gross value added contribution of the MEWS sector at a district (Kreis) level in the lignite coalfields and regions



Source: Own compilation based on DIW Berlin et al. in press

Fig. 4.1.2: Lignite extraction and number of employees in the lignite industry



Sources: Some values rounded. Own calculations based on Öko-Institut (2018a, 2017b); SRU (2017); GWS, DLR, and DIW Berlin (2018); RWI (2017); Coal Industry Statistics (2018, 2017).

Notes: The number of employees refers to the status at the end of the year. It is not directly comparable over time. The data for 1990 only includes employees in lignite mining. In contrast, employees in the lignite-fired power plants for public power supply are included in 2017. Also, the restriction to power plants with a net capacity of over 50 MW does not apply for the employee figures. Of the total of 20,891 employees at the end of 2017 (incl. Helmstedt), 4,985 worked in power plants for public power supply (Coal Industry Statistics 2018).

Tab. 4.1.1: Socio-economic performance indicators of the lignite regions for 2015

	Rhineland	Lusatia	Central Germany	Germany
Per capita GDP	42.97 thousand euros	25.93 thousand euros	27.47 thousand euros	37.13 thousand euros
Percentage of population over 50	43 %	55 %	48 %	43 %
Unemployment rate*	7.3 %	11.0 %	9.2 %	5.7 %
Gross value added	213,711 million euros	23,374 million euros	73,845 million euros	2,729,662 million euros
Contribution of lignite*,**	0.60 % (1.228 million euros)	3.86 % (873 million euros)	0.42 % (299 million euros)	0.09 % (2.368 million euros)
Contribution of Mining, Energy and Water Supply (MEWS)	4 %	13 %	5 %	3 %
Contribution of manufacturing industry	25 %	37 %	32 %	30 %
Contribution of services	75 %	62 %	68 %	69 %
Workforce	3,060,197	459,214	1,451,409	43,057,000
Contribution of lignite***	0.31 %	1.81 %	0.18 %	0.05 %
Contribution of Mining, Energy and Water Supply (MEWS)	1.59 %	3.05 %	1.89 %	1.34 %
Contribution of manufacturing industry	19 %	29 %	26 %	24 %
Contribution of services	80 %	69 %	73 %	74 %

Sources: Coal Industry Statistics (2017b); VGRdL (2017); DIW Berlin et al. in press, own calculations

Notes: * Reference year 2014; ** Only relative to the net power generation DIW Berlin et al. in press; *** Employees in lignite mining and the lignite-fired power plants for public power supply.

4.2 EMPLOYMENT EFFECTS

- **Currently, roughly 18,500 persons are employed directly in lignite-fired power plants and lignite mining. Another 4,000 to 8,000 employees work in hard coal-fired power plants.**
- **The employment figures in the lignite industry will decrease to approx. 14,500 by 2030 without additional climate policy intervention. Additional measures to implement the 2030 climate targets could lead to a reduction to roughly 8,000 employees.**
- **Most of the direct employees in the lignite industry could also take normal retirement, even with an accelerated coal phase-out to reach the 2030 climate target.**
- **As some indirect and induced jobs would be compensated by other economic developments in a transformation process over 15 to 20 years, adding the direct, indirect and induced effects on jobs overestimates the employment effect of a coal phase-out.**

In 2018, approx. 18,500 persons are employed directly in the lignite industry (power plants and open-cast mines). Of those, 8,900 work in the Rhineland coalfields, 7,800 in the Lusatian coalfields, and 1,900 in the Central German coalfields. Another approx. 150 people still work in the shut-down Helmstedt coalfields, 600 people for the Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft (LMBV), which is responsible for renaturation of the former GDR open-cast mines, and 300 people work at the Romonta montan wax factory. As coal mining is far more labour-intensive than work in power plants, and almost all hard coal-fired power plants run on imported coal, there are far fewer employees in the hard coal industry. The hard coal-fired power plants employ roughly 4,000 to 8,000 people nationwide (see Tab. 4.2.1) (DIW Berlin et al. in press; Öko-Institut 2017b; Coal Industry Statistics 2017a; SRU 2017).

18,500 direct employees work in the lignite industry; there are a further 4,000 to 8,000 in hard coal-fired power plants.

Indirect and induced employment effects

Indirect and induced employment effects are difficult to quantify, as not all jobs can be attributed clearly (SRU 2017). For example, indirect employees work for suppliers who provide services and intermediate goods for the coal industry. Induced employment results from the fact that employees in the coal industry spend their wages to the benefit of other companies. Based on a series of studies (incl. EEFA (2011, 2010)), RWI (2017) concludes that for every direct employee in the lignite industry, there are another 0.6 indirect and induced local employees (as the study does not differentiate clearly between coalfields and regions, the broader definition of lignite regions will be used below for local employment effects). For every direct employee in the lignite industry in Germany, there are roughly 1.8 indirect and induced employees. Accordingly, the industry also currently employs roughly 33,000 persons indirectly or in induced jobs, roughly 11,000 of them in the lignite regions (see Tab. 4.2.1). 4,800 to 9,600 indirect and induced employees are assumed for the hard coal sector.

As indirect and induced jobs can be partially compensated by other economic developments in a 15 to 20-year transformation process, the effects of the coal phase-out on employment would be overestimated by adding these jobs.

As indirect and induced jobs can be partially compensated by other economic developments in a transformation process over 15 to 20 years, it is to be assumed that most of these jobs will only be shifted, not lost. As a result, adding the direct, indirect and induced workplace effects overestimates the employment effect of the coal phase-out. In addition, the corresponding effects are generally calculated from historic time series, and therefore do not represent the dynamics of structural change, and are therefore generally overestimated (Arepo Consult 2017).

Decline in employment figures

Jobs in the coal industry will already decrease to approx. 14,500 in the next few years based on the measures passed to date.

Based on previous decisions, unless other measures are taken in the coal sector, further jobs would be lost due to reduced production of coal-based electricity and decreased lignite extraction. (DIW Berlin et al. in press; BCG and Prognos 2018; Öko-Institut, BET and HWR 2017). The Öko-Institut assumes that, taking the resolutions on the lignite security reserve into account (see Chapter 5.3), the number of indirect employees in the lignite industry will decrease from 18,500 to approx. 14,500 by 2030 (see Tab. 4.2.2). In the event of a linear reduction in coal-fired power generation above and beyond the security reserve to achieve the 2030 sector targets, roughly 6,500 further direct jobs would be affected (Öko-Institut 2018a). The exact extent and regional distribution of the decline depends on the specific structure of the phase-out. In the event of a coal phase-out strictly by power plant age, Rhineland would be affected by declining employment to a greater relative extent due to its older power plants than the two coalfields in Eastern Germany (DIW Berlin et al. in press). These figures do not yet include potential additional consequences due to the pending restructuring processes at RWE and E.ON, in which up to 5,000 jobs are to be cut at the two companies.

Normal retirement

Two thirds of the direct employees in the lignite industry are over 45. As a result, many of the employees can retire at the normal age even in the event of an accelerated coal phase-out to implement the 2030 climate targets.

A coal phase-out would not condemn all employees to unemployment. Roughly two thirds of the approx. 18,500 direct employees in the lignite industry are over 45 years of age (Coal Industry Statistics 2017d; IÖW 2017). In addition, a coal phase-out would also generate additional demand for labour for accelerated recultivation of the open-cast mines. In the event of a linear coal phase-out trajectory to reach the 2030 sector target, the number of employees remaining in lignite mining in the period until 2030 is lower than the number of jobs required in mining and recultivation, taking the retirement age into consideration (see Tab. 4.2.3) (Öko-Institut 2018). Many of the employees could therefore retire at the normal age, and would not be at risk of unemployment (DIW Berlin et al. in press; Öko-Institut 2018a; SRU 2017).

Tab. 4.2.1: Current employees in lignite mining and the lignite and hard coal-fired power plants

Employees	Lignite (open-cast mines and power plants)					Hard coal (power plants)	Total
	Rhineland coalfields	Lusatian coalfields	Central German coalfields	Rest of Germany	Total	Germany	
Direct*	~8,900	~7,800	~1,900	0	~18,500	~4,000–8,000	~22,500–26,500
Indirect and induced*	~5,300	~4,700	~1,100	~22,100	~33,300	~4,800–9,600	~38,100–42,900

Source: Some values rounded. Own calculations based on Öko-Institut (2018a, 2017b); SRU (2017); GWS, DLR, and DIW Berlin (2018); RWI (2017); Coal Industry Statistics (2018).

Notes: * Lignite: Employees in lignite mines and the lignite-fired power plants for public power supply in 2017 (Coal Industry Statistics 2018); Data excludes the Helmstedt coalfields and employees of the Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH (LMBV) for open-cast mine recultivation (Lusatian coalfields: 410 employees, Central German coalfields: 210 employees) (Öko-Institut 2018a); Hard coal: 5,000 to 9,000 employees in the hard coal-fired power plants in 2016 less 800 to 1,000 employees due to job cuts at Steag (SRU 2017); ** Lignite: Factor 1.6 in the coalfields and 2.8 for the rest of Germany (RWI 2017); Hard coal: Factor 1.2, based on an average factor of 0.6 for hard coal mining (GWS, DLR, and DIW Berlin 2018) and in line with the data from Öko-Institut (2017b), that lignite-fired power plants generate roughly twice as much indirect employment as lignite mining.

Tab. 4.2.2: Decrease in direct employment in the lignite industry due to the coal phase-out*

	2015	2020	2025	2030
Employment development in the **lignite industry*** assuming previous measures (esp. lignite security reserve)**	20,696	16,770	16,970	14,472
Employment development in the lignite industry in compliance with the 2030 climate target (linear reduction)*** (incl. recultivation****)	20,696	16,770	12,642	8,011

Source: Öko-Institut (2018a), own calculations

Notes: * Lignite mining (incl. recultivation of the open-cast mines and lignite refinement) and lignite-fired power plants; ** Assumption of rising volume of lignite extracted per employee as in the past ten years; *** Assumption of constant lignite extraction volume per employee (no productivity advances, as the volume of lignite extracted is decreasing); **** For 30% of the jobs lost per annum from 2020 on, new employment will be created transitionally in recultivation (for a further four-year period).

Tab. 4.2.3: Employment development in lignite mining

	2015	2020	2025	2030
i) Development of the need for employment in **lignite mining** assuming previous measures (esp. lignite security reserve)*	15,273	~12,300	~12,500	~10,700
ii) Development of the need for employment in lignite mining in compliance with the 2030 climate target (linear reduction)** (incl. recultivation***)	15,273	~12,300	~9,700	~6,400
iii) Development of employment figures in lignite mining taking the standard retirement age into consideration (without new hires)	15,273	~12,300	~8,600	~6,000

Source: Öko-Institut (2018a), own calculations

Notes: * Assumption of a rising volume of lignite extracted per employee as in the past ten years;** Assumption of constant lignite extraction volume per employee (no productivity advances, as the volume of lignite extracted is decreasing); *** For 30% of the jobs lost per annum from 2020 on, employment will be created transitionally in recultivation (for a further four-year period).

4.3 HOW TO MAKE THE STRUCTURAL CHANGE A SUCCESS

- **A successful structural change requires both measures for younger employees in the coal industry who cannot retire for age reasons, and investments into future-proofing the regions.**
- **Structural policy must address innovations and the economic potential of all sectors, e.g. by supporting the economy, science, infrastructure and civil society.**
- **In the short and medium terms, employment can also be created via an ambitious building refurbishment subsidy programme. The foreseeable general shortage of skilled workers also offers employment prospects.**
- **The investments required for the structural change can be financed by setting up a structural change fund using Federal Government resources.**

Unlike the processes in Eastern Germany after 1990, the upcoming structural change can be planned and will occur over an extended period of time.

A targeted structural policy could reduce the negative consequences of a coal phase-out. Unlike historical processes in Eastern Germany, one main advantage of the upcoming structural change is that it can be planned and will occur over an extended period of time. For a successful economic development in the coal regions, structural change must be shaped actively and in good time by all stakeholders involved (DIW Berlin et al. in press; BMWi 2017a; SRU 2017).

Successful structural change requires measures for employees too young to retire. However, the priority is to secure future value creation in the regions by supporting existing and new companies and creating new, future-proof jobs.

Prospects for employees currently working in the lignite industry

The coal phase-out will result in new demand for labour to dismantle power plants and for the earlier remediation of the coal mines.

By 2030, roughly two thirds of the around 18,500 remaining direct employees in the lignite industry can retire as planned. The coal phase-out will also create new demand for labour to dismantle power plants and for earlier remediation of the coal mines (see Chapter 4.2). For another 10% of the current employees, early retirement schemes such as full or partial retirement from the age of 55 could be possible, as is already usual in some of the mining companies (SRU 2017).

