SRU German Advisory Council on the Environment

Start coal phaseout now

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Summary

Anthropogenic climate change has alarming consequences for Germany and the world. For eight years, carbon emissions in Germany have not dropped materially – even in the electricity sector despite ever-increasing renewables shares. A major fraction of these emissions is attributable to electricity generation from lignite and hard coal. In the past few years, coal based power generation has remained relatively constant for various reasons, particularly because of failures in energy and climate policy.

1. The new German government should therefore immediately initiate a coal phaseout. It would not only lead to major emission reductions at relatively low cost, but also have considerable positive effects on the environment and human health, especially because emissions of mercury, sulfur dioxide, nitrogen oxides, and particulate matter would be reduced. Low-emission power generation is also required for successful decarbonization of the transport and heat sectors, which will increasingly be electrified as sector coupling increases.

Various challenges must be tackled for a fast reduction of coal power. Reliable power supply must be ensured, and the phaseout must include socially responsible assistance for the 20,000 to 30,000 coal jobs and regions that would be affected. In addition, financing must be secured for the follow-up costs of mining. The German Advisory Council on the Environment (SRU) believes that all three challenges can be solved; this statement presents measures to that end. Once the new government has been formed, the new federal government should immediately make the following important decisions for a design of a coal phaseout:

Specification of a CO_2 emissions budget for the coal sector

- From a scientific perspective, future emissions from German coal plants should not exceed a total of 2,000 MT CO_2 if Germany wishes to make its necessary contribution to the climate protection agreement agreed in Paris. The exact distribution of the remaining carbon budget will entail distribution effects that policymakers will have to keep in mind. Specifying the remaining carbon emissions budget in a coal phaseout law comparable to the nuclear consensus from 2000 would give plant operators and other affected parties planning security.

Launching a coal phaseout in three phases

- The SRU finds that a three-phase coal phaseout makes sense in light of economic structural development and security of supply:

  – a quick launch of the phaseout with short-term closures of especially emissions-intensive power plants by 2020,

  – temporary further operation of the most modern coal plants up to 2030 with limited capacity utilization to ensure supply security and lessen the impact of social challenges,

  – successive closures of the last coal plants in the course of the 2030s in compliance with the previously specified CO_2 emissions budget.

Implementation of a Coal Commission for the parallel design of a phaseout path and structural policy

- The commission should include members of all areas affected. Importantly, they should not advise the German government on “whether” to have a coal phaseout, but “how” along the lines of the carbon emissions budget previously defined by the German government. In parallel, strategies for the further development of affected regions should be worked up.

1 Introduction

2. A failure to reduce global greenhouse gas emissions considerably in the next few years will have catastrophic consequences. The dramatic effects of unmitigated climate change are increasingly making themselves felt. For instance, the latest findings indicate that the Gulf Stream could be affected more than previously assumed (LIU et al. 2017), which would considerably impact the European climate. In addition, the consequences of climate change – in close connection with concomitant food scarcity and poverty – also play a major role in migration.

On the other hand, numerous developments have given rise to hope in the past few years. The climate conferences in Paris (2015) and Marrakesh (2016) showed that a growing number of countries are aware of their responsibility. In the past few years, global emissions have remained roughly constant despite continuing economic growth (LE QUÉRÉ 2016). Coal power production has started to shrink in China and is not growing as quickly in India as it used to. As a result, global emissions may come in under the figure expected for 2030 despite the recent change in US climate policy (HÖHNE et al. 2017). One reason is the success of renewables, especially photovoltaics and onshore wind. In the past few years, both technologies have experienced a cost degression and are now already cheaper than conventional power plant technology in many places.

3. Germany faces a paradoxical situation. While the country was an early mover with renewables, contributing considerably to their global success, it nonetheless runs the risk of missing its own national climate targets for 2020 and 2030. For eight years, carbon emissions in Germany have not dropped materially. The main reason is the continuing stable level of coal based power generation, which makes up more than a fourth of national emissions (UBA 2017c). For this reason, the German Advisory Council on the Environment (SRU) advises the German government to adopt additional climate protection measures. An immediate launch of a coal phaseout would be an important step in the right direction. In contrast, it would be irresponsible to water down the climate targets now.

Contradictory trends mean that Germany is not living up to its international responsibility but is instead undermining its international credibility as host of the international climate conference in 2017 (SRU 2016). With this statement, the SRU urgently calls on the German government to initiate an incremental coal phaseout as quickly as possible in a participatory process towards producing a consensus.

2 Benefits of a coal phaseout

4. Quickly and effectively reducing coal based power generation in Germany would be an important, affordable contribution to protecting the climate, the environment, and human health. It would also have significant energy-economic benefits.

2.1 Climate protection

2.1.1 The consequences of climate change for Germany and the world

5. The risks of unmitigated climate change have been studied in detail for many sectors (IPCC 2014; O'NEILL et al. 2017). Fundamental changes are expected for ecosystems as a result (OSTBERG et al. 2013; GERTEN et al. 2013), not only for coral reefs and habitats in the Arctic, which are already strongly affected by climate change. Even if global warming is kept to 2 °C, simulations show that up to a fifth of global landmass is highly likely to undergo a change in ecosystem of at least medium scale. If temperatures increase by 5 °C, medium-scale change would come to roughly 80 % of global landmass (OSTBERG et al. 2013). As a result, an affected ecosystem's fundamental bio-geochemical and structural properties would change, resulting in a risk of substantial changes to entire ecosystem properties. Similar far-reaching effects are also predicted for ocean ecosystems (HOEGH-GULDBERG and BRUNO 2010).

In addition, such extreme weather events as heat waves, droughts, extreme precipitation, and floods are already becoming more common. The herby caused risks for humans and nature will grow further with increasing greenhouse gas emissions. For instance, by 2100 ambitious climate policy could keep sea level rise to only 28 to 56 cm, whereas 57 to 131 cm is expected if greenhouse gas emissions remain unabated (MENGEL et al. 2016). Such an increase in sea level would have existential consequences for some regions, such as the Maldives, whose islands are scarcely a meter above sea level.

In addition, the availability of fresh water is expected to drop significantly as temperatures rise (SCHEWE et al. 2014). For instance, the effects of temperatures rising more than 2 °C would probably increase the share of people living in conditions of absolute water scarcity by 40 % (ibid.). In some regions, dwindling availability of fresh water would have severely detrimental effects on plant growth (ELLIOTT et al. 2014). In many regions of the world, the effects of climate change, in part for this reason, would reduce agricultural yield – and hence food production (ROSENZWEIG et al. 2014). In sub-Saharan Africa, a mere global warming of 1.5 °C by 2030 would mean that 40 % of the land currently used for corn crops would no longer be suitable for the varieties planted today (World Bank 2013). If the temperature rises by more than 2 °C, total agricultural yield could drop by some 15 to 20 % – and not only in this region (ibid). This drop would have significant consequences for food security, which in turn might increase the flow of refugees from affected regions. Furthermore, changes in the climate system affect human health directly and indirectly. For instance, increasingly frequent extreme weather events (such as heat waves) directly impact human health by increasing mortality and morbidity (IPCC 2014, p. 741). In addition, indirect effects result from changes to the environment and ecosystems. For example, the occurrence of certain diseases changes as the habitat of disease-carrying insects moves (ibid.). Another indirect consequence of climate change on human health stems from social changes brought about by climate change (ibid.). Malnutrition, mental stress, and financial losses could result from developments brought about by climate change, thereby detrimentally affecting human health (ibid.).

6. If the climate continues to heat up, large-scale, often irreversible change processes could take place in the Earth system. These “tipping point processes” are nonlinear processes in which the quality of a status changes when a critical threshold is crossed. In the Earth system, the result could be fundamental changes to the basis of livelihood for most people. For instance, evidence has been found that the thermohaline circulation in the Atlantic is slowing down, which is probably related to the melting of Greenland‘s ice sheet caused by climate change (RAHMSTORF et al. 2015; LIU et al. 2017). If temperatures continue to increase, there is a risk that this trend will worsen. Also known simply as the “Gulf Stream system,” this circulation in the Atlantic brings warm masses of water to the north, providing a mild climate there. A weakening of this circulation system would have drastic effects on weather systems, especially in Europe (LEVERMANN et al. 2012; 2005).