Only 4,000 to 5,000 employees will have to find a new profession after 2030.

For the remaining quarter of the younger employees in the lignite industry – approx. 4,000 to 5,000 – a coal phase-out will require them to consider a change of profession for the period after 2030. Diversified training in the mining companies can give them a solid foundation for this. Via a principle of rotation, like that implemented e.g. at Vattenfall in Berlin, trainees can learn different skills in various functions to prepare them for a wider range of employment opportunities.

An ambitious energy-focused building refurbishment programme could offer significant regional economic potential. With an appropriate subsidy programme, 19,000-37,000 new local jobs could be created.

In the short and medium term, employment could be created in the energy-focused building refurbishment sector. Energy-focused building refurbishment offers a high regional economic potential, as roughly two thirds of all buildings are over 40 years old. With a suitable subsidy programme and assuming a refurbishment rate of 2-3%, this could create an additional 19,000 to 37,000 local jobs and also contribute to achieving a climate-neutral building stock by 2050 (DIW Berlin et al. in press).

The future skills shortage in all regions will make a change of profession easier.

It is assumed that the impending shortage of skilled labour will make it easier to change jobs (Markwardt et al. 2016; ifo Institut 2014). In a survey of Lusatia, roughly 40% of companies surveyed reported a lack of sufficiently qualified personnel, which they viewed as a risk for their medium to long-term business success. The same is true for a lack of specialists in craft and commercial sectors and for academic specialists in business management and engineering (Markwardt et al. 2016).

However, the wage level in the lignite industry is far higher than comparable new areas of employment (DIW Berlin et al. in press; SRU 2017). As a result, it cannot be ruled out that employees will earn less when changing industry (DIW Berlin 2017a).

In addition, measures to compensate for lost income for employees affected by job losses are also conceivable (DIW Berlin et al. in press; SRU 2017); see Chapter 4.4 on potential redundancy plan costs).

Structural development measures

Targeted and sustainable regional development is essential to future-proof the lignite regions, above and beyond compensating the social costs of the coal phase-out (SRU 2017). Promoting the economy, science, infrastructure and civil society are ways to make the structural change a success:

Promoting the economy, science, infrastructure and soft location factors can make structural change a success.

Economy: Regional economic development in the lignite regions could focus on industries of the future, like renewable energy, energy efficiency, building refurbishment, electromobility, digitalisation and tourism (DIW Berlin et al. in press; SRU 2017; E3G 2015). For example, closed open-cast mines can be repurposed for both tourism and leisure facilities, or as sites for wind and photovoltaic farms (DIW Berlin et al. in press, SRU 2017).

Regional business development should focus on future industries like renewable energy, energy efficiency, electromobility, digitalisation and tourism.

As it may be difficult to attract major new industrial developments to Lusatia, and the company structure is fragmented and heterogeneous with low patent and start-up activities, the existing studies primarily recommend promoting innovation activities in existing companies (Markwardt et al. 2016; E3G 2015; ifo Institut 2014). For example, corresponding measures include targeted contacting of companies for idea generation, promotion of partnerships between business and science or ensuring seamless financial support throughout the entire innovation cycle (Markwardt et al. 2016). Rhineland and Central Germany offer more points of contact to existing industries like the chemicals and automotive industries (SRU 2017).

Given the fragmented company structure with low patent and founding activity, support for innovation activities in existing companies is recommended for Lusatia.

Science: Higher education and research institutions are significant drivers of innovation and cooperation partners for the private sector (BTU 2017). As a result, research promotion and greater dovetailing of research and business – especially in small and medium-sized enterprises – and increasing the number of spin-offs from research institutions play a key role in developing industry-relevant projects and establishing new companies (DIW Berlin et al. in press). New jobs in (non-)university research and development could help keep young people in particular in the (Eastern German) lignite regions and attract or incentivise the establishment of companies or subsidiaries (SRU 2017).

Increased dovetailing of research and business and an increase in spin-off companies is key to attract new corporate developments.

Infrastructure: Good transport connections, fast Internet and other infrastructure facilities are not only important location factors for companies, they also make regions attractive, especially for young people (DIW Berlin et al. in press). As a result, specific infrastructure projects should be promoted in the Eastern German lignite regions in particular. They include expansion of the digital infrastructure, better rail connections to metropolitan regions (e.g. Berlin and Dresden for Lusatia) and neighbouring countries (Agora Energiewende 2016b, 2017a).

In the Eastern German lignite regions in particular, specific infrastructure projects should be promoted.

Soft location factors: In order to counter the existing emigration trend, soft location factors should also be promoted. Standards of living and attractiveness are what make people stay in a region and companies invest in a region, as they can find the staff they need here. Given the demographic changes, a structural development concept should also target cultural and leisure activities, support for civil society activities of all kinds, e.g. in the arts, culture and preserving traditions, and services for young families (Agora Energiewende 2016b, 2017a; SRU 2017; Wuppertal Institut 2016). Vattenfall and RWE have been active in this area in the past (event sponsorship, contributions to financing kindergartens or football clubs, see Chapter 4.4). Establishment of a local endowment fund earmarked for this purpose could promote civil society activities sustainably and unbureaucratically in the long term (Lausitzer Perspektiven 2018; IRR 2017; Metropolregion Mitteldeutschland 2017).

Regional initiatives are important for developing and implementing structural change concepts.

Structural change can only succeed if the soft location factors are also improved.

Ideas for structural development must build on the local characteristics and strengths. Corresponding regional initiatives will be initiated in the regions, like Zukunftsagentur (future agency) Rheinisches Revier (formerly Innovationsregion Rheinisches Revier GmbH from 2014-2018), Innovationsregion Lausitz GmbH (iRL, since 2016) and Europäische Metropolregion Mitteldeutschland e. V. (since 2014), which are developing concepts for a future without lignite in the regions. To support the lignite regions, the German Federal Government launched the Unternehmen Revier (Operation Coalfields) subsidy programme (BMWi 2017a), which is also to draw up investment concepts (WL 2018; IRR 2017; Metropolregion Mitteldeutschland 2017).

Structural change fund to finance measures

EU, German Government and Federal State funds are available to finance structural change in the lignite regions.

Fundamentally, funding is available from the EU, the German Government and the Federal States, as well as the shared federal and state responsibility 'Improvement of the Regional Economic Structure' to finance structural change in the lignite regions (GRW) (DIW Berlin et al. in press, Wuppertal Institut 2018). For example, Lusatia receives approx. 35 to 40 million euros from the European Structural and Investment Fund annually. This results in the following problems that must be addressed:

- For some funds, the application and processing workload for smaller and medium-sized companies is prohibitively high in some cases. Assistance with the application process could be improved or periods between application and approval could be reduced (Markwardt et al. 2016).
- In addition to this, conventional EU structural funding aims to develop the structures of structurally weak regions, not to prevent weakening of currently relatively prosperous regions (Markwardt et al. 2016). For example, the effects of a politically induced coal phase-out could be included in the calculations for the next funding period.
- If existing funds are redistributed, adaptation of the corresponding European criteria to benefit the lignite regions could also result in a debate on distribution with other structurally weak regions (Agora Energiewende 2017a; Markwardt et al. 2016).
- The need to observe EU state aid regulations in Improvement of the Regional Economic Structure programme, for example, means that national funding is only possible to a limited extent.

A separate fund using German Government resources could be created to finance the structural change.

A separate fund using Federal Government resources could be set up to finance structural change. The Coalition Agreement between the CDU, CSU and SPD (2018) indicated that further funds will be made available for regional structural policy due to the coal phase-out. Coordination with the European Commission is required to determine how a fund specifically for the lignite regions can be created in compliance with the EU state aid regulations (DIW Berlin et al. in press). Funds should guarantee competition for the best ideas for structural change and must define which stakeholders are eligible for funding. It is crucial that the recipients are companies and persons tapping new, sustainable business areas with innovations.

4.4 COSTS AND BENEFITS OF THE COAL PHASE-OUT

» **In the short term, coal-fired plant closures would result in a slight increase in the electricity wholesale prices.**

» **The decrease in employment due to the coal phase-out can lead to redundancy plan costs. Some cities and municipalities will be affected by losses of municipal tax revenue.**

» **An accelerated coal phase-out could avoid expansion of open-cast mines and therefore resettlement, as well as further environmental and health problems.**

An accelerated coal phase-out has both costs and benefits. The costs range from system costs in the electricity sector and redundancy plan costs, to losses of municipal tax revenue. Besides climate protection, the benefits of a coal phase-out include avoidance of resettlements and destruction of environmentally valuable surfaces as well as reduced environmental and health costs due to emission of air pollutants.

An accelerated coal phase-out will lead to a slight increase in the wholesale electricity prices.

Effects on the electricity system and the electricity wholesale price

In the short term, closure of coal-fired power plants would probably lead to a slight increase in electricity wholesale prices (DIW Berlin 2014e; PwC 2016). The electricity price effects of a coal phase-out depend largely on the specific coal phase-out instrument. The long-term effect of a complete phase-out of coal-fired power generation by 2040 compared with a reference scenario was estimated to be 0.18 ct/kWh (ewi 2016). For the reference scenario, the study assumes an increase in the electricity price to 7.59 ct/kWh in 2040. This assumption is within the range of standard cost trend forecasts.

One result of this medium-term increase in electricity wholesale electricity prices would be to bolster natural gas-fired power plants, which require higher electricity prices than lignite-fired power plants in particular in order to operate viably. Accordingly, at 75%, purchases of natural gas form the largest individual item in the increased expenditure for the electricity system (ewi 2016). Statements on the increase in the electricity wholesale electricity prices therefore depend significantly on the development of raw material prices. Potential wholesale price effects of the coal phase-out must be considered in the context of the European electricity market, which compensates the effects significantly.

The decrease in the shared contributions under the German Renewable Energy Sources Act (EEG) will diminish a potential impact on the electricity price due to the coal phase-out by roughly 50%.

As rising electricity wholesale prices automatically lead to a reduced shared contributions under the German Renewable Energy Sources Act (EEG), the electricity price effects for domestic customers and companies not exempt from the EEG shared contribution are only equivalent to roughly 40-60% of the change (enervis 2015; DIW Berlin 2015a).

Costs of compensation for employees

The trade union Ver.di had the costs of redundancy plans calculated for the event that none of the employees in the power plants find other employment after an early phase-out, and thus all receive their previous wages including further increases per the collective agreement until they reach retirement age (enervis 2016). This represents an extreme scenario, as it is to be assumed that new jobs will be created in other areas, as described above (see Chapter 4.3.). For this extreme scenario, enervis calculated redundancy plan costs of approx. 158 million euros per annum for a period from 2016 to 2050 for the power plant employees alone. The costs are calculated from the difference between a coal phase-out by 2040 (Agora Energiewende 2016a) and a reference scenario in which the last coal-fired power plant is not shut down

As expected employment effects are limited, costs of potential redundancy plans must also be assumed to be correspondingly low.

until 2050. Similar estimates apply for the employees in lignite open-cast mines who were not considered in this survey, but are roughly equivalent in number to the staff of all coal-fired power plants.

Losses of municipal tax revenue

The coal phase-out will cause losses of trade tax revenue in the affected communities.

While losses of tax revenue in the communities affected by the coal phase-out cannot be fully compensated by construction of wind and solar farms, future tax revenues from renewable energy sources will be more broadly distributed (Michel 2018).

Municipal owners or stakeholders e.g. in RWE AG or Steag must expect write-downs and dividend cuts.

Municipalities which co-own coal-fired power plants must expect additional write-downs. In the Rhineland region, for example, many municipalities hold shares in RWE AG. Due to poorer operating results in recent years, some of their dividend payments have been reduced or even suspended. Write-downs of value impairments caused the city of Essen to report losses of 680 million euros in its stock assessment in 2013 alone (Michel 2018, 2017). There are similar developments at Steag, one of the largest operators of hard coal-fired power plants.

A coal phase-out endangers the financing of smaller local projects by the coal companies.

Moreover, in the past in particular Vattenfall and RWE have sponsored numerous events in the coal regions and also contributed to financing kindergartens or football clubs. Due to the weaker business position, they have cut back these activities significantly, especially since Vattenfall's withdrawal from Lusatia. A certain compensation can and should be created for all of these cases from structural funds (see Chapter 4.3).

Avoided resettlements

Resettlement of approx. 5,000 people and deforestation of the remainder of Hambach Forest could be avoided.