7. In Germany, too, the effects of climate change will differ by region even as they fundamentally affect many different areas of society (BRASSEUR et al. 2017). If global greenhouse gas emissions continue to rise unabated, the changes to the climate system already taking place are expected to worsen significantly in Germany, as well (DEUTSCHLÄNDER and MÄCHEL 2017). For instance, the number of very hot days will continue to increase, and heat waves will become more common. The heat wave of 2003 took an additional 25,000 to 52,000 lives in several European countries (LARSEN 2006; KOPPE et al. 2004). In France, for example, 15,000 deaths were registered, compared to around 10,000 in Italy and some 7,000 in Germany (GREWE et al. 2014; JENDRITZKY 2007; ROBINE et al. 2007).

Germany can also expect precipitation patterns to change. In a number of regions of Germany, heavy winter precipitation is already increasing and hail is becoming more common. This trend is expected to worsen if climate change remains unmitigated (KUNZ et al. 2017). Furthermore, flooding is expected to become more frequent. A study investigating Germany’s five largest rivers found that flood damage can be expected to increase if climate change remains unmitigated up to the end of the century (HATTERMANN et al. 2016). The flood on the Elbe River in 2013 showed what such extreme events might look like.

In Germany, too, the forecast changes in both temperature and precipitation pose risks to human health, nature, and the environment. For instance, the impacts on soils in Germany are mainly negative (PFEIFFER et al. 2017). Organic substances and nutrient reserves in soils are decreasing. In combination with changing or regionally different levels of waterlogging, dry soil, and soil erosion, this reduction reduces soil productivity, thereby endangering the soil’s productive function. Forests in Germany are also affected. In the course of climate change, the habitats of tree species are shifting, as is the species composition of forests. Changed precipitation structures and longer hot spells foster the development of dangerous insects and increase the frequency of forest fires (KÖHL et al. 2017).

Weather conditions changed by climate change also negatively impact human health (AUGUSTIN et al. 2017). In particular, the chronically ill and elderly will suffer from a growing number of exceptionally hot days and more frequent heat waves. Very hot days, for instance, negatively affect people already suffering from poor health (such as circulatory and respiratory diseases), the elderly, infants, and toddlers (AUGUSTIN et al. 2011; GABRIEL and ENDLICHER 2011; GARCÍA-HERRERA et al. 2010; JENDRITZKY 2007; EIS et al. 2010; OUDIN ÅSTRÖM et al. 2015; UBA 2015b; XU et al. 2014a; 2014b). At the workplace, the risk of heat-related performance losses and resulting absences may increase in some professions (HORNBERG und PAULI 2010), especially in metropolitan areas. Climate change may also detrimentally affect air quality. In turn, respiratory, circulatory, and infectious diseases might become more common, which would not only have considerable consequences for human well-being, but also lead to increasing healthcare costs (TRÖLTZSCH et al. 2012).

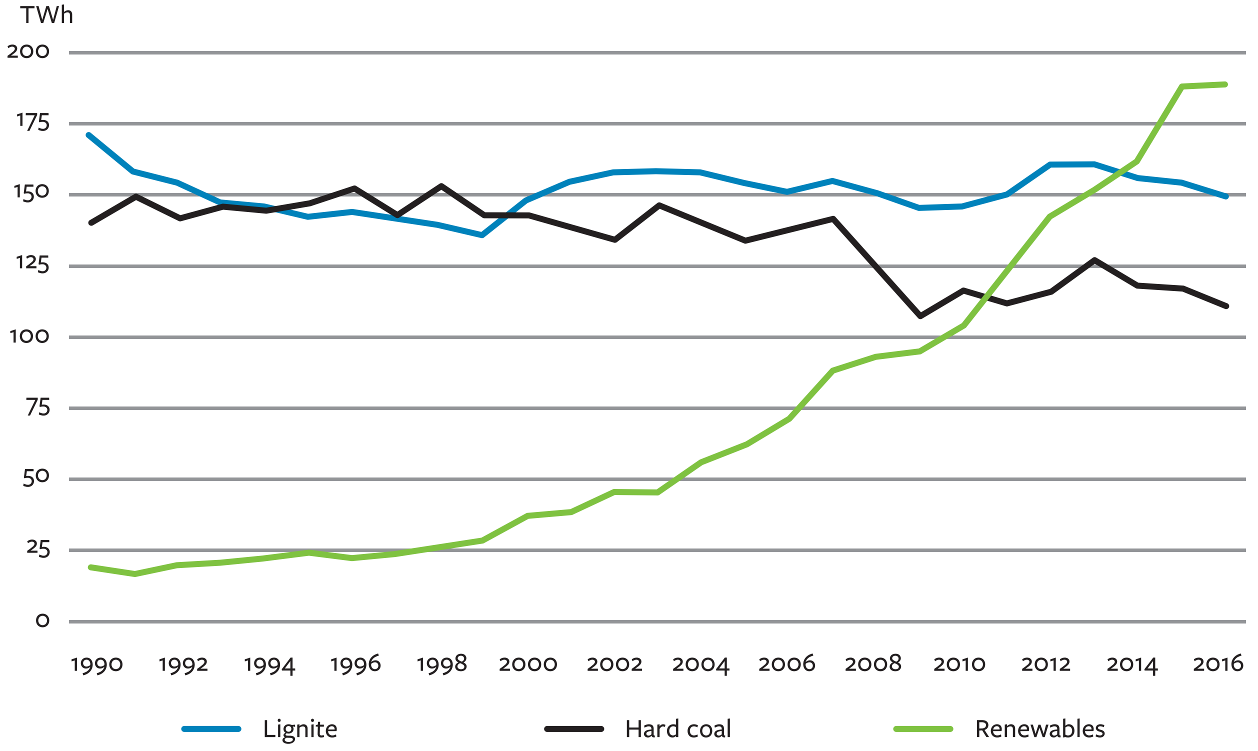
The aforementioned effects of unmitigated climate change for Germany apply only to the short and mid-term perspective. In the long term, rising temperatures will probably have even more far-reaching impacts by changing atmospheric and ocean circulations on a grand scale. In Germany, too, the result would be unpredictable consequences for the climate, ecosystems, livelihoods, and the economic system.

2.1.2 The climate-policy need for an immediate coal phaseout

8. In the Paris Climate Agreement, the global community set the target of keeping global warming well below 2 °C – and at 1.5 °C if possible. If the remaining global carbon emissions budget is equitably distributed (see section 2.1.3), Germany would need to be nearly greenhouse gas-neutral by midcentury in order to make an appropriate global contribution to climate protection. A third of Germany's current greenhouse gas emissions

Figure 1

Power generation from coal and renewables 1990–2016 (TWh/a)



SRU 2017; data source: AGEB 2017

stems from the energy sector, 85 % of which is caused by coal based power generation (UBA 2017c). The need for climate policy to turn away from the combustion of fossil carbon thus implies a phaseout of carbon-intensive coal power in the midterm (next 20 years) as well as a phaseout of natural gas and petroleum, two other sources of fossil energy, in the long term (next 30 years) (Agora Energiewende 2017).

9. In the past few years, renewable electricity has grown quickly enough to overcompensate for the reduction in nuclear power. Nonetheless, carbon emissions in Germany have not dropped enough, neither in power generation nor overall, for the country to reach its climate targets. The main reason is emissions from the continued production of electricity from lignite and hard coal, which has remained at a high level since 1990 (Figure 1). Most of the carbon emissions savings from the closure of older coal plants were merely offset by emissions from newer, albeit more efficient plants (UBA 2017a).

The constant level of power generation from lignite and hard coal is mainly the result of low carbon certificate prices and lower global hard coal prices. The variable cost of lignite and hard coal facilities is therefore far below that of gas-fired power plants. The resulting low spot market prices for electricity make all fossil power plants less profitable. As a result, gas-fired power plants in particular are used less frequently and are being pushed out of the market in Germany and neighboring countries.