In Germany, over 120,000 people have already had to be relocated for lignite open-cast mining in recent decades. An accelerated coal phase-out eliminates the need to dig new open-cast mines or mine sections (DIW Berlin et al. in press; DIW Berlin 2017c; SRU 2017; Öko-Institut 2017b). This can avoid further destruction of landscapes and resettlement of towns:

- In Rhineland, the already approved open-cast mines Garzweiler II and/or Hambach could be reduced in size, preserving villages with over 3,000 residents (Berverath, Westrich, Kuckum, Keyenberg, Lützerath, Immerath). In addition, the remaining sections of the Hambach Forest could be protected from deforestation. Hambach Forest has existed since the last ice age and, as one of the oldest forests in Germany, it is home to a diverse ecosystem of flora and fauna (DIW Berlin 2014a; Agora Energiewende 2016a; SRU 2017).
- In Lusatia, the Mühlrose special field of the Nochten 2 open-cast mine is slated for redevelopment. By 2020, a decision is also to be made on whether subfield II of the Welzow-Süd open-cast mine is to be developed (LEAG 2017). Without the two new developments, the villages and districts Trebendorf, Proschim and Welzow could be preserved, and resettlement of roughly 1,000 people could therefore be avoided (Klima-Allianz Deutschland 2017; Agora Energiewende 2016a; SRU 2017).
- In Central Germany, expansion of the Vereinigtes Schleenhain open-cast mine would no longer be necessary (SRU 2017; DIW Berlin 2017c). As a result, the villages of Pödelwitz and Obertitz, with a population of roughly 80 people, would no longer have to be resettled (DIW Berlin 2014a; Öko-Institut 2017b). In addition, development of the Lützen open-cast mine, which would require resettlement of 930 people in the towns or villages of Stößwitz, Sössen, Gostau, Kölzen, Röcken, Michlitz, Bothfeld, Schweßwitz and Lützen, could be avoided (Klima-Allianz Deutschland 2017).

Reduced environmental and health problems

International studies show that a coal phase-out would lead to significant positive effects for the environment and health (J. Casey et al. 2018; J. A. Casey et al. 2018).

Overall, the environmental costs for electricity from lignite and hard coal in Germany in 2016 were roughly 46 billion euros (UBA 2017b). Only a fraction of these specific environmental costs of coal-fired power generation are already internalised via emissions trading and the energy tax (FÖS 2018). For example, over half of Germany's mercury emissions and a large part of Germany's sulphur dioxide emissions came from coal-fired power plants (see Tab. 4.4.1). In terms of particulate matter, note that coal-fired power plants primarily emit ultra-fine particulate (particle diameters of less than 0.1 μm), which are not yet recorded adequately due to their low mass (SRU 2017). Air pollutants are primarily local in nature, but can also be transported long distances in certain circumstances (UBA 2017b; SRU 2017). They are linked with a series of environmental impacts and illnesses, which could be reduced by a coal phase-out. They include (UBA 2017b; SRU 2017; BMWi 2018a):

Reducing emissions of air pollutants is expected to have positive effects on the environment and health. The environmental costs of coal-fired power generation in Germany were roughly 46 billion euros in 2016.

- Aggravated respiratory illnesses (like asthma, chronic bronchitis) and cardiovascular illnesses (like high blood pressure, heart attacks) due to nitrogen dioxide emissions, low-lying ozone and particulate matter;
- Chronic effects on the nervous system and neurocognitive restrictions among children due to introduction of mercury into the food chain;
- Excessive fertilisation and acidification of soils and bodies of water via nitrogen oxide emissions, with negative consequences for biodiversity.

Other environmental costs of lignite open-cast mines are caused by lower groundwater levels and iron ochre sedimentation of bodies of water (DIW Berlin 2014e). As a result, the electricity wholesale price paid for a kilowatt hour is not even one quarter of the true external costs, which are largely paid by the general public (see Fig. 4.4.1).

The environmental and health costs of coal-fired power generation are many times higher than the wholesale electricity prices.

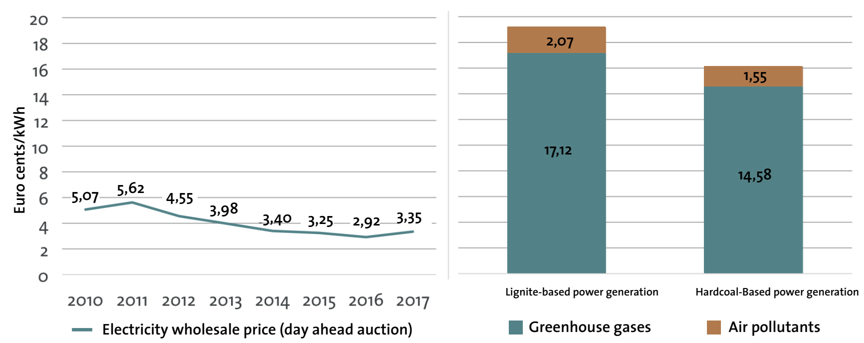
Tab. 4.4.1: Emissions of selected air pollutants in 2016

		Coal-fired power plants	Germany
Mercury (Hg)	Tonnes	~5.6	9.8
Sulphur dioxide (SO_2)	Thousands of tonnes	~143*	356
Nitrogen oxides (NOx)	Thousands of tonnes	~155	1,217
Particulate matter (PM_{10})	Thousands of tonnes	~7	203

Note: * SOx

Sources: UBA (2018c, 2018d, 2018b), own calculations

Fig. 4.4.1: Specific environmental costs (incl. health costs) and achievable electricity wholesale prices for lignite and hard coal-based power generation compared



Source: Own compilation based on UBA (2017b), UBA (2012) and Fraunhofer ISE (2018b)

4.5 SECURING RENATURATION COSTS OF OPEN-CAST MINES

- **Operators of lignite mines are obliged to bear the follow-up costs of mining, and form corresponding provisions.**
- **To date, the total follow-up costs of mining have not been studied against the backdrop of an early termination of energy use of coal.**
- **There is a risk that the previous provision system will not be adequate, in particular in the context of an accelerated coal phase-out.**

To date, the operators of the lignite open-cast mines have formed provisions of approx. 4 billion euros to cover the follow-up costs of lignite mining.

Operators of lignite mines are obliged to bear the follow-up costs of lignite mining (Section 55 of the German Federal Mining Act (BBergG), version dated 30/11/2016), and to form corresponding provisions in their balance sheets. The follow-up costs include in particular recultivation of open-cast mines after the end of lignite extraction (DIW Berlin 2017c). The provisions formed by the end of 2016 totalled roughly 4 billion euros. Of that, 2.4 billion euros were contributed by RWE, 1.5 million euros by LEAG and 0.14 billion euros by Mitteldeutsche Braunkohlengesellschaft mbH (MIBRAG) (DIW Berlin 2017c). To date, the total follow-up costs of mining have not been studied against the backdrop of an early phase-out of coal-fired power generation. In addition, it is not certain that the existing provision system ensures that the operators will actually bear the follow-up costs. .

Overview of the pending follow-up costs of mining

The provisions were calculated based on the operators' cost estimates.

The majority of the follow-up costs of lignite mining will be incurred in the future, making them difficult to estimate (SRU 2017; DIW Berlin 2017c). The corresponding provisions are calculated based on the cost estimates by operators according to detailed subsequent use plans (FÖS and IASS Potsdam 2016; SRU 2017).

RWE indicates that 80% of the follow-up costs are not incurred until after an open-cast mine is shut down, and that it has already formed roughly 70-80% of the necessary provisions.

RWE commissioned and published three dedicated reports on the required provisions (RWE Power, RWTH, and BET 2017; RWE Power and KPMG 2016; MTC 2017). These reports indicate that 80% of the costs of recultivating the Rhineland coalfields will not be incurred until an open-cast mine is closed. While rehabilitation accounts for 74% of the costs, resettlements and relocations only make up 8% of the costs. RWE reports that the company has already formed approx. 70-80% of the necessary provisions. However these reports do not indicate how the provisions have been formed, and they do not contain any estimates of how the required provisions and other balance sheet items would change in the event of an early coal phase-out.

A report commissioned by government agencies could provide clarity on the total volume and maturity date of the follow-up costs, and how they are secured.

Efforts should be made to have independent and transparent cost estimates produced for a more precise evaluation of the costs in the event of an early phase-out of coal-fired power generation (Agora Energiewende 2016a; DIW Berlin 2017c; SRU 2017). A report commissioned by government agencies could provide clarity with regard to the total volume and maturity of the follow-up costs, and ensuring that they are covered. The results of previous studies by operators and Federal States should influence this study so that costs can be estimated and measures to ensure the costs are covered can be assessed on this basis. The remediation reports by Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH (LMBV), which is responsible for remediation of the GDR open-cast mines, provide further information on the follow-up costs.

Minimisation of the risks for financing of the follow-up costs

The balance sheet provisions formed by the open-cast mine operators to finance the follow-up costs of mining reflect the future burdens of payment based on their calculated cash value.

If recultivation starts earlier, the operators would have to increase the provisions.

The total of the provisions therefore no longer depends only on estimates of the follow-up costs, but also on when they are due, the inflation rate and the discounting rates (DIW Berlin 2017c). If recultivation starts earlier (e.g. due to an accelerated coal phase-out), the requirements for recultivation measures increase, price increase rates are higher or discounting rates are lower, and the operators would have to increase the provisions (DIW Berlin 2017c; SRU 2017).

Provisions are liabilities that must be matched by assets in balance sheets. In some cases, the mining companies' assets are investments in conventional power plants or open-cast mining infrastructure. If these assets lose value at a faster rate, as would be expected in the event of a coal phase-out, other assets would have to be provided as collateral for the provisions. In recent years, conventional power plants have already had to make additional write-downs (SRU 2017).

The previous practice of hedging provisions primarily by investing in conventional power plants and open-cast mine infrastructure entails risks, in particular in the context of a coal phase-out.

To date, the provisions are not insolvency-proof, i.e. they could be lost if the operator becomes insolvent (Agora Energiewende 2016a; FÖS and IASS Potsdam 2016; DIW Berlin 2017c). If the operator is a subsidiary, the parent company is fundamentally liable for the costs if there are controlling and profit transfer agreements. However, under certain circumstances, the parent company can avoid liability by terminating these agreements in good time or by restructuring under company law ((DIW Berlin 2017c), (FÖS and IASS Potsdam 2016), Section 303 of the German Stock Corporation Act (AktienG), version dated 10/05/2016). Due to its company structure, liability concerns have been expressed with regard to EPH, which owns LEAG and MIBRAG via a series of intermediate companies ((DIW Berlin 2017c; Öko-Institut 2017b). EPH itself confirmed that it is not currently liable for LEAG's debts (Steinmann 2017).

Moreover, the provisions already formed are not insolvency-proof.

Ensuring the polluter pays principle

There are many proposals for minimising risks in mining-related provisions, and thus guaranteeing that operators will bear the follow-up costs of lignite mining. Besides independent cost estimates, this includes in particular the following measures (Agora Energiewende 2016a; FÖS and IASS Potsdam 2016; DIW Berlin 2017c; SRU 2017):

Additional measures are required to ensure that the follow-up costs are borne by the operators.

- Follow-up liability law: As in the nuclear sector, a follow-up liability law could ensure that the parent corporations would be liable for their subsidiaries' follow-up costs of mining even after restructuring.
- Collateral in accordance with the German Federal Mining Act: Per Section 56 of the German Federal Mining Act (BBergG), the responsible mining authority could demand insolvency-proof collateral, like insurance, bank guarantees or a letter of comfort from the parent company instead of balance sheet provisions. For example, at the end of December 2017, the Upper Mining Authority determined that the Nochten open-cast mine must provide collateral in the form of special assets (Pinka 2018).
- Public-law funds: As in the nuclear sector, a public law fund resourced from the finances of the mining companies could be imposed.

A public law fund would be the most transparent solution with the highest insolvency protection for particularly long-term follow-up costs (FÖS and IASS Potsdam 2016; DIW Berlin 2017c). For example, a levy could be imposed on lignite extracted in the future to finance it (Agora Energiewende 2016a).

A public law fund could be formed at regular intervals by the operators e.g. via a lignite levy.

5 INSTRUMENTS FOR REDUCING THE USE OF COAL IN THE ENERGY SECTOR

Summary

German coal-fired power plants are subject to various policy instruments, specifically the European Emissions Trading System (ETS) and various regulations on emissions of other pollutants. To reach the climate policy targets (cf. Chapter 2.5) and remove barriers to the implementation of the energy transition (cf. Chapter 1.4), additional measures are required to achieve a reduction and phase-out of coal-fired power generation. A reliable, structured and continuous reduction of coal-fired power generation cannot be ensured with the current instruments alone.

Chapter 5.1 introduces the main instruments that currently apply to the use of coal in energy generation (ETS and EU Industrial Emissions Directive). The subsequent chapters present potential further policy instruments suitable to achieve a reduction of coal-fired power generation: Chapter 5.2 deals with the CO_2 minimum price and other price instruments, Chapter 5.3 with the closure of power plant capacities and Chapter 5.4 with the capping of annual production at coal-fired power plants, while Chapter 5.5 introduces instrument combinations.

EMISSIONS TRADING

The ETS pushes up the cost of emission-intensive energy generation through capping and pricing CO_2 emissions. However, there will be no significant emission reductions unless the price of emission allowances consistently raises the cost of coal-fired power generation (i.e. the marginal costs) above the cost of gas-fired power generation. The CO_2 price required to achieve this aim mainly depends on the difference in various fuel prices and on power plant efficiency. In the past, the so-called fuel switch price has been extremely volatile, fluctuating between approx. 5 euros/t of CO_2 for old hard coal-fired power plants and up to 100 euros/t of CO_2 for new lignite-fired power plants.

The current emission allowance price of around 20 euros/t of CO_2 (August 2018) and the current fuel switch prices have already pushed some hard coal-fired power plants, especially older ones, out of the market for a considerable number of hours and modern combined-cycle power plants have profited. To fully replace lignite-based power as well, the ETS price must remain consistently at an even higher level, which is however not expected before 2030.

PROS AND CONS OF POTENTIAL ADDITIONAL INSTRUMENTS

Hence, a continuous and reliable coal phase-out requires the implementation of further instruments. A distinction is made between instruments which work indirectly via pricing and regulatory approaches which apply directly to certain power plants or certain types of power plants.

Analysis has shown that stakeholders' control over the transformation process is highest when coal-fired power plant capacities are shut down according to a predetermined order. Controllability is crucial, in particular with regard to impacts on security of supply and structural change. Controllability also ensures reliable planning conditions for investments in the new energy system. Due to the high concentration of lignite-based jobs in a small number of regions, it would be advisable to select instruments which ensure that both lignite-fired power plants and hard coal-fired power plants contribute to CO_2 reductions from the start. Given that price-based instruments, such as the CO_2 minimum price, always interact with other market factors, it is more difficult to estimate their concrete effects on individual power plants. The choice of instruments thus involves a trade-off between reliable planning conditions and flexibility. For instance, if transferable or tradable residual amounts of electricity or CO_2 emissions are defined for each power plant instead of fixed phase-out years, planning conditions will be less reliable.

As an alternative to immediate closure, coal-fired power plants can also be transferred to a reserve. However, this option is associated with high costs for the public.

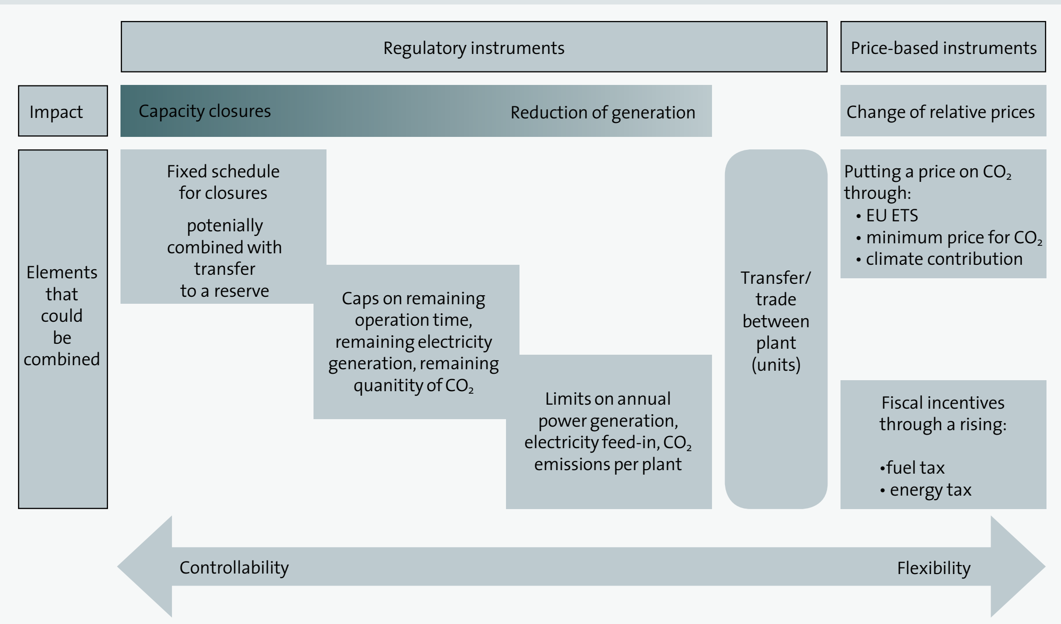
If predetermined closure is combined with caps on annual generation for remaining power plants, compliance with a defined total CO_2 budget will be more accurate. The caps ensure that the initial closures will indeed reduce emissions by avoiding higher electricity production at the remaining coal-fired power plants. The drawback associated with combined instruments is increased complexity which may delay the political negotiation process.

LEGAL ADMISSIBILITY AND WATER BED EFFECT

Expert appraisals published so far assume that the closure of coal-fired power plants is legal and principally requires no compensation if the investments have fully paid off. However, operators should be granted a transitional period of one or two years. By contrast, it is not assured that the EU would approve an expansion of the lignite security reserve. Certain legal risks arise from capping electricity generation at active power plants: In the absence of transfer options, the maximum limits must still allow for profitable operations, thereby placing tight restrictions on the instrument's design. According to experts, raising energy taxes exclusively in the field of coal-fired power generation would be problematic on legal grounds. By contrast, there is no legal impediment to raising taxation of all fossil fuels, e.g. for the purpose of introducing a CO_2 minimum price.

After the ETS reform, it has become much less likely that a reduction in coal-fired power generation in Germany will lead to a surplus in emission allowances in the ETS (so-called water bed effect), either in the short- or the medium-term. On the one hand, the new EU Emissions Trading Directive allows governments to cancel certificates in the amount of the emissions saved. On the other hand, the market stability reserve works against the water bed effect due to its automatic withdrawal of a certain quantity of excess emission allowances (cf. Chapter 5.1 and 5.3).

Fig. 5.0.1: Potential elements for policy instruments to reduce the use of coal in the energy sector



Source: Ecologic Institute based on IZES (2015), p. 141, SRU(2017), p. 32, Öko-Institut (2017), p. 53.

5.1 EXISTING INSTRUMENTS

- **The European Emissions Trading System (ETS) is currently the central EU climate policy instrument in the electricity sector. Under the system, CO_2 emissions pricing is to provide an incentive for emission reductions.**
- **Under the ETS, electricity generators are motivated to switch fuel when the price of emission allowances raises the cost of coal-fired power generation (specifically the marginal costs) above the cost of gas, thereby affecting the merit order on the electricity market. The price level required for a fuel switch in Germany depends predominantly on fuel prices and the efficiency of the power plants. In the past few years, the fuel switch price has been very volatile.**
- **It is difficult to predict the trend in energy prices and the development of the CO_2 price, and forecasts were often wrong in the past. Consequently, it is unclear when and for which period the price level necessary for a fuel switch will be reached. Even after the ETS reform, the CO_2 price signal alone is therefore insufficient to ensure a reliable and continuous reduction of coal-fired power generation in Germany.**
- **In the majority of cases, the limit values applying to pollutants (nitrogen oxide, mercury) that arise from the EU Industrial Emissions Directive can be complied with through combustion measures and technological upgrades. Hence, the Directive is not suitable to ensure a reliable coal phase-out.**

The European Emissions Trading System

The regulatory parameters for coal-fired power generation are currently provided by the EU in the form of the Emissions Trading System and the Industrial Emissions Directive.

Introduced in 2005, the ETS is the central climate policy instrument at the European level. A progressively declining cap applies to the CO_2 volumes emitted by the plants in the system. Under the ETS, one emission allowance (or certificate) must be submitted to the responsible government authority for each tonne of CO_2 emitted in the fields of power generation and energy-intensive industries. Emission allowances can be bought and are fully fungible, resulting in the formation of a price per tonne of CO_2 emissions. At present, the price is approx. 20 euros/t of CO_2 (August 2018 (EEX 2018a, 2018b)). As a result, electricity generation becomes more expensive the higher the CO_2 content of the underlying fuel and the lower the efficiency of the plant. This provides an incentive to reduce greenhouse gas emissions and switch to lower-carbon fuels (fuel switch). The ETS thus aims to integrate the environmental costs of CO_2 emissions and climate change into the price-setting process on the electricity market. This approach mitigates the price advantages of CO_2-intensive coal against lower-carbon natural gas, which arise if such external costs are not internalised.

The ETS reform passed in 2018 will gradually reduce the number of surplus certificates and should thereby trigger higher CO_2 prices.

Following several years of negotiations, an ETS reform entered into force in April 2018. Primarily, the system was reformed to address the approx. 1.7 billion surplus certificates that had formed on the emission allowance market under the previous rules (as per 2016, (European Commission 2017b; Sandbag 2017)). Due to the surplus, the emission allowance price hovered below 10 euros/t of CO_2 from 2012 until the beginning of 2018. At times, it even dropped below 5 euros.

In the period 2021 to 2030 (fourth trading period), the reformed system now provides for a 2.2% cutback of the total emission allowances issued per year instead of the previous 1.7%. In 2015, the EU had also decided to introduce a so-called 'market stability reserve' to reduce surplus emission allowances. This instrument is designed to draw part of the surplus off the market as of 2019. Under the reform, the instrument was beefed up: In the period 2019 to 2023, the market stability reserve is to absorb 24% of surplus certificates a year – double the original amount. As of 2024, this proportion will decline to 12%. Moreover, as of 2023, all emission allowances within the market stability reserve that exceed the previous year's auction quantity will be deleted. This will result in the deletion of over 2 billion certificates (Thomson Reuters 2017b).

Box 5.1: Elimination of the water bed effect

In the debate about national climate change mitigation measures in ETS sectors, it is often argued that the emission allowances released by such measures lead to additional emissions abroad (so-called 'water bed effect'). This, so the argument goes, neutralises the mitigation effect of national instruments. The ETS reform addresses the water bed effect on two different levels:

Firstly, the revised 2018 ETS Directive allows member states which shut down national generation capacities to reduce the auction volumes of emission allowances in the ETS by the corresponding amount. Governments can thus ensure that additional domestic measures do not result in more emissions abroad.

Secondly, the beefed-up market stability reserve also counteracts the water bed effect: Instead of creating an additional supply of emission allowances abroad, supplementary national measures raise the reserve that is withdrawn from the market. Given the deletion of surplus emission allowances within the reserve as of 2023 the risk of carbon leakage is limited (Öko-Institut 2018b).

The revised ETS Directive allows member states to reduce the auction volumes for emission allowances in the amount corresponding to the emissions of the generation capacities they shut down.

Changing the merit order on the electricity market

A fuel switch occurs when the CO_2 price triggers a sufficient change in the power plants' generation costs (relevant are the marginal costs) to modify the merit order on the electricity market (see Chapter 1.3). Lower-carbon power plants will be preferred to more CO_2-intensive plants. Primarily, this involves a switch from coal-fired to gas-fired power plants (so-called 'fuel switch').

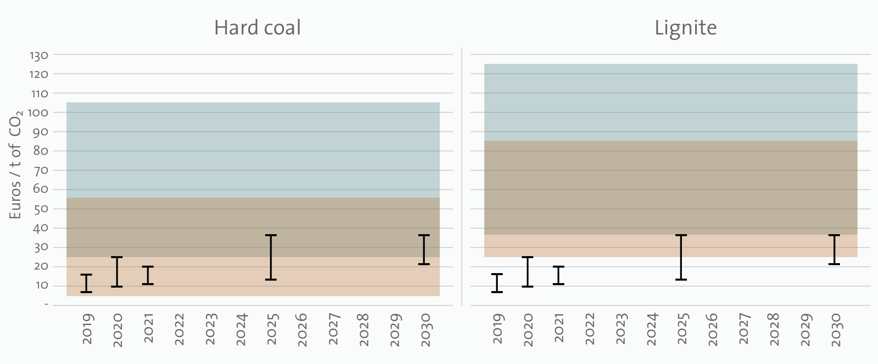
Aside from the cost of CO_2 emissions under the ETS, two further factors affect the marginal costs, namely the price difference between the various fuels and the efficiency of the power plants. With fuel prices subject to fluctuations, the fuel switch price also changes constantly: The larger the price difference between hard coal or lignite and natural gas, the higher the CO_2 price needs to rise and remain over time in order to permanently change the merit order on the electricity market. The lower the efficiency of the coal-fired plants (hence the higher the cost of their power generation), the lower the CO_2 price necessary to trigger the fuel switch to more efficient gas-fired power plants. Hence, when the CO_2 price goes up, older and less efficient coal-fired plants are increasingly pushed out of the merit order. More efficient coal-fired plants, however, can hold on longer and require a higher CO_2 price to become more expensive than gas-fired power plants.