2.1.3 The budget approach as a basis for a coal phaseout

10. For climate protection, it is not decisive when exactly the last coal plant closes or how much carbon is emitted in specific target years, but rather how much carbon is emitted totally within a given timeframe. It therefore makes sense to calculate the maximum total amount of carbon emissions that corresponds to an appropriate German contribution to international climate protection: the budget approach. Starting from this budget approach, it is clear that early savings can help maintain residual amounts for future emissions (Figure 2). Conversely, postponing action means that more drastic steps will eventually need to be taken. Emission targets for specific interim years are important as road markings but must reconcile with the overall budget.

11. In the following section, the scientific basis for a carbon emissions budget – which, in the end, must be politically defined – is shown for coal power in Germany. In a second step, these numbers are compared to cumulative emissions from various climate protection scenarios drawn up for the German government.

Calculating a CO_2 emissions budget for the energy sector and coal based power generation

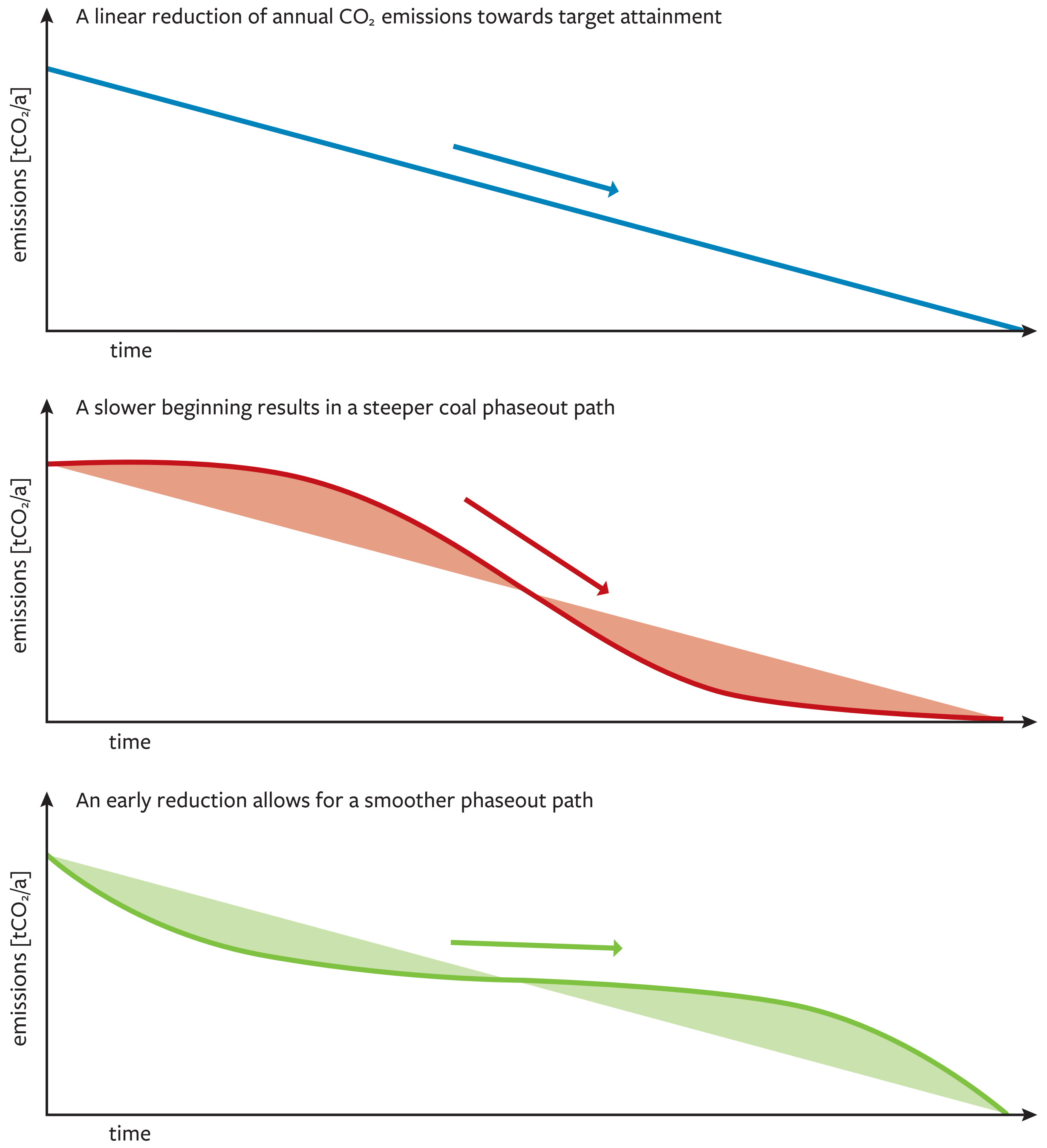
12. For the 2 °C target to be reached, cumulative global CO_2 emissions must not exceed around 1,000 GT counting from 2011 (IPCC 2013, p. 25). From 2011 to 2014, 157 GT CO_2 was emitted. Therefore, 850 GT CO_2 was left at the beginning of 2015 (ROGELJ et al. 2016). In contrast, if the goal is 1.5 °C, only 240 GT CO_2 was left in 2015. The calculations are based on a 66 % probability of the targets being reached. For a higher probability, emissions would have to be reduced even more.

If negative emissions (such as from the coupling of biomass use and carbon capture) and other geo-engineering technologies are included, the remaining carbon emissions budget could be larger. However, it is not clear when these technologies will be market-ready. They will probably be expensive and entail ecosystem risks that will be hard to calculate (SRU 2009). A sustainable climate protection strategy should therefore focus on achieving climate targets without the use of geo-engineering and negative emission technologies.

13. In allocating the remaining carbon emissions budget to individual countries, one central question is how to deal with historic emissions. If past emissions are considered when allocating the remaining budget, the share still available for historically emission-intensive countries is reduced. If all greenhouse gas emissions since industrialization were completely accounted for, most industrialized countries – including Germany – would have already used up or even far exceeded their share of the total emissions budget (MATTHES et al. 2017). Another approach is to use the date of the agreement reached by the community of states for a common climate target – the Paris Climate Agreement of 2015 – as the starting point. In this case, national emission shares could be calculated on a globally standard per capita basis. In 2015, the German population (81.4 million) made up 1.1 % of the global population (7,346.6 million). To reach the 1.5 °C target (with 66 % probability), Germany would therefore have an emissions budget of 240 GT CO_2 x 1.1 % = 2,600 MT CO_2. For the 2 °C target, the emissions budget would be 850 GT CO_2 x 1.1 % = 9,350 MT CO_2 (MATTHES et al. 2017). These values are far below the cumulative emissions of 13,500 to 17,600 MT CO_2, which are calculated in scenarios for the Federal Ministry of the Environment, Nature Conservation, Building and Reactor Safety (BMUB) (Table 1; ÖkoInstitut and Fraunhofer ISI 2015).

Figure 2

Schematic coal phaseout paths characterized by an equal CO_2 emissions budget



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14. For allocating the remaining national carbon emissions budget to individual sectors, a study by Öko-Institut and Prognos (MATTHES et al. 2017) carried forward the current share of 40 to 42 % of total emissions as a starting point for the energy sector. Numerous other studies, however, assume that the power sector should be decarbonized faster than other sectors because the mitigation potential is less expensive there (UBA 2016b). For instance, a study for the Federal Environmental Ministry (ÖkoInstitut 2015) only allotted a smaller share of 32 % of the cumulative CO_2 emissions from 2015 to 2050 to the energy sector. The Climate Action Plan 2050 also calls on the energy sector to make the greatest savings in percent and absolute terms by 2030, resulting in emissions being cut in half relative to 2014 (Table 2; BMUB 2016). This greater reduction contribution from the energy sector is consistent with calculations from the European Commission

(European Commission 2011) and various scientific calculations (SRU 2011; ÖkoInstitut and Fraunhofer ISI 2014; NITSCH 2013; KLAUS et al. 2010).

15. If the energy sector in Germany is allowed to emit 32 % of the country's remaining emissions, the sector's remaining volume is about 3,000 MT CO_2 based on the global remaining CO_2 emissions budget for the 2 °C target (with historic emissions left out). For the 1.5 °C target, only around 800 MT CO_2 would be left. From the scientific perspective, the German energy sector's CO_2 emissions budget for the period from 2015 to 2050 should therefore remain below 3,000 MT CO_2 if Germany wishes to make an appropriate contribution to the climate protection agreed in Paris. The share of the coal sector in this maximum budget should not exceed 2,000 MT CO_2 in order to keep a budget of 1,000 MT CO_2 for gas-fired power plants, which have lower specific emissions and are usually more flexible. For the more ambitious 1.5 °C target, the budget for cumulative emissions from German coal plants is no more than 500 MT CO_2. The annual emissions from coal plants in Germany currently amount to around 250 MT CO_2. Clearly, postponing a phaseout of coal power has made the target corridor extremely ambitious. The upcoming legislative period is thus the last opportunity to set a course for appropriate implementation of the Paris climate protection goals in Germany.

The current climate protection scenarios for the German Environmental Ministry (ÖkoInstitut and Fraunhofer ISI 2015) result in cumulated energy sector emissions of 4,300 to 5,600 MT CO_2, far more than the CO_2 emissions budget that is in line with the 2 °C target. Most of these emissions – 2,300 to 3,800 MT CO_2 – come from coal plants. The planned emissions savings for the energy sector in the Climate Action Plan 2050 would lead – assuming a linear reduction path – lead to total emissions of 4,100 MT CO_2 until 2030 (Table 1). This reduction path thus also exceeds the CO_2 emissions budget derived from Paris and is therefore not consistent with the climate protection targets agreed there. In other words, Germany would not make an appropriate contribution to global climate protection efforts. If the energy sector – or Germany overall – were to insist on a larger CO_2 emissions budget, additional savings would have to come from other sectors or countries if the overall emissions target is to be reached.

In terms of climate protection, when exactly the last coal plant is shut down is less important than meeting the agreed CO_2 emissions budget. Studies focusing on

Table 1

Cumulative CO_2 emissions for Germany 2015–2050 (MT CO_2)

Calculation approaches and scenarios		Total emissions	Energy sector	Coal based power generation
Per capita approach from the global CO_2 budget	Consideration of historic dimension (1.5 °C and 2 °C targets)	already exceeded	already exceeded	already exceeded
	Target of 1.5 °C reached (66 % probability)	2,600	800	< 500
	Target of 2 °C reached (66 % probability)	9,350	3,000	< 2,000
Climate Action scenario	Scenario KS 95 from BMUB	13,500	4,300	2,300
	Scenario KS 80 from BMUB	17,600	5,600	3,800
Climate 2050	Cumulative emissions based on the intermediate target for 2030	Only information for total greenhouse gases	4,100 (by 2030)	not available

Assumptions underlying the calculation: In the per capita approach, the energy sector is allotted 32 % of Germany's total CO_2 emissions; the Climate Action Plan assumes a linear reduction of emissions up to 2030.

SRU 2017; data source: Öko-Institut and Fraunhofer ISI 2015; MATTHES et al. 2017; IPCC 2013; BMUB 2016

Table 2

Emission trends and sector targets for 2030 in the Climate Action Plan 2050

	Greenhouse gas emissions in Germany (MT CO_2 equivalent)				Emissions reduction in %				
	1990	2014	2030		Real: 1990–2014	Target: 2014–2030		Target: 1990–2030	
			from	to		from	to	from	to
Energy sector	466	358	175	183	23 %	51 %	49 %	62 %	61 %
Buildings	209	119	70	72	43 %	41 %	39 %	67 %	66 %
Transport	163	160	95	98	2 %	41 %	39 %	42 %	40 %
Industry	283	181	140	143	36 %	23 %	21 %	51 %	49 %
Agriculture	88	72	58	61	18 %	19 %	15 %	34 %	31 %
Other	39	12	5	5	69 %	58 %	58 %	87 %	87 %
Total	**1248**	**902**	**543**	**562**	**28 %**	**40 %**	**38 %**	**56 %**	**55 %**

SRU 2017; data source: BMUB 2016

compliance with the Paris Climate Agreement estimate, however, that a coal phaseout needs to be completed by 2030 or no later than 2035 (MATTHES et al. 2017; PIETRONI et al. 2017).

2.2 Positive health and environmental effects of a coal phaseout

16. Coal plants are major emitters of mercury, sulfur dioxide (SO_2) and nitrogen oxides (NO_x). In 2015, for instance, all of the power plants in the energy sector accounted for some 65 % (5.9 kt) of mercury emissions, 61 % (213.9 kt) of sulfur dioxide emissions, and 24.8 % (293.9 kt) of nitrogen oxide emissions in Germany (UBA 2016a). These emissions came from coal plants in particular (ca. 95 % of the mercury and ca. 70 % of the NO_x emissions: UBA 2017e). The energy sector's share of particulate matter (PM_{10}) in overall emissions was just below 5 % (10.2 kt) (UBA 2016a), though nitrogen oxides and sulfur dioxide are also precursor substances for secondary particles. These emissions from coal plants thus increase the burden from particulate matter.

Sulfur dioxide emissions were reduced considerably in the past by means of regulations; they are no longer a major challenge for health and the environment in general (UBA 2013). The situation is different, however, for mercury, nitrogen oxides, and particulate matter, which will therefore be dealt with in greater detail below.

A phaseout of coal power would lead to positive health and environmental effects since these substances would no longer be emitted, as long as coal plants are not replaced by power plants that are fired with fossil fuel or have other dangerous environmental and health impacts. At present, however, sound data are not available to quantify the exact health benefits if these substances were no longer emitted.

2.2.1 Health effects

Mercury

17. A heavy metal, mercury is highly relevant for human toxicology (SRU 2008, Item 774 ff.). Mercury from coal plants enters the environment in particular via atmospheric emissions and wet deposition. Some of the mercury compounds can remain in the atmosphere for a long time and be transported across long distances so that they are distributed across a large area (UBA 2016c). Around 20 % of the mercury emissions annually emitted in Germany (around 9.1 kt in 2015) goes into German landfills, while the rest is transported internationally (ILYIN et al. 2016; UBA 2017d). Concentrations of mercury in the air and mercury depositions in Germany are high in a European comparison (ILYIN et al. 2016). Because the heavy metal is persistent and ubiquitous, one speaks of a global mercury cycle. Every point of mercury emission, including natural sources (forest fires, volcanic eruptions, etc.), contributes to this cycle (UNEP 2008; SALOMON 2009).

18. Microorganisms convert some of the mercury that enters soils and water into organic compounds (methylmercury). Living organisms can easily take up these compounds, which have bioaccumulative properties. Aside from its use in dentistry (amalgam fillings), humans are exposed to mercury in Germany primarily by eating fish, mussels, and crustaceans that have taken up organic mercury compounds through the food chain (UBA 2016c).

In terms of the heavy metal's impact on people, the focus is on chronic effects on the nervous system and fetal development. Methylmercury is able to pass the blood-brain barrier and the placenta through blood. Infants and toddlers are considered especially vulnerable. Exposure to high levels of mercury during fetal development can lead to neurocognitive limitations in children. Fetuses are especially vulnerable to chronic mercury exposure (SYVERSEN and KAUR 2014; DRASCH et al. 1994; CAROCCI et al. 2014).

The European Food Safety Authority (EFSA) puts the tolerable weekly intake (TWI) for methylmercury at 1.3 µg/kg of body weight (EFSA 2012). Exposure via food for the European population (median of 95 % percentile) is close to that value and even exceeds it in some cases (a. SRU 2008, Item 774 ff.; UBA 2016c; EFSA 2012), so that the avoidance of exposure plays a special role in all exposure paths towards preventive healthcare. The German Federal Institute for Risk Assessment (BfR) recommends that pregnant women not eat fish species with especially high levels of methylmercury, such as tuna (BfR 2008). For mercury buildup in ocean fish, especially slow-growing species at the end of the food chain, natural levels of mercury in the geosphere and other natural sources also play an important role in addition to anthropogenic sources. Historic emissions that have built up in sediments and soils and are now being re-mobilized are especially responsible for the continuing high levels in fish, some of which still very clearly exceed the quality values in the Water Framework Directive 2000/60/EC in large fluvial areas in Germany (BMUB and UBA 2013; LAWA et al. 2016). When new mercury enters surface water, atmospheric deposition (around 10 %) plays a smaller role than, for instance, urban areas (around 30 %), erosion (around 23 %), and groundwater (around 18 %) (UBA 2017b).