Fig. 5.1.1 presents various forecasts of the trend in ETS certificate prices until 2030. The forecasts were produced in 2018 and 2017 (after the adoption of the ETS reform). This shows that expectations of future emission allowance price levels vary considerably – although there is overall agreement that the trend is rising. In 2020, certificate prices are expected to range between 10 euros and 23 euros/t, in 2025 between approx. 14 and 35 euros/t and in 2030 between 22 and 35 euros/t. The diagram compares the price forecasts with the past fuel switch prices necessary to effect a change from old and new hard coal / lignite-fired power plants to modern combined-cycle power plants in the period 2003 to early 2018. In the last 15 years, fuel switch prices for hard coal fluctuated between approx. 5 and 55 euros/t for old power plants and approx. 25 and 105 euros/t for new power plants. A considerably higher CO_2 price level is required to push lignite out of the market: In the period 2003 to early 2018, the price ranged between approx. 25 and 85 euros/t for old power plants and around 35 to 125 euros/t for new power plants (Öko-Institut 2018b).

Emissions trading is expected to contribute to a switch from hard coal to gas in power generation. However, the effect on lignite will be negligible.

Fig. 5.1.1: Forecasts of ETS certificate prices until 2030 and range of historical fuel switch prices for old coal-fired power plants to combined-cycle power plants, 2003 to 2018

The marked bandwidths reflect the expected price of emission allowances. The colours present the ranges of historical switch prices: red and brown for old coal-fired power plants, blue and brown for new power plants.



Source: Certificate prices: Carbon Pulse 2018, ICIS 2017, Thomson Reuters 2017a; Fuel switch prices: Öko-Institut 2018

At present, the switch from hard coal to gas-fired power plants occurs at CO_2 prices of just under euros 10/t (see Chapter 1.3). Propelled by current emission allowance prices within the ETS (around euros 20/t of CO_2, August 2018), the first hard coal-fired power plants in Germany, specifically older ones, are slipping behind gas-fired power plants in the merit order on the electricity market. Based on current market conditions (specifically fuel prices), gas-fired power plants would push out all German hard coal-fired power plants at a price of euros 40/t of CO_2 or above. In the case of lignite, the switch point currently approximates euros 20/t for older plants and euros 50/t for the most efficient modern lignite-fired power plants (see Chapter 1.3). Hence, it is clear that the ETS can contribute to the switch from hard coal-based electricity generation to gas, especially where older power plants are concerned. But it is unlikely that emission allowance prices will trigger a comprehensive switch from lignite to gas-fired power plants in the coming ten years.

Change in profitability

A CO_2 price of 15 euros /t or above puts the profitability of older lignite plants at risk. Given a stable price level of 25 euros/t or above, old lignite-fired power plants could be shut down within a few years.

However, as well as having the potential to change the merit order on the electricity market during certain hours, the CO_2 price also affects the profitability of lignite-fired power generation. To a large degree, lignite-fired power plants and lignite open-cast mines are run by the same companies (integrated enterprises). Due to the mining operations fix costs make up a high percentage of the total costs these companies face (Öko-Institut 2017b) (see Chapter 1.2). They cover these fixed costs via contribution margins generated from electricity sales. According to the Öko-Institut, a CO_2 price of euros 15/t is sufficient to put the profitability of older lignite plants at risk in the medium term, as the additional CO_2 cost pushes down the contribution margins. Given a long-term stable price level of euros 25/t or above, old lignite-fired power plants could be shut down within a few years (Öko-Institut 2018b).

Uncertainties

Future trends in CO_2 prices and fuel switch prices are subject to significant uncertainty.

However, both the trend in fuel switch prices and the future level of the CO_2 price are subject to uncertainty. Past projections have often turned out to be wrong. This is due to the fact that the CO_2 price is driven by a range of different factors, including, among others, the price of the different energy sources, the macroeconomic trend, the expansion of renewable energy and the promotion of energy efficiency. Experts argue that further factors are involved. In the past, the perceived reliability of the CO_2 reduction targets and the long-term commitment to these targets may also have affected the price trend (MCC 2017; Koch et al. 2014).

The ETS is not designed to guarantee a fuel switch.

Although the ETS ensures that the EU does not exceed a certain emission quantity in a specific period, the system is not designed to guarantee a fuel switch.

On top of this, the indirect impact the ETS exerts via the electricity market does not allow policy-makers to control the pace and spatial distribution of the coal phase-out. However, control is crucial both for the timely achievement of the emission reductions under the adopted climate targets and for a technologically and economically sound advancement of the energy sector transformation (see Chapter 1.4 and Chapter 3.3). Regional control plays a central role where the impact of local structural change and aspects of security of supply are concerned (see Chapter 4 and 3.5).

In addition, emissions trading does not allow for any control on where or when coal-fired power capacity is shut down.

Thus, despite the recent reform and signs that effectiveness will increase, the ETS alone cannot guarantee a reliable, structured and continuous reduction of coal-fired power generation in Germany. At most, it can contribute to this objective.

Options of strenghtening EU emissions trading

With the ETS reform just taking effect, EU member states are currently unlikely to agree on any strengthening of the system, e.g. via the introduction of an EU-wide minimum price or a more ambitious cap reduction. It is true that an amendment of the ETS may result from the EU's obligations under the UN process. The reformed ETS Directive calls on the Commission to carry out regular reviews of the constituent provisions in connection with the global stocktaking requirement under the Paris Agreement. This includes both the cap and the linear reduction factor. In 2018, the first review is due in the context of the Talanoa dialogue. However, it is unlikely that substantial amendments will be adopted on this occasion. The probability of further reforms is higher in the context of the subsequent global stocktake in 2023. On top of this, the parameters governing the market stability reserve will be reviewed as early as 2021 (Carbon Brief 2017; European Commission 2018a).

In the next few years, EU member states are unlikely to agree another reform of the emissions trading system.

EU Industrial Emissions Directive (IED)

In addition to the ETS, coal-fired power generation in Germany is also subject to Directive 2010/75/EU on Industrial Emissions (IED). Among others, the Directive applies to large combustion plants with a furnace heating capacity exceeding 300 MWth. This covers the majority of German coal-fired power plants. The Directive includes minimum environmental criteria, specifically in terms of air pollutant emissions. EU-wide minimum thresholds are determined on the basis of the best available technology (BAT). In 2017, the BAT requirements applying to coal-fired power plants were updated, introducing new environmental standards for large combustion plants. These include stricter standards for emissions of dust, sulphur and nitrogen dioxides as well as the first-ever emission standards for mercury under European law (European Commission 2017a). The new environmental standards must be transposed into national law within four years (by 2021) and existing plants will be obliged to adhere to them by this date.

While in regard of sulphur dioxide and dust, the operating data of large combustion plants in Germany already comply with the emission limit values specified in the updated BAT leaflet, the new nitrogen oxide and mercury standards require power plants to make adjustments.

Lignite-fired power plants in particular will require upgrades to meet the required annual average values. At 160 to 190 mg/m3, the annual average values for nitrogen dioxide at current large lignite-fired power plants frequently exceed the new limit values (SRU 2017). According to the Federal Environment Agency (UBA), at present no more than four lignite-fired units in Germany would comply with this threshold even if the national average limit is set at the upper end (175 mg/m3). This means that combustion measures (e.g. optimisation of combustion conditions) or emission-based upgrades may become necessary, depending on the limit values that will be set under the Federal Emission Control Act and the permit requirements at the power plant sites (SRU 2017). The EU mercury emission requirements will also necessitate measures in many cases. Whether or not a measure will pay off for a specific site is

Although stricter emission limits for air pollutants will require some power plants to upgrade, the instrument is not suitable to ensure a structured coal phase-out.

primarily an economic decision that must be taken by the power plant operator. This is why the Directive and its national implementation is not a suitable instrument to ensure a reliable, structured and continuous reduction in coal-fired power generation. It is difficult to say to what extent higher limit values will lead to optimisation, upgrades or closures of power plants.

Tab. 5.1.1: Annual average threshold values for nitrogen oxide and mercury emissions, current large combustion plants with more than 1,500 operating hours a year, applicable as of 2021

Pollutant	Type of power plant (current plants)	Annal average threshold values
Nitrogen oxides	Fluidised bed combustion (lignite and hard coal), lignite dust firing, over 300 MW_{th}	< 85–175 mg/Nm^3
	Hard coal dust firing, over 300 MW_{th}	65–150 mg/Nm^3
Mercury	Lignite-fired power plants	< 1–7 $\mu g/Nm^3$
	Hard coal-fired power plants	< 1–4 $\mu g/Nm^3$

Source: European Commission (2017a)

5.2 CO_2 MINIMUM PRICE AND OTHER PRICE INSTRUMENTS

- **Fixing a minimum CO_2 price for the electricity sector can provide early and permanent incentives to avoid emissions. If set at the right level, the price will change the merit order on the electricity market and thereby reduce coal-fired power generation. However, it does not allows for control over the coal phase-out's impact on single regions.**
- **An exclusively national CO_2 price could make German power plants less competitive in Europe and thus reduce the amount of electricity they generate. To mitigate these leakage effects, it would make sense to introduce a minimum price in conjunction with neighbouring member states. However, this may result in delays.**
- **Further approaches involving a reduction of coal-fired power generation via pricing include the 'climate contribution' proposed by the Federal Ministry of Economics in 2015 on the one hand and higher energy taxes on the other. However, not only are both instruments affected by legal risks, they are also relatively complex.**

Price or market-based instruments make fossil energy generation more expensive in relation to climate-friendly options. Principally, this can be achieved via quantitative limits and pricing, as in the case of the ETS, or via additional levies. Several EU countries are currently discussing a minimum CO_2 price for the electricity market as a supplement to the ETS. Further feasible instruments include higher energy taxes on coal and the 'climate contribution' proposed by the Federal Ministry of Economics in 2015. In principle, the above-mentioned instruments initially aim to make electricity generation by emission-intensive power plants, specifically coal-fired plants, more expensive, resulting in lower production levels. If the price is sufficiently high, the instruments can also lead to closures.

Price-based instruments make CO_2-intensive electricity more expensive.

National minimum CO_2 price in the electricity sector

One of the options for supplementing carbon pricing under the ETS is the introduction of a minimum CO_2 price in the electricity sector. Under this approach, a fixed price level is guaranteed via a flexible surcharge on the certificate price. This removes uncertainty about future price levels in the ETS. In contrast to the ETS scheme without minimum price, it also provides incentives to cut emissions at an early stage. Depending on the form and level of the minimum CO_2 price, this could cause a fuel switch from hard coal and lignite to gas. The price level necessary to achieve changes in the merit order depends on the price difference between the various fuel prices and on power plant efficiency (see Chapter 5.1). Under current conditions, hard coal-fired power generation would decline if the price is around 10 euros/t of CO_2 or above. A price level of 20 euros or above would currently be required to reduce the use of lignite in the electricity mix. Hence, if a minimum CO_2 price were the only instrument in operation, it would initially tend to push hard coal out of the market. Compared to a fixed sequence of closures (see Chapter 5.3), the minimum CO_2 price has the advantage that intervention into basic ownership rights is less pronounced. Yet, for managing structural change and security of supply, the instrument is associated with a number of risks since there is very little room to control where plants are shut down.

The minimum CO_2 price can push coal-based electricity out of the market but does not allow controlling where and when specific coal plants drop out of the market.

Regional minimum CO_2 price in the electricity sector

Various EU member states are currently considering the introduction of a minimum CO_2 price in the electricity sector, among them France, Sweden and the Netherlands (icap n.d.; Carbon Market Watch 2013; euobserver 2017; The Guardian 2016). In the

UK, the instrument has already been in force since 2013 (see Box 5.2). Cooperation between several European countries could have a number of advantages. On coupled electricity markets, such a regional approach would prevent German power plants from losing competitiveness compared to European rivals and thus losing market share. According to modelling results for the year 2020, an exclusively national minimum price of 25 euros/t of CO_2 would already change Germany from a net exporter to an importer of approx. 40 TWh of electricity a year (Öko-Institut 2018b). There is also a risk of carbon leakage: Assuming an exclusively national minimum price, the extra electricity produced abroad would be predominantly hard coal and gas-based. This transfer of emissions to other countries would eliminate over half of Germany's emission reductions (Öko-Institut 2018b).

A minimum price introduced in conjunction with neighbouring countries prevents economic disadvantages and reduces carbon leakage.

To prevent this, the joint introduction of a minimum price by a group of countries would be preferable, e.g. the central-western European electricity market consisting of Belgium, Germany, France, Luxembourg, Netherlands, Austria and Switzerland. In this scenario, a minimum price amounting to 25 euros/t of CO_2 would reduce net electricity imports to Germany to approx. 17 TWh (Öko-Institut 2018b). Gas-fired power plants abroad would benefit from the changes in import-export flows. As a result, gas-fired power plants abroad would push out German coal-fired power plants and the proportion of German emission reductions offset by extra emissions abroad would decline to one-quarter. Additional generation of nuclear power is not likely since, thanks to its low marginal costs, nuclear power is already at the top of the merit order (Öko-Institut 2018b).

To a large extent, the emission allowances released in the case of a regional minimum CO_2 price would be absorbed by the ETS market stability reserve, which in turn reduces the water bed effect (see Chapter 5.1). Although the revised 2018 Emissions Trading Directive allows countries to downscale the auctioning volume of emission allowances when national measures reduce generating capacity (see Box 5.1), it is unclear whether this regulation would also apply in the case of a minimum CO_2 price.

The need for coordination is likely to delay introduction compared to a national solution.

One drawback associated with the regional approach is the need for increased coordination. Even if there is basic agreement, the concrete implementation is likely to throw up a number of questions and may delay introduction compared to a national solution.

Impact on the electricity price

An effective minimum price leads to a moderate increase in electricity wholesale prices. Effects on end consumers can be compensated for.

According to modelling results for the year 2020, a minimum CO_2 price as part of a regional approach will lead an increase in electricity wholesale prices, but the impact depends on the set level. The increase will vary from 6 euros/MWh (0.6 ct/kWh) if the minimum price is 15 euros/t CO_2 to approx. 20 euros/MWh (2 ct/kWh) if the minimum price is 35 euros/t CO_2 (Öko-Institut 2018b). It should be noted that electricity wholesale prices have dropped significantly in the last few years due to the expansion of renewable energy. The rise in prices affecting consumers who pay the EEG levy is mitigated by a decline of the levy as renewable energy-based plants generate higher income due to higher wholesale prices. This effect offsets approx. one half of the rise in electricity prices (see Chapter 1.3). If the government wanted to avoid any further strain on households, the additional income generated from the minimum price could, for instance, be used to lower the electricity tax. Energy-intensive industries which compete at the international level could receive compensation for additional electricity costs. The current electricity price compensation scheme already compensates affected companies for the so-called indirect CO_2 costs, i.e. the share of the electricity price that relates to the CO_2 costs arising from the ETS. This approach should also be compatible with EU state aid regulation if used together with a minimum CO_2 price (Öko-Institut 2018b). As a result, European companies can be protected against competitive distortion even if the CO_2 price is not harmonised within the G20 - as called for by the industrial sector (IG BCE 2018).

Box 5.2: Minimum CO_2 price in the UK

A minimum CO_2 price for all power generation plants that are subject to the European ETS has been in force in the UK since April 2013. On top of the ETS emission allowances, electricity suppliers also pay a fuel tax, the so-called 'carbon price support', whose amount is determined in advance for three-year periods. The level of the tax is set such that the minimum price is reached via the combination of both components. At present, the surtax is £ 18/t of CO_2 [20.71 euros]. In the financial year 2016/2017, this brought in additional government income of £ 1 billion [1.1 billion euros] (House of Commons 2018).

At the time the minimum price was first introduced, the government planned to raise it gradually to £ 30/t of CO_2 [34.52 euros] by 2020 and to £ 70/t CO_2 [80.55 euros] by 2030 (Sandbag 2013). However, since the ETS certificate price remained low, the surtax was frozen at £ 18/t of CO_2 and will not be raised any further until 2021. This is to guarantee the UK's competitiveness compared to other EU countries. On top of this, energy-intensive industrial companies receive compensation for rising electricity prices. As a minimum, the instrument will be retained until the completion of the coal phase-out in 2025 (House of Commons 2018, Department for Business, Energy & Industrial Strategy 2018).

The use of coal in UK power generation has declined significantly since 2013. While coal-fired power plants still accounted for 22% of total power generation in 2015, they generated no more than 2% in the second quarter of 2017. The minimum price is considered to be one of the drivers of this trend, although the expansion of renewable energy and stricter environmental requirements also contributed (Department for Business, Energy & Industrial Strategy 2018). However, since the German electricity market is much more intertwined with its neighbours than the UK, this model cannot be copied on a one-to-one basis.

Extension and increase of energy tax on coal

At present, the use of coal for power generation is not subject to taxation if used in plants with a nominal capacity above 2 MW. The government could extend taxation to include the use of coal in larger power plants, thereby providing another price signal in addition to the ETS. However, Rodi (2017) has previously pointed out that a tax equity problem could arise from a hike in energy taxation that applies exclusively to coal-fired power generation. If this was true, the possible imposition of energy tax on hard coal alone could also be problematic under constitutional law.

Taxing coal while exempting other energy sources is problematic on legal grounds. Taxation of all fuels is a feasible option of implementing a minimum CO_2 price.

However, a CO_2-based hike on all fossil fuels should be less problematic if it involves a consistent tax structure and consistent tax rates. Such application to all power generation fuels would represent a de facto introduction of a minimum CO_2 price. Tax level could be linked to the price of ETS emission allowances (see Box 5.2).

Climate contribution

The Federal Ministry for Economic Affairs and Energy proposed the 'climate contribution' in 2015 with the aim of reducing the proportion of old CO_2-intensive coal-fired power plants in total power generation. In contrast to a general minimum CO_2 price in the electricity sector, the climate contribution specifically increases the cost of electricity generated by old lignite-fired power plants, while hard coal and gas-fired power plants, which set the price in the merit order, are initially not affected (UBA 2015a). According to modelling, this scheme would have resulted in a minimal increase in electricity prices of around 2 euros/MWh (0.2 ct/kWh) (Öko-Institut and Prognos 2015).

The climate contribution would specifically raise the price of electricity generated by old lignite-fired power plants.

The proposal met with massive resistance from unions and power plant operators. In the end, the proposal was dropped. Instead, the Federal Government introduced the so-called 'lignite security reserve' in combination with the subsequent closure of affected lignite-fired power plants as a first short-term step towards reducing coal-fired power generation.

5.3 SHUT-DOWN OF GENERATION CAPACITY

» **The shut-down of generation capacity facilitates control over the coal phase-out process, in particular with regard to security of supply and structural change. The instrument also ensures reliable planning conditions for investments in the new energy supply system.**

» **Plant operators would benefit from additional flexibility if a transfer or trading option for electricity or CO_2 quotas were introduced. However, at the same time, this would affect controllability and planning security.**

» **The expert appraisals published to date assume that a coal phase-out involving a fixed sequence of closures can be compensation-free, at least in the case of power plants that have already paid for themselves.**

» **Transferring power plants to a reserve is very costly for the government. On top of this, it is uncertain whether the European Commission would approve such transfers on state aid grounds.**

» **To ensure legal security, the sequence of closures must be based on objective criteria. Justified unequal treatment, e.g. to guarantee security of supply, is admissible.**

The shut-down of coal-fired generation capacity can be achieved by setting concrete dates for the closure of individual plants or plant units, determining thresholds for residual electricity or residual CO_2 volumes or transferring power plants to a reserve (Öko-Institut 2017; SRU 2017; IZES 2015).

Fixed sequence of closures

Analogous to the nuclear phase-out, a fixed schedule of closures could be drawn up for coal-fired power plants (residual lifespans). In addition, it should be clearly stated that new coal-fired power plants and open-cast mines will no longer be approved. The sequence of closures can be linked to various criteria, e.g. power plant age or CO_2 intensity (so-called specific emissions).

A fixed sequence of closures provides reliable planning conditions for grid expansion, security of supply and regional development.

Due to the direct impact of the closures, it is possible to accurately control a shut-down process that is based on a fixed schedule. The instrument thus offers very reliable planning conditions for all stakeholders (UBA 2017f), including plant operators and local regions. Clear parameters also make it easier for grid operators to plan and guarantee security of supply. Furthermore, the impact of closures is independent of the trend in energy prices, changes in CO_2 prices or fluctuations in electricity demand. However, the emission reduction achievable through closures depends on the trend in capacity utilisation at the remaining power plants. Hence, to increase accuracy, combinations with further instruments are currently being discussed (see Chapter 5.5).

Constitutional law and EU law

The closure of coal-fired power plants is a legitimate regulation of property if it is proportionate to the pursued objectives.

The expert appraisals published to date assume that a coal phase-out involving a fixed sequence of closures can be implemented in compliance with constitutional law. Since power plants are shut down on environmental grounds and are not serving a public function, the instrument involves a legal regulation of property according to Art. 14 of the German Basic Law rather than an expropriation. Pursuant to Art. 14 (1) sentence 2, the legislator may determine the content of the property law. Leaving the content of adopted legal positions intact in perpetuity is not a requirement under the ownership guarantee. However, the regulation of property must comply with the principle of proportionality. This means that it must be both suitable and necessary for the objective that is being pursued. Moreover, the burden on the owner must be in proportion with the interests pursued by the regulation (BBH 2016; IZES 2015; Rodi 2017; Ziehm 2017; Schomerus and Franßen, forthcoming).

Any regulation in compliance with the constitution must take account of the principle of equality according to Art. 3 of the German Basic Law, i.e. the sequence of closures must adhere to uniform standards. By contrast, unequal treatment justified by objective reasons, for instance to ensure security of supply, is admissible (BBH 2016; Ziehm 2017; Schomerus and Franßen, forthcoming).

According to the principle of equality, the sequence of closures must be based on factual criteria.

Legal action can be avoided if government and operators agree on a joint strategy for the sequence of closures (SRU 2017). From a constitutional point of view, such consensus is not required to initiate a reduction in coal-fired power generation (BBH 2016).

The shut-down of coal-fired power plants via a coal phase-out act is also likely to conform with EU law. Article 194 of the Treaty on the Functioning of the European Union (TFEU) allows member states to choose between various energy sources and decide on the conditions of their use as well as the general energy supply structure (Klinski 2017, BBH 2016). In addition, the revision of the Emissions Trading Directive expressly allows for national shut-down measures (Schomerus and Franßen, forthcoming).

The revised EU Emissions Trading Directive expressly allows for national shut-down measures in parallel to the Emissions Trading System.

Transition periods and amortisation of investments

As regards the proportionality requirement governing the regulation of property, it is not yet clear to what extent operators are entitled to the amortisation of their investments and how many years of useful life are required to reach this point. According to calculations carried out by the UBA (2009), initial investments in coal-fired power plants pay off after 15 to 20 years of operations, while adequate profits should be generated after 25 years. The average age of German lignite-fired power plants is 35 years. Hard coal-fired power plants have an average age of 30 years (see Chapter 1.1). BBH (2016) assumes that closures after 25 years of operations can be effected within a transition period of one year without requiring compensation. Power plants with heat extraction or long-term supply contracts, as well as the affiliated open-cast mines, may require longer transition periods or compensation payments (BBH 2016). Schomerus and Franßen (forthcoming) also conclude that amortised power plant units can generally be shut down without requiring compensation. However, they also believe that a transition period may be necessary since power plant operators often conclude supply contracts for future periods based on expected generation volumes. Transition periods could therefore prevent potential economic losses. Pursuant to Schomerus and Franßen, a period of up to two years is sufficient to allow operators to adjust their marketing strategies to the closure.

It is not yet clear to what extent operators are entitled to the amortisation of their investments. However, experts believe that start-up investments in coal-fired power plants pay off after 15 to 20 years.

Expert appraisals state that one to two years represent an adequate transition period.

Transfer and trade of residual electricity or CO_2 volumes

Fixed closure schedules can be combined with the stipulation of residual electricity volumes or residual CO_2 volumes that can be transferred from one power plant to another or sold to a different operator. The benefit of this trading or transfer option is greater flexibility for operators as they respond to the requirements of the electricity market and choose the most profitable strategy. However, companies would probably price in allocated residual electricity or CO_2 volumes even if they are allocated free of charge. This is one of the lessons learned from the ETS. Since prices are much more frequently set by coal-fired power plants than by nuclear power plants, the expected impact on the electricity price is much higher than for allocations of residual electricity volumes to nuclear power plants under the nuclear phase-out programme.

While the transfer or trade of residual electricity or CO_2 quantities provides power plant operators with greater flexibility, it reduces planning security for everyone else.

Furthermore, the transfer and trading of residual electricity or CO_2 volumes restricts the government's options of controlling the transformation process and reduces planning security for regions and grid operators (Klinski 2017). Trading or transfer options could be made subject to approval to ensure that they do not have any significant adverse effects at the local level, or jeopardise security of supply.

CO_2 limit values

CO_2 limit values affect older lignite-fired power plants first.