19. In 2013, Germany signed the United Nations' Minamata Convention, whose objective is to "protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds" (BMUB 2017). The convention also calls for power plant emissions to be regulated as a reduction measure. The current conclusions from 17 August 2017 on which available technologies are best for large combustion facilities (Item 61) contain spectrums for mercury levels (BREF LCP 2016) that are stricter than the value currently in force in Germany.

20. From the perspective of the environment and health policy, a phaseout of coal power would be welcome, especially because coal power is the main emitter of anthropogenic mercury emissions in Germany in terms of its content in the air. Because of the complicated cycle of matter described above, this phaseout can only reduce the burden on biotas – and hence, on humans – in the long term, but it would also be an important contribution to reducing the international transport of mercury. In general, every reduction of pollutant emissions is important, particularly because people already consume large amounts of mercury through their food in some cases (Item 18). Although the contributions of current mercury emissions from power plants are difficult to quantify mercury levels in waters and biotas, the levels are relatively low (LAWA et al. 2016); nonetheless, preventive health care principles call for these emissions to be reduced.

Nitrogen oxides

21. Concentrations of nitrogen oxides (NO_x), especially nitrogen dioxide (NO_2), in the air are a major challenge for air purity today. Emissions from coal plants contribute to what is known as the NO_2 background load. The share of the background load in the overall load (local load plus background load) is sometimes quite high. For instance, the background load share is around 53 % on 27 main transit roads in Berlin (Senatsverwaltung für Stadtentwicklung und Umwelt 2013). However, transport is very clearly the main emitter of local emissions at such highly polluted locations, both in terms of local emissions and the urban background share.

The health effects of NO_x are well documented, and NO_2 is known to be an especially effective compound (WHO 2013; EPA 2016; EEA 2013). NO_2 causes irritation and is a very reactive oxidation agent. It does not easily dissolve in the water so that the pollutant is not absorbed in the upper respiratory tract, but in deeper areas (bronchioles and alveoli). There, NO_2 can damage cells, start inflammatory processes, and contribute to hyperreactivity of the bronchi. A pre-existing allergic respiratory disease is a risk factor for hyperreactivity. In addition, respiratory inflammation and chemical changes in airborne allergens can contribute to a worsening of allergic reactions, for instance to pollen (FRANZE et al. 2005; TUNNICLIFFE et al. 1994). Environmental epidemiology studies have also shown connections between NO_2 and respiratory diseases, circulatory diseases, and greater mortality (WHO 2013; EPA 2016). Recent studies also show an association with type 2 diabetes mellitus and low birth weights (LAVIGNE et al. 2016; LIPFERT 2017). In addition, an increase in hospital stays due to chronic bronchitis and bronchial asthma have been documented as a result of high levels of NO_2 (see e.g. OOSTERLEE et al. 1996; PERSHAGEN et al. 1995). Furthermore, the irritation effect of allergies has been shown to worsen, the body's defense against infections be limited, and lung growth in children be stunted after extended exposure to a NO_2 concentration of 40 to 100 µg/m³ (WHO 2000). But even at concentrations below 40 µg/m³ NO_2 respiratory symptoms were described among children in individual cases after long-term exposure (NEAS et al. 1991). People suffering from respiratory diseases (such as hay fever, bronchial asthma, and chronic bronchitis) and people with circulatory diseases are particularly sensitive to NO_2 exposure and are therefore considered especially vulnerable, as are children (LANUV NRW 2010; KEHE and EYER 2013; KRAFT et al. 2005).

The NO_2 limit in Air Quality Directive 2008/81/EC for the protection of human health is 40 µg/m³ as an annual average. Preliminary studies from the German Environmental Agency (UBA) show that this limit was still exceeded at 57 % of locations near traffic in 2016 (UBA 2017g). In addition, nitrogen oxides can promote the formation of ground-level ozone and are precursor substances for particulate matter. Ozone is an irritant that attacks mucous membranes in particular and can detrimentally affect lung function and performance (LANUV NRW 2010).

Because of the current pollution situation in Germany, it is generally important to reduce NO_2 emissions. A phaseout of coal power would help reduce the health effects of NO_2 loads.

Particulate matter

22. Although particulate matter is mainly caused by road traffic, coal plants also contribute to the burden, such as by creating secondary particles from SO_2 and NO_x emissions (Item 16; AMANN and WAGNER 2014). Particulate matter from coal plants is emitted far from the ground and generally distributed across a wide area. It is very hard to quantify the share of emissions in near-source pollution (PLAß and CONRAD 2017). For lignite mining, preliminary estimates of particulate matter shares from the use of coal in total particulate matter pollution were made at individual measurement locations, showing a maximum value of 11 % (Bezirksregierung Köln 2017).

Particulate matter can enter human lungs deeply, while ultrafine particles (with an aerodynamic diameter smaller than 0.1 µm) can even enter body tissue via blood vessels (WHO 2013; 2000). In general, particulate matter loads in outdoor air are a relevant environmental risk factor for all sectors of the population and, relative to other environmental stress factors, lead to a large number of illnesses in Germany as expected (PLAß and CONRAD 2017). The SRU, too, has repeatedly looked into the health impacts of particulate matter in breathing air and made recommendations to reduce this pollution (SRU 2000, Items 786, 808, and 1016; 2008; 2012).

The main health effects concern the respiratory tracts and the circulatory system (BEELEN et al. 2008; HOEK et al. 2013; RAASCHOUNIELSEN et al. 2013; HORNBERG et al. 2013). They are affected by the size, shape, and number of particles as well as by their chemical components and surface qualities (for a detailed investigation, see SRU 2002, Item 550 ff.). Particles from combustion processes have an especially great impact. The health effects of outdoor air pollution from particulate matter have long been described and can be caused by both short-term and long-term exposure (HEINRICH et al. 2002; PETERS et al. 2002; OSTRO 2004). Exposure to particulate matter can also exacerbate pre-existing, generally chronic diseases. The described effects of short-term exposure are a greater number of outpatient visits to hospitals for people with pre-existing respiratory and circulatory diseases and greater "premature" mortality from circulatory and respiratory diseases (harvesting effect). Long-term exposure has been shown to be related to issues from generally worse health and fatigue to chronic diseases and lung cancer (HEINRICH et al. 2002; PETERS et al. 2002; BEELEN et al. 2008; HOEK et al. 2013; RAASCHOUNIELSEN et al. 2013). A connection between long-term exposure and cardiopulmonary diseases, such as heart attacks and asthma, has been documented especially often (BEELEN et al. 2008; HOEK et al. 2013; RAASCHOUNIELSEN et al. 2013; HORNBERG et al. 2013; PLAß und CONRAD 2017). Recent investigations indicate that particulate matter loads are also associated with neurodegenerative diseases (Alzheimer's) and diabetes mellitus (HE et al. 2017; WU et al. 2015). People with pre-existing respiratory diseases (such as bronchial asthma and chronic bronchitis) are especially vulnerable to particulate matter exposure, as are children (PLAß and CONRAD 2017).

Coal plants also emit ultrafine particles, which are especially relevant for human health (e.g. KANG et al. 2011). The clinical, toxicological, and environmental-hygiene relevance of ultrafine particles in outdoor air has not yet been sufficiently researched (HORNBERG et al. 2013; HAHN 2017). This research gap is especially important because individual recent studies indicate their special importance for human health, particularly at early stages of circulatory diseases and strokes. The mass of such particles in the air people breathe is very small relative to larger particles. Current legal limits pertain to mass and therefore do not adequately reflect exposure concentrations. A risk assessment based on the mass is not sufficient for an assessment of particulate matter, either, because these particles are also small and variable and may contain aerosols. The number of particles and the share of the particle surface area with substances that cause cancer or are co-carcinogenic and allergens should instead be taken into greater consideration.

At present, numerous national and international statistically epidemiological estimates of the health impacts of different compositions of particulate matter are available. In the future, exposures and health impacts need to be characterized more from the clinical viewpoint and in terms of environmental hygiene and environmental toxicology in order to provide more evidence that the selected indicators are sufficiently specific and exact for mortality and the disease load of particulate matter pollution (HAHN 2017).

Conclusion

23. The negative health impacts of nitrogen oxides, mercury, and particulate matter on human health are well documented. However, there is a lack of sound investigations for Germany to quantify the disease load from pollution that can be attributed to emissions from coal plants (PLAß and CONRAD 2017). In particular, there is a lack of estimates of the contribution of current coal plant emissions to specific pollution situations (PREISS et al. 2013; PLAß and CONRAD 2017). Airborne pollutants occur as mixtures, not individual substances, which also needs to be taken into consideration. But there is no doubt that a phaseout of coal power would reduce the emissions load and thus have the potential to reduce the disease load.

2.2.2 Environmental impacts of nitrogen oxides

24. Nitrogen oxide emissions from coal plants are a special burden on the environment, as well. Germany still exceeds the national emission limits for nitrogen oxides in the National Emission Ceilings Directive 2001/81/EC (EEA 2017). However, corrections are pending; if approved by the European Environment Agency (EEA), Germany would be in compliance with the limits (Deutscher Bundestag 2016). These emissions have negative effects on terrestrial and aquatic ecosystems by contributing to their eutrophication and acidification. The latter also applies for sulfur dioxide emissions. Eutrophication in particular remains a major challenge for the protection of biodiversity in Germany (SRU 2015b). For instance, critical loads for eutrophicating pollutants are exceeded for some 48 % of sensitive terrestrial ecosystems (such as boggy heathlands, swamps, and peat bogs) (SCHAAP et al. 2014). Acidification affects another 8 % of these ecosystems. Eutrophication reduces habitats low in nutrients, which reduces or even wipes out species typical for such areas. An increase in plants with an affinity for nitrogen suppresses species adapted to conditions with low nutrients. These adapted plants make up 70 % of the vascular plants on Germany's Red List (LAI 2012).

25. In addition to inputs from rivers, which mainly originate from agriculture and dominate the overall load, nitrogen from the air excessively fertilizes the North Sea and Baltic (SRU 2015b). As a result, 33 and 22 %, respectively, of nitrogen inputs in these marginal seas are from atmospheric deposition. In German salt waters, nitrogen is often the most important nutrient for algae growth. Excessive inputs of nutrients promote the growth of microalgae, changing the entire food network. As an indirect effect of excessive fertilization, water becomes increasingly murky, which also changes species composition. For instance, seagrass beds are shrinking, algae blooms are increasing in tidal flats, and zones with little or no oxygen are forming in the depths of the Baltic, in particular as a result of the excessive input of nitrogen in the North Sea and Baltic. This is an important reason why the good environmental condition sought after in the implementation of the European Marine Strategy Framework Directive 2008/56/EG is not being reached (HELCOM 2014; NARBERHAUS et al. 2012; WOLFF et al. 2010). Likewise, eutrophication effects mean that almost all transitional and coastal waters in the German North Sea and Baltic are not in good ecological condition in accordance with the Water Framework Directive (BMUB and UBA 2013). A phaseout of coal power would therefore be a significant contribution towards reducing the eutrophication of terrestrial and aquatic ecosystems from inputs of nitrogen oxides.

2.3 Energy-economic benefits

26. A power supply based on renewables will have times of great and little supply. The supply system therefore has to focus on integrating large amounts of fluctuating renewables. In the near future, the conventional fleet will thus have to consist exclusively of flexible power plants to cover a highly fluctuating residual load. In the past few years, however, gas power plants, which have lower emissions and are usually more flexible, have increasingly been forced out of the power market in Germany and Europe because of relatively high fuel prices compared to less expensive hard coal and lignite in particular. To make matters worse, CO_2 certificate prices on the European Emissions Trading Scheme are currently very low, thereby favoring emissions-intensive power plants. The result is problematic not only from the viewpoint of climate policy, but also in terms of the flexibility needed in the power sector (SRU 2015a). Shutting down coal plants would increase the capacity utilization of gas-fired power plants, which, in turn, allows for better integration of fluctuating renewables (Agora Energiewende 2016b).

27. An additional climate policy challenge is emissions reductions in the transport and heat sectors by means of increased electrification. This will only succeed, however, if the electricity used is already low in CO_2 or, ideally, CO_2 free (KUNZ and MAIER 2017). Increasing power demand in the transport and heat sectors thus must not lead to greater load factors for coal plants, which would only shift emissions across sectors. An immediate, structured phaseout of coal power is therefore a necessary precondition for successful sector coupling with the transport (SCHILL und GERBAULET 2015) and heat sectors towards climate protection (ECKE et al. 2017).

3 Challenges of a coal phaseout

28. Up to now, the German government has not taken a clear position on ending coal power, much less described specific measures and a phaseout path. Yet, they will be necessary towards giving companies and society certainty about the path forward and trust in the Energiewende. Only then can affected industries and regions get a clear roadmap to plan and implement the necessary structural developments. The social discussion about the role and future of nuclear power paralyzed national energy policy for decades until a consensus about a phaseout was reached. Based on this experience, the German government should actively shape the discussion of a phaseout roadmap for coal and attempt to reach a socially and economically acceptable consensus that keeps an eye on the long-term goal of climate neutrality in power supply (see section 4.1.4; SRU 2015a). In the following chapter, various challenges for a phaseout of coal power are presented. They can be categorized in terms of specific effects on locations, the structural development of affected regions, and ensuring security of supply.