Current discussions of further approaches to shutting down coal-fired power plants also include the stipulation of CO_2 limit values in the sense of minimum technological requirements (Rodi 2017; DIW Berlin 2014c). CO_2 limit values would primarily be problematic for older lignite-fired power plants. In terms of European law, the Industrial Emissions Directive (IED) leaves it up to the member states to set efficiency requirements. However, the formulation of Art. 9 of the Directive is not clear on the admissibility of CO_2 limit values (Klinski 2017). Experts argue that the introduction of national CO_2 limit values for power plants may be admissible thanks to the protective measures clause under Art. 193 of the TFEU. However, this assessment is not undisputed (Rodi 2017; IZES 2015; Klinski 2017; Ziehm 2014). Where conformity with EU law is concerned, the introduction of CO_2 limit values is thus associated with a higher level of uncertainty than fixed closure schedules based on a coal phase-out act (Schomerus and Franßen, forthcoming). At present, Section 5 Par. 2 of the German Federal Emissions Control Act (BlmSchG) excludes the introduction of CO_2 limit values.

CO_2 limit values are associated with higher legal uncertainty than the fixed sequence of closures.

Transfer of coal-based generation capacities to a reserve

Instead of immediate closures, coal-fired power plants can also be transferred to a reserve. In this case, the power plants would cease regular production and would operate exclusively to remove supply shortages. Operators would receive compensation for keeping guaranteed capacity available. In 2016, the Federal Government chose this option in the context of the introduction of the so-called lignite security reserve. Throughout the period 2016 to 2019, lignite-fired power plants with a combined capacity of 2.7 GW are gradually being transferred to this reserve before being shut down after a cycle of four years.

Keeping generation capacity in reserve is rather expensive: The cost of the current lignite security reserve is expected to be approx. euros 590 million/GW of shut-down capacity.

From a technological perspective, the relevance of this reserve to security of supply is somewhat doubtful since coal-fired power plants have long lead times and cannot react fast enough when temporary shortfalls arise (IZES 2016). Moreover, a number of reserves have already been set up to ensure security of supply (see Chapter 1.1). On top of this, the lignite security reserve is expensive, with total expected costs amounting to approx. euros 590 million/GW of shut-down capacity (Bundesregierung 2016). Critics also believe that this scheme creates incentives to keep plants on the grid beyond the point of profitability.

It is uncertain whether the European Commission would approve a massive expansion of the security reserve.

In terms of EU law, capacity reserves are considered to be state aid and must be approved by the European Commission. To date, the Commission has approved various capacity mechanisms to maintain security of supply, among others in Belgium, France, Greece, Italy, Poland and Germany (European Commission 2018b). The EU Commission’s approval under state aid law has been granted exclusively on the grounds of climate policy benefits and minor intervention in the competitive structure. Contributions to security of supply have not been mentioned by the Commission (European Commission 2016). Should the security reserve be expanded to a substantial degree, intervention in the competitive structure will be more significant and approval is therefore uncertain.

5.4 LIMITATION OF ANNUAL PRODUCTION BY COAL-FIRED POWER PLANTS

- **As an alternative to the closure of coal-fired power plants, the government could also provide for the limitation and continuous reduction of production volumes at individual plants. This could be implemented via maximum annual electricity feed-in quantities, emission budgets or full-load hours. However, in legal terms, it is likely that production limits are only admissible to the extent that power plants can still be operated on a profitable basis.**
- **The instrument would be beneficial in terms of structural policy since employment effects could be spread out. However, this advantage is cancelled out when operators are given the option of transferring or trading quotas between power plants.**
- **Hence, an annual limitation of production at individual plants is not a suitable instrument to reduce coal-fired power generation. In combination with closures, however, the situation is different.**

The limitation of power production at coal-fired power plants can relate either to the amount of electricity fed into the grid, the CO_2 emissions or the full-load hours and can be determined on an annual basis. Below the maximum threshold, operators are free to decide which amount of electricity they produce at what time. The result is a reduction of coal-based power generation without direct closures of generation facilities.

As an alternative, the limit could be imposed on power plants above a certain age (Öko-Institut 2017; DIW Berlin 2015). DIW Berlin (2014c), for instance, suggests an emission limit of 3,154 t of CO_2 a year per MW of installed capacity for power plants over the age of 30. Depending on plant's efficiency, the limit restricts annual capacity utilisation of lignite-fired power plants to 31-39% and of hard coal-fired power plants to 40-49%, while the impact on gas-fired power plants would be minimal at 89-100%. As a result, CO_2 emissions arising from coal-fired power generation could drop by 66% by the year 2040.

How it works

Moderate production limits can be beneficial in structural policy terms as the effects on employment can be spread more evenly.

A moderate annual production limit can also have benefits in terms of structural policy since the effects on employment can be spread more evenly over power plants and open-cast mines and can be gradual in nature (UBA 2017b; SRU 2017). From an energy system perspective, the instrument could be beneficial in that it specifically forces lignite-fired power plants to adopt a (more) flexible mode of operation. This is based on the assumption that the plants would generate during hours with high electricity prices when few renewable energy plants feed into the grid. Experts believe that even older lignite-fired power plants can operate more flexibly either without any upgrades or with minor upgrades only (UBA 2017f). Given the current framework conditions, plant operators do not often use these capabilities as ramping up and down puts additional strain on the plant.

As regards the climate impact, it is not yet clear how carbon leakage to other member states could be avoided (water bed effect). In the short and medium-term, no carbon leakage is expected to occur thanks to the new market stability reserve regulation. In addition, the revised Emissions Trading Directive allows for the cancellation of emission allowances when power plants are shut down which can ensure that there is no water bed effect, even in the long term (see Chapter 5.3). However, at present it is unclear to what extent this applies to production limits.

Legal risks

Annual production limits are subject to legal uncertainty which could be solved by including a transfer or trading option.

In terms of constitutional law, annual limits on electricity feed-in quantities, emission volumes or full-load hours represent a legal regulation of property pursuant to Art. 14 of the German Basic Law just as fixed closure sequences. Such a regulation must be proportional and must comply with the principle of equality pursuant to Art. 3 of the German Basic Law (see Chapter 5.3). However, annual limits harbour the risk that power plants become unprofitable and have to be shut down. It is difficult for the legislator to accurately calculate the profitability threshold for each power plant (or even each unit). Hence, there is a risk of disproportionality as power plants may have to be shut down on profitability grounds before their closure would be justifiable on grounds of climate change mitigation. This could lead to a compensation duty for the government. However, if operators are given the option of transferring or trading their annual quotas with other power plants, the instrument would be admissible under constitutional law (Schomerus and Franßen 2018).

The compatibility of production limits with European law is disputed.

Some experts believe that fixed annual limits on emissions, electricity volumes or full-load hours may be incompatible with EU law (BBH 2016; IZES 2015). This is based on the assumption that the Emissions Trading Directive does not permit national measures with similar objectives. Furthermore, there may be a conflict with a provision under the IED which excludes CO_2 limit values. If one assumes that even national CO_2 limit values can be justified via the protective measures clause under Art. 193 of the TFEU (see Chapter 5.4), other CO_2 limits should also be admissible (Klinski 2017; Ziehm 2014). However, this argument is disputed (BBH 2016).

Transfer and trading option

The transfer or trading of production volumes conflicts with the controllability of the transformation and reduces planning security for regions and grid operators.

If the annual quotas can be transferred or traded between power plants, operators enjoy a higher level of flexibility. This can mitigate economic hardship (Schomerus and Franßen 2018). The disadvantage associated with this flexibility option is that operators could transfer all of their allocated quotas to a small number of power plants and shut down the other facilities. This would restrict the government's capacity to control where and when the transformation takes place and deteriorate planning conditions for regions and grid operators. The advantages of the quota system, i.e. the spread of potential job losses and the coercion of power plants to adopt flexible modes of operation, would be cancelled out.

5.5 COMBINING INSTRUMENTS

- **A combination of the closure and production limit instruments would ensure greater accuracy in attaining the overall target budget for CO_2 emissions in the electricity sector.**
- **Furthermore, there have been suggestions of combined regional minimum CO_2 prices and closures. In contrast to the minimum CO_2 price as the only instrument, both lignite and hard coal-fired power plants would contribute to emission reductions. The resulting income could be used in the coal phase-out context.**
- **However, the drawback associated with combined instruments is increased complexity which may delay the political negotiation process.**

The combination of various instruments can result in the pooling of the respective advantages. Feasible combinations could involve several regulatory instruments together or regulatory instruments combined with price-based instruments (see Chapters 5.2, 5.3 and 5.4 for the advantages and disadvantages associated with individual instruments.) On the other hand, combinations of political instruments usually raise the level of complexity. This may prolong the political negotiation process necessary to define the details for any instrument combination.

The combination of closures with annual production limits improves accuracy for reaching target CO_2 reduction volumes.

Combination of closures and limits on annual production

Closures can lead to significantly higher emission reductions if combined with annual production limits for those coal-fired power plants that remain in operation. Production limits can ensure that closures are indeed effective in reducing emissions since they avoid a situation where remaining coal-fired power plants, which were previously running below full capacity, simply raise their production volumes. Moreover, the combination is robust as it is not influenced by energy price trends, changes in CO_2 prices and fluctuations in electricity demand (UBA 2017f).

Combination of regional minimum CO_2 prices in the electricity sector and closures

It has also been proposed to combine a regional minimum CO_2 price in the electricity sector with closures (Öko-Institut 2018b). While the minimum CO_2 price would initially affect hard coal-fired power plants only, lignite-fired power plants could be addressed via stipulated closures. The resulting income could be used in the coal phase-out context, e.g. for structural development or as compensation for faster closures.

The combination of minimum CO_2 prices with closures would ensure that both hard coal and lignite plants contribute to emission reductions. Moreover, this combination would generate additional income.

ABBREVIATIONS

BAT	Best Available Technologies
BDEW	Bundesverband der Energie- und Wasserwirtschaft (Federal Association of the German Gas and Water Industries)
BlmSchG	Bundes-Immissionsschutzgesetz (German Federal Imission Control Act)
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMWi	Bundesministerium für Wirtschaft und Energie (German Federal Ministry for Economic Affairs and Energy)
BNetzA	Bundesnetzagentur (Federal Network Agency)
CCPP	Combined-cycle power plant
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power Generation
CO_2	Carbon dioxide
EEG	Erneuerbare-Energien-Gesetz (German Renewable Energy Sources Act)
EnWG	Energiewirtschaftsgesetz (German Energy Industry Act)
EPH	Energetický a průmyslový holding
ETS	European Emissions Trading System
EU	European Union
GDP	Gross Domestic Product
GG	Grundgesetz (Basic law)
GHG	Greenhouse gases
GRW	Joint Task 'Improvement of Regional Economic Structure'
IEA	International Energy Agency
IED	EU Directive 2010/75/EU on Industrial Emissions
IPCC	Intergovernmental Panel on Climate Change
LEAG	Lausitz Energie Bergbau AG
LMBV	Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft
MEWS	Mining, Energy and Water Supply
Mibrag	Mitteldeutsche Braunkohlengesellschaft mbH
NDCs	Nationally Determined Contributions
PP	Power plant
PtG	Power-to-Gas
PV	Photovoltaics
TFEU	Treaty on the Functioning of the European Union
TSO	Transmission System Operator
UBA	Umweltbundesamt (Federal Environment Agency)
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

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ANNEX

Table Annex 1: Installed capacity and efficiency of lignite power plant blocks (>50 MW)

Power plant	Block	Start (retrofit)	Net elect. capacity (MW)	Electrical efficiency	Company	Security reserve from	Percentage of heat [%]	Kg CO_2/ KWh	In t CO_2 2017	SO_2 2015	NO_x 2015	PM 10 2015
Rhineland coalfields												
Frechen/Wacht-berg		1959 (1988)	176	0.33	RWE		72	1.242	1,310,090	264	399	15
Niederaußem	C	1965	295	0.33	RWE			1.237				
Niederaußem	D	1968	297	0.358	RWE			1.237				
Niederaußem	E	1970	295	0.358	RWE	Oct '18		1.237				
Niederaußem	F	1971	299	0.358	RWE	Oct '18		1.237	27,174,168	9,361	18,019	437
Niederaußem	G	1974 (2008)	628	0.37	RWE		1	1.181				
Niederaußem	H	1974 (2009)	648	0.37	RWE			1.181				
Niederaußem	K	2002	944	0.43	RWE			0.976				
Weisweiler	E	1965	321	0.33	RWE			1.315				
Weisweiler	F	1967	321	0.33	RWE			1.315	18,945,349	4,135	12,571	214
Weisweiler	G	1974	663	0.36	RWE		3	1.23				
Weisweiler	H	1975	656	0.36	RWE			1.23				
Frimmersdorf	P	1966 (1990)	284	0.33	RWE	Oct '17		1.317	3,582,337	1,488*	3,032*	71*
Frimmersdorf	Q	1970 (1990)	278	0.33	RWE	Oct '17		1.317				
Ville/Berrenrath		1991	98	0.38	RWE		61	1.079	825,612	-	-	-
Neurath	A	1972	294	0.33	RWE			1.238				
Neurath	B	1972	294	0.33	RWE			1.238				
Neurath	C	1973	292	0.33	RWE	Oct '19		1.238				
Neurath	D	1975	607	0.366	RWE		0	1.181				
Neurath	E	1976	604	0.366	RWE			1.181	29,900,372	5,982*	22,595*	520*
Neurath	BoA 2	2012	1060	0.43	RWE			0.976				
Neurath	BoA 3	2012	1060	0.43	RWE			0.976				