3.1 Effects on power plants and mines

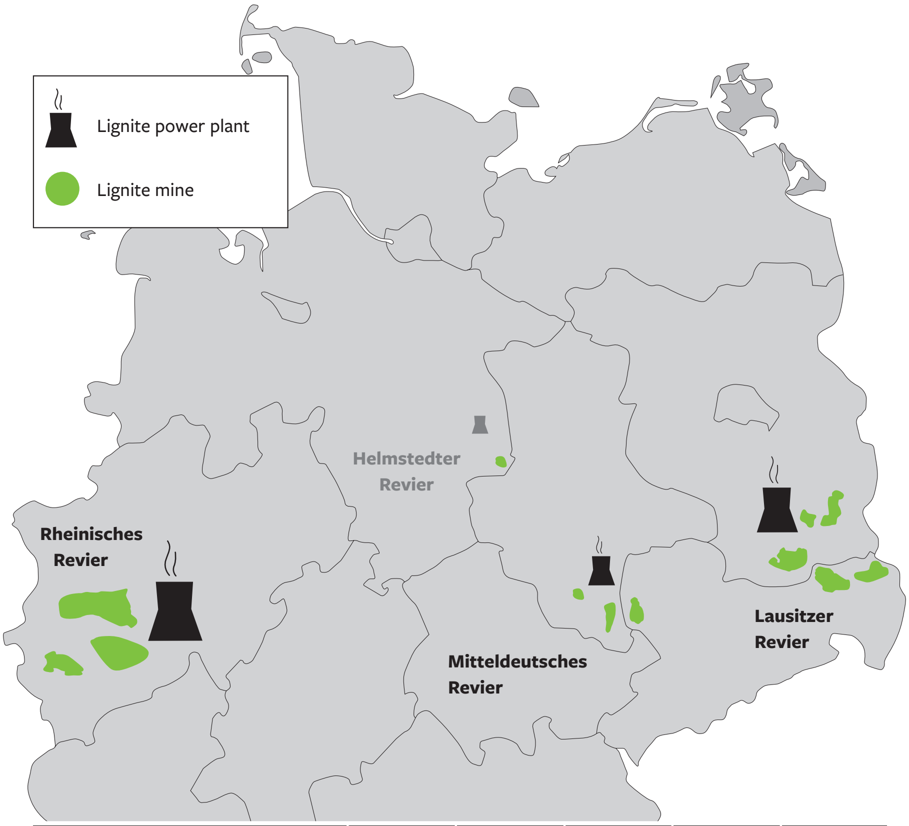
3.1.1 Lignite industry in Germany

29. In addition to environmental and health effects, the end of coal power in Germany will entail a wide range of regional and sectoral distribution effects that must be taken into account during the design process. In terms of lignite, both power plants and mines would be affected by closures. Lignite is mined in three areas (called "Reviere") in Germany: the Rheinisches Revier near Cologne, the Mitteldeutsches Revier near Leipzig and the Lausitzer Revier near Cottbus (Figure 3). In the Helmstedter Revier, the last remaining power plant Buschhaus was closed in September 2016. At the same time, mining there came to an end at the last exhausted mine (OEI et al. 2016). In the Rheinisches Revier, a large number of the power plants were built before 1980, whereas most of those in East Germany were connected to the grid in the 1980s and 1990s. The East German power plants from the 1980s are only slightly more efficient than West German facilities from the 1970s (ÖkoInstitut 2017). There is a clear correlation between the age and efficiency of facilities put into operation after 1990. Older power plants have lower efficiency and therefore emit more CO_2 per MWh of electricity generated. The different age groups will also influence the upcoming structural effects for regions if the facilities are shut down by age or CO_2 intensity. The German government therefore took into account not only the age of power plants but also regional impacts when selecting power plants to be put into a security reserve (GERBAULET et al. 2012; OEI et al. 2014; Agora Energiewende 2016a; MATTHES et al. 2017; HORST et al. 2015).

In addition to electricity (142 TWh annually), lignite power plants also produce heat, though in a much smaller amount (17 TWh). More than two thirds of this heat

○ Figure 3

Lignite power plants and mines in Germany



Lignite plants built [GW] (without reserve)	Before 1980	1981-1990	1991-2000	2001-2010	Since 2011
Rheinisches Revier	7 (5.5)	–	–	1	2.2
Helmstedter Revier	–	0.3 (0)	–	–	–
Mitteldeutsches Revier	–	–	2.7	–	–
Lausitzer Revier	1	2.8 (1.9)	2.4	–	0.6

The numbers in parentheses are remaining capacities after the launch of the security reserve. In Helmstedter Revier, the last power plant and its mine closed normal operation in September 2016.

SRU 2017; data source: Bundesnetzagentur 2017

(12 TWh) comes from smaller cogeneration units. As part of a coal phaseout, this heat would have to be replaced by technologies that emit less CO_2 in these locations (MATTHES et al. 2017; ÖkoInstitut 2017; Öko-Institut and Fraunhofer ISI 2015).

30. In March 2017, LEAG announced when presenting a new concept for the Lausitz Revier that the new mines planned in Jänschwalde Nord, BagenzOst, Spremberg-Ost, and parts of Nochten 2 would not be opened. The reason given was "recent changes in federal policy and economic framework conditions" ("LEAG legt Revierkonzept für die Lausitz vor", press release from Lausitz Energie Bergbau AG on 30 March 2017). However, the Mühlrose special field in the Nochten 2 mine is to open still, requiring some 200 people to move so that 150 million tons of lignite can be excavated. By 2020, the company aims to make a final decision about opening the WelzowSüd TF II mine, which would require 810 people to relocate. However, calculations show that meeting climate protection targets rules out excavation of the already permitted amounts of coal in existing mines that will be able to fuel lignite power plants until they close (GERBAULET et al. 2012; OEI et al. 2014; 2017; ÖkoInstitut 2017; HERMANN et al. 2017; MATTHES et al. 2017). The planned openings and extensions of existing mines in Lausitz (Nochten 2 and Welzow Süd TF II) and central Germany (Vereinigtes Schleenhain) are therefore not needed. Because the amounts of coal already permitted in North Rhine-Westphalia already significantly exceed the amounts needed to comply with the climate targets, the Garzweiler II and Hambach mines there should also be shrunk. This step would also avoid relocating villages and further destroying landscapes, with the accompanying negative social and ecological effects.

3.1.2 Hard coal industry in Germany

31. The hard coal used in the power sector in Germany comes almost entirely from Colombia, South Africa, and Russia (Deutscher Bundestag 2014). The Paris Climate Agreement requires a global coal phaseout. A coal phaseout in Germany and other countries will inevitably have social effects in the production countries (OEI and MENDELEVITCH 2016), which are not investigated further here. Likewise, this paper does not cover the overall environmental footprint of coal power or the multifarious ecological and health effects of hard coal reductions in the export countries (HARRIS et al. 2016; SCHÜCKING 2013). Rather, the focus is exclusively on coal power in Germany and regions with lignite mines.

Industrial consumers purchase most of the hard coal still produced at the last two hard coal mines (Prosper-Haniel and Ibbenbüren). When hard coal mining subsidies expire, the remaining hard coal mines will close by 2018 because unsubsidized German hard coal is not competitive on the global market.

When it comes to hard coal, the coal phaseout in Germany will therefore mainly affect power plant locations. Most of the hard coal power plants in Germany are in North Rhine-Westphalia, along the coast of the North Sea, and on rivers in Baden-Württemberg. A large number of companies – such as Steag, RWE, Uniper, EnBW, Vattenfall, ENGIE, GKM, and numerous municipal utilities – operate hard coal power plants in Germany. A phaseout of hard coal thus is not as concentrated in Germany. In addition, fewer jobs are at stake than with lignite, making balancing these job losses easier (see section 3.2.1; HERMANN et al. 2017).

3.1.3 Changes in the supply of ash and gypsum as power plant byproducts

32. In addition to electricity and heat, coal power plants produce residual substances that are either commercialized or disposed of as waste (Table 3).

Ash, slag, and gypsum are used – if the quality allows – as building materials, in road and path construction, and as filler material (BRIESE et al. 2014). When the power plants are closed, the supply of suitable material will decrease significantly.

In Germany, some 3.8 million tons of hard coal ash and some 11 million tons of ash from lignite power plants was produced in 2014 (Table 3) (VGB Powertech 2017). Hard coal flue ash in particular is a high-quality component/additive in cement and concrete. Brown coal ash is mainly used as filler material in the mines the coal came from. Reducing these amounts, however, is unlikely to cause a severe shortage: Hard coal flue ash can also be replaced with limestone, slag sand, and other mineral materials. Because the need for limestone for flue gas purification will decrease in the course of the coal phaseout, the volume that becomes available can be used to replace flue ash in the building sector (SCHWARZKOPP et al. 2016). The need for filling material in the mines will also drop as lignite mining decreases.

Since the 1980s, flue gas purification has been obligatory in coal plants. As a byproduct of flue gas desulfurization (FGD), considerable amounts of synthetic calcium sulfate compounds accumulate. These products are called FDG gypsum. This highly pure gypsum is mixed together with natural gypsum, which usually comes from quarries in Germany, to produce building products.

In Germany, 6.8 million tons of FGD gypsum was produced in 2014, most of it in lignite coal plants (Table 3; VGB Powertech 2017). In addition, 4.5 million tons of natural gypsum and anhydrides (another calcium sulfate compound) are produced in quarries annually. Most of the 11.3 million tons of gypsum is used in the building sector for building products and cement manufacturing. Around 2.3 million tons of gypsum is currently exported (SCHWARZKOPP et al. 2016).

In the midterm, the coal phaseout will lead to a supply shortfall for gypsum. In principle, the market can substitute for gypsum by switching to other building approaches and materials and by diversifying the supply. A reduction in domestic gypsum production from flue gas desulfurization may reduce exports, increase the production of natural gypsum, and increase demand for recycled gypsum. Recovering gypsum from gypsum waste is crucial for reasons of protecting resources and nature and complying with the requirements in the Circular Economy Act. Necessary preconditions – functioning technology, preparation sector, buyers – have already been fulfilled, so the next step is to establish recycled gypsum on the market by actively supporting it. In parallel, the foundations must be laid for greater volume potential for high-quality recycled gypsum. To this end, gypsum must be collected in quality categories where it is created by means of systematic dismantling in buildings being torn down and, for the future, consideration of dismantling during construction. Gypsum waste also has to be able to enter recycling facilities directly instead of deviating through expensive faux reutilization, such as stabilizing uranium sludge ponds in the Czech Republic or filling up quarries (BUCHERT et al. 2017).