CHP Merkenich	Block 6	2010	75	0.42	RheinEnergie AG		82	0.976	537,244	86	317	4
Lusatian coalfields												
Boxberg	N	1979 (1993)	465	0.35	LEAG		1	1.162	19,135,707	13,215	13,469	486
Boxberg	P	1980 (1994)	465	0.35	LEAG			1.162				
Boxberg	Q	2000	857	0.423	LEAG			1.01				
Boxberg	R	2012	640	0.437	LEAG			1.01				
Jänschwalde	A	1981 (1996)	465	0.375	LEAG		2	1.169	23,626,776	17,818	18,639	648
Jänschwalde	B	1982 (1996)	465	0.375	LEAG			1.169				
Jänschwalde	C	1984 (1996)	465	0.375	LEAG			1.169				
Jänschwalde	D	1985 (1996)	465	0.375	LEAG			1.169				
Jänschwalde	E	1987 (1996)	465	0.375	LEAG	Oct '19		1.169				
Jänschwalde	F	1989 (1996)	465	0.375	LEAG	Oct '18		1.169				
Schwarze Pumpe	A	1997	750	0.41	LEAG		14	1.077	11,386,634	9,237	5,813	66
Schwarze Pumpe	B	1998	750	0.41	LEAG			1.077				
CHP Cottbus	1	1999	74	0.4	HKWG Cottbus mbH		90	1.018	163,439	90	163	0
Central German coalfields												
Deuben		1936 (1993)	67	0.34	Mibrag		37	1.1	8,640,00**	1,470	824	-
Buschhaus	D	1985	352	0.38	Helmstedter Revier GmbH	Oct '16		1.036	3	384	209	2
CHP Chemnitz Nord II	Block B	1988	57	0.38	eins GmbH & Co. KG		80	0.984	1,102,501	843	679	31
CHP Chemnitz Nord II	Block C	1990 (2010)	91	0.38	eins GmbH & Co. KG			0.984				
Schkopau	A	1996	450	0.4	Uniper		21	1.033	5,502,113	4,173	3,468	124
Schkopau	B	1996	450	0.4	Uniper			1.033				
Lippendorf	LIP S	1999	875	0.42	EnBW		8	0.923	11,376,121	9,947	8,013	127
Lippendorf	R	2000	875	0.42	LEAG			0.923				

* Figure for 2014

** Figure for 2015

(BNetzA 2018a; LEAG 2018; EEA 2018b, 2018b; UBA 2018f; EBC 2018; Stadtwerke Cottbus 2018; Öko-Institut 2017b, 2017d; RWE Power 2010; RWE Generation SE 2018a)

Note on specific emissions: Electrical efficiency was used to calculate the specific emissions. In CHP power plants, the yield of electrical capacity decreases due to the heat output, which in turn increases the overall utilisation of the fuel, and thus the overall efficiency of the power plant. This has a positive effect on the specific emissions of the power plant. Öko-Institut (2017b) performed calculations taking CHP operation and utilisation into account. Figures for power plants <200 MW are based on own calculations. The specific emissions are derived from the efficiencies and the respective emission figures for lignite from the corresponding open-cast mines. Heat use is not incorporated.

Table Annex 2 Installed capacity and efficiency of hard coal-fired power plants (>50 MW)

Power plant	Block	Start (retrofit)	Net capacity (MW)	Electrical efficiency (estimated)	Company	CHP	Kg CO_2/KWh	In t			
								CO_2 2017	SO_2 2015	NO_x 2015	PM_{10} 2015
PP Marl I	Steam industry	1939	120	0.27	Evonik	Yes	1.2403	1,701,963	700	1,591	27
	Block 4	1971	55	0.35	Evonik	Yes	0.9588				
	Block 5	1983	60	0.38	Evonik	Yes	0.8836				
CHP Wolfsburg-Nord	Generator A	1959 (2000)	62	0.43	Volkswagen AG	Yes	0.7953	774,121	511	347	21
	Generator B	1959 (2000)	62	0.43	Volkswagen AG	Yes	0.7953				
PP Leverkusen		1962	103	0.33	Currenta	Yes	1.0242	705,942	454	289	8
PP Lünen	Lünen 6	1963 (1996)	149	0.42	Steag	No	0.8144	995,360	884	1,166	20
	Lünen 7	1970 (1997)	324	0.42	Steag	Yes	0.8096				
CHP Römerbrücke	Coal-fired plant	1964 (2005)	50	0.42	Energie SaarLorLux AG	Yes	0.8048	173,819	70	68	4
Scholven	B	1968	345	0.35	Uniper	Yes	0.9797	4,300,742	1,814	3,418	126
	C	1969	345	0.35	Uniper	Yes	0.9726				
	FWK Buer	1985	70	0.39	Uniper	Yes	0.8722				
Reuter	Reuter C	1969	124	0.35	Vattenfall	Yes	0.9726	450,537	52	247	5
CHP Moabit	Moabit A	1969 (1990)	89	0.40	Vattenfall	Yes	0.8450				
Farge	Farge	1969 (2007)	350	0.44	ENGIE	No	0.7638	1,259,810	524	983	42
Gemeinschaftskraftwerk Kiel		1970 (1992)	323	0.41	GK Kiel GmbH	Yes	0.8346	1,116,575	386	1,057	37
PP Krefeld-Uerdingen N 230		1971	110	0.35	Currenta	Yes	0.9588	887,879	575	473	19
PP Mannheim	Block 6	1975 (2005)	255	0.44	GK Mannheim	Yes	0.7726	6,858,626	1,419	3,395	139
	Block 7	1982	425	0.38	GK Mannheim	Yes	0.8895				
	Block 8	1993	435	0.41	GK Mannheim	Yes	0.8294				
	Block 9	2015	843	0.46	GK Mannheim	Yes	0.7308				

Wilhelmshaven	1	1976	757	0.37	Uniper	No	0.9260	1,322,071	1,566	1,989	61
PP Hafen	Block 6	1979	303	0.37	swb	Yes	0.9074	1,520,633	961	1,072	0
PP Mehrum	Block3	1979 (2003)	690	0.43	Stadtwer-ke Hannover AG	No	0.7815	1,929,983	2,442	2,002	27
Bergkamen	A	1981	717	0.38	RWE	Yes	0.8953	1,639,651	2,350	2,069	50
Völklingen-Fenne	MKV	1982	179	0.38	Saar GmbH	Yes	0.8895	1,046,235	1,216	1,385	16
	HKV	1989	211	0.40	Saar GmbH	Yes	0.8503				
Gersteinwerk	K2	1984	614	0.39	RWE	No	0.8779	24.671	0	0	0
CHP Wolfsburg-West	Block 1	1985	139	0.39	Volkswagen AG	Yes	0.8722	1,721,936	1,457	1,626	65
	Block 2	1985	139	0.39	Volkswagen AG	Yes	0.8722				
Karlsruhe	RDK 7	1985 (2005)	517	0.44	EnBW	Yes	0.7726	3,841,547	1,961	1,804	23
	RDK 8	2014	834	0.46	EnBW	Yes	0.7348				
CHP Heilbronn	HLB 7	1985 (2009)	778	0.45	EnBW	Yes	0.7553	2,394,697	1,482	2,023	32
Ibbenbüren	B	1985 (2009)	794	0.45	RWE	Yes	0.7553	2,512,586	1,394	2,190	28
Zolling	Zolling Block 5	1986 (2011)	472	0.45	ENGIE	Yes	0.7469	1,502,946	0	4	0
Heyden	4	1987	875	0.39	Uniper	No	0.8611	1,977,821	1,377	1,796	23
Reuter West	Reuter West D	1987	282	0.39	Vattenfall	Yes	0.8611	2,491,619	324	2,297	47
	Reuter West E	1988	282	0.40	Vattenfall	Yes	0.8557				
PP Walsum	Walsum 9	1988	370	0.40	Steag	Yes	0.8557	3,125,023	2,155	3,643	41
	Walsum 10	2013	725	0.46	Steag	Yes	0.7388				
Wedel	Wedel 1	1988 (1993)	137	0.41	Vattenfall	Yes	0.8294	1,136,524	650	856	43
	Wedel 2	1989 (1993)	123	0.41	Vattenfall	Yes	0.8294				
Hannover	Block1	1989	136	0.40	Stadtwerke Hannover	Yes	0.8503	1,590,978	795	938	23
	Block2	1989	136	0.40	Stadtwerke Hannover	Yes	0.8503				
CHP Elberfeld	Block 3	1989	85	0.40	WSW	Yes	0.8503	356,373	177	228	0

CHP Frankfurt-Höchst	Block B	1989	66	0.49	Infraserv & Höchst	Yes	0.6891				
CHP Frankfurt-West	Block 2	1989	62	0.40	Mainova	Yes	0.8503	929,738	343	535	6
	Block 3	1989	62	0.40	Mainova	Yes	0.8503				
PP Hastedt	Block 15	1989	119	0.40	swb	Yes	0.8503	776,324	273	581	3
PP Herne	Herne 4	1989 (2013)	449	0.46	Steag	Yes	0.7388	1,531,134	1,509	1,881	22
CHP Offenbach		1990	54	0.40	Energieversorgung Offenbach AG	Yes	0.8450	233,705	104	96	2
CHP München-Nord	2	1991	333	0.40	SWM	Yes	0.8397	1,701,489	167	1,276	44
Staudinger	5	1992	510	0.41	Uniper	Yes	0.8346	1,889,339	354	1.453	70
Tiefstack	Tiefstack	1993	194	0.41	Vattenfall	Yes	0.8294	1,213,337	755	866	11
PP Rostock	Rostock	1994	514	0.41	EnBW	Yes	0.8244	2,335,824	275	1,999	49
CHP Altbach/Deizisau	ALT CHP 2	1997 (2012)	336	0.44	EnBW	Yes	0.7682	1,250,276	628	947	13
Trianel Kohle-PP Lünen		2013	735	0.46	Trianel Lünen	Yes	0.7388	3,429,207***	588	613	21
Westfalen	E	2014	764	0.46	RWE	No	0.7348	2,709,042	1,180	2,342	26
CHP Moorburg	A	2015	800	0.46	Vattenfall	Yes	0.7308	6,157,809	349	641	
	B	2015	800	0.46	Vattenfall	Yes	0.7308				
PP Wilhelmshaven	Kraftwerk Wilhelmshaven	2015	731	0.46	ENGIE	No	0.7308	2,114,040	403	757	12

***Figure for 2016

(BNetzA 2018a; EEA 2018b, 2018a; RWE Generation SE 2018b; UBA 2018f; EBC 2018; Öko-Institut 2017b; DIW Berlin 2014b)

Note on specific emissions: Similar to the procedure for lignite-fired power plants, the specific emission figures are based on the utilisation degree of the power plants. For this purpose, the average emission factor of 93,888 tCO2/TJ of the hard coal utilised in Germany is used (UBA 2017i). For efficiencies, see DIW (2014b). CHP operation was not incorporated in this.

Table Annex 3: Power plants in the reserve (>50 MW)

Power plant	Block	Start (retrofit)	Net capacity (MW)	Company	CHP	In t CO_2	SO_2	NO_x	PM 10
						2017	2015	2015	2015
CHP Altbach/Deizisau	ALT CHP 1	1985	433	EnBW	Yes	Emissions in Table Annex 5 for Altbach/Deizisau			
CHP Heilbronn	HLB 5	1965 (2010)	125	EnBW	No	2,394,697	1,482	2,023	32
CHP Heilbronn	HLB 6	1966 (2010)	125	EnBW	No				
PP Bexbach	BEX	1983	726	Steag	No	508,496	1,393	1,548	25
PP Walheim	WAL 1	1965 (2011)	96	EnBW	No	74,782	59	83	1
PP Walheim	WAL 2	1967 (2011)	148	EnBW	No				
Weiher	Weiher III	1976	656	Steag	Yes	408,420	1,207	1,162	13

(BNetzA 2018a; EEA 2018b, 2018a; EBC 2018)