Even if the reduction of supply of byproducts from power plants, such as hard coal flue ash and FGD gypsum, does not lead to a dramatic shortfall in supply, the sector – and politicians – face the task of investigating the sustainability of possible solutions and supporting their rollout.

3.1.4 Liability for the long-term costs of lignite mining

33. One important aspect in a lignite phaseout is ensuring the financing of long-term costs for coal mining. From reunification to 2017, more than 10 billion euros was spent by the federal and state governments to clean up polluted sites from former GDR mines. This funding was put into the company founded for this purpose: Lausitzer und Mitteldeutsche Bergbau Verwaltungs-GmbH (LMBV). An additional 1.23 billion euros was approved for the timeframe from 2018 to 2022 by the federal government and the East German lignite states of Brandenburg, Saxony, Saxony-Anhalt, and Thuringia (LMBV 2017). In addition to these legacy costs from GDR times, the various mine operators finance the re-cultivation of former mines. Depending on how the process is conducted, the term “re-cultivation” used below covers re-naturalization, re-cultivation in a narrower sense, and the complete redesign of landscapes. The funding required for this purpose used to come from the ongoing operation of coal mines and coal plants. The necessity of a coal phaseout therefore means that an investigation is needed to determine whether the operators have sufficient funding to cover the remaining long-term costs of coal power. These long-term costs have special characteristics:

Table 3

Production and use of power plant byproducts from coal plants in Germany in 2014

	Hard coal		Lignite		
Capacity (MW_{th})	69,406		68,900		
combusted coal (million t)	44		163		
Byproduct	**Generation**	**Usage**	**Generation**	**Usage**	
				Mine	**Other**
	million t	%	million t	%	%
Granulated slag	0.75	100	–	–	–
Boiler ash/sand	0.37	98	1.81	99	1
Fly ash	3.10	96	9.08	99	1
Fluidized bed ash	0.31	85	0.26	96	3
FGD[1] gypsum	1.66	99	5.15	11	89
SAP[2] product	0.28	100	–	–	–
Total	**6.47**	**97**	**16.30**	**71**	**29**

[1] Flue-gas desulfurization
[2] Spray absorption process

Source: VGB Powertech 2017

- Most of the costs are only incurred when the mining areas are re-cultivated, which will be in the future. While the re-layering of earth masses begins parallel to the operation of the mine, the cost of possible residual lakes are incurred over a timeframe of up to 50 years (ÖkoInstitut 2017). Mining companies might no longer have any income from coal power because all of the power plants will have been closed by then.

- Some of the costs – such as ensuring sufficient water quality in the artificial lakes and reducing groundwater levels by means of pumps, in some cases permanently – will also remain after re-cultivation has been completed; they therefore represent long-term costs. The reason for the latter is that buildings in some regions were built below the original groundwater level.

- The exact number for the costs and the times when they will be incurred remain unclear. The German government has difficulty estimating these aspects because officials cannot investigate companies‘ internal documents.

34. The mining companies are legally obligated to pay entirely for all costs incurred. For this purpose, they must create detailed plans for subsequent use while the mine is still in operation. Based on these plans, the company estimates costs that will be incurred in the future. To cover these, provisions are set aside each year on the liabilities side of the balance sheet. At the end of 2016, the provisions were reported at 2.8 billion euros for RWE, 1.5 billion euros for LEAG, and (as of the end of 2015) 0.14 billion euros for Mitteldeutsche Braunkohlengesellschaft mbH (MIBRAG) (Bundesanzeiger 15.11.2016; 28.12.2016; 23.05.2017). The value of these provisions must be matched with assets on the balance sheet. These assets are generally investments in specific infrastructure projects, such as power plants and conveyor systems in mines. If these assets depreciate or must be written down, the companies must produce additional assets on the balance sheet to cover these provisions sufficiently.

35. The following risks are possible when it comes to covering the cost of re-cultivation:

- The provisions set aside might be too low to finance the cost of re-cultivation. The reasons include underestimating costs, overestimating interest rates for interest on the provisions, or incurring costs earlier than expected. The respective mining firm would then have to come up with additional funds in order to increase the provisions and cover the additional costs.

- The real value of the assets does not correspond to the book value of the provisions set aside. This risk can come about particularly if part of the provisions were invested in conventional power plants or mining infrastructure. For instance, a number of large energy supply companies have been forced to depreciate their assets further in the past few years because the real value of these assets was far below the amount reported in the books (OSTER and ERDMANN 2017; CALDECOTT et al. 2017). If additional write-downs become necessary, the respective mining firm will have to add assets to finance the provisions.

These risks could result in the mining firm needing to provide additional (unplanned) money at some point in the future. If the firm has sufficient liquidity to cover these additional costs, no public money will be needed for recultivation. But there is a risk of the mining firm lacking liquidity or no longer existing when these additional costs are incurred. If the company is a subsidiary of a larger corporation, the corporation is liable for these additional costs in principle. However, parent companies can get out of their legal liability by undergoing corporate restructuring if appropriate profit assignment contracts were previously terminated between the firms (WRONSKI et al. 2016; OEI et al. 2017). For instance, the structure of the Czech parent company Energetický a průmyslový holding a.s. (EPH), which owns LEAG and MIBRAG via various additional subsidiaries and holdings, could hamper liability (OEI et al. 2017; ÖkoInstitut 2017; Greenpeace 2017). Analyses by Green Budget Germany (GBG) (WRONSKI et al. 2017) show that RWE‘s spinoff of innogy also makes the liability question more complicated in North Rhine-Westphalia. For instance, if RWE went bankrupt, innogy would not be liable for possible claims related to the long-term costs of coal and nuclear power. To ensure the polluter-pays principle, additional political measures would therefore be needed.

36. Table 4, based on a study by GBG and the IASS (Institute for Advanced Sustainability Studies) (WRONSKI et al. 2016), shows an overview of possible liability problems for the long-term cost of lignite mining along with possible solution approaches. Here, it is clear that a lack of independent, publicly accessible cost estimates has so far created great information asymmetries to the detriment of the public sector (and civil society) and to the benefit of the operators.

Table 4

Possible problems and solutions for liability of long-term lignite mining costs

Possible problem	Possible solution	Resulting subsequent effect
Insufficient provisions	independent public cost audit	Increase in provisions
Real value of provisions set aside is too low	regular independent audits	Increase in assets to cover provisions
Mining firm is insolvent	Security payments or security assets ("internal fund")	Additional security solution within the company
Termination of (profit assignment) contracts with the parent company	Guarantees from parent company	Parent company ensures liability
Parent company is insolvent	public-law fund or founding of private-law foundation	Additional external security solutions

SRU 2017; data source: WRONSKI et al. 2016

3.2 Structural development in coal regions

37. If coal power decreases, regional structural change will be accelerated, including job losses in the affected industries. This change must be designed to be socially responsible, and new jobs in the energy sector or in other industries must be created to compensate for the lost jobs. It bears emphasizing that a structural change of this magnitude is not exceptional historically and that Germany has already successfully managed more severe structural changes. However, it should be kept in mind that some regions in eastern German federal states will be affected a second time after the number of jobs in the coal sector fell considerably as a result of reunification. The focus should therefore be on transferring successful solution approaches and avoiding past mistakes based on past experience, such as reunification and the reduction in hard coal mining in western Germany. A proactive structural policy supports this change and should be designed along with the phaseout path.

3.2.1 Direct jobs in the coal sector

38. The number of jobs affected in the lignite sector has been the subject of various studies in the past few years. The results vary between around 25,000 (UBA 2015a) and some 75,000 (r2b energy consulting and HWWI 2014) jobs affected. The deviations are the result of different reference figures and assumptions. A distinction is made between direct, indirect, and induced job effects. Based on official statistics, the number of people directly working in the coal sector at present can be clearly stated (Table 5). On the other hand, exact data are not quantifiable for the number of indirect jobs in the coal sector, such as maintenance, customer service areas at energy providers, and upstream and downstream sections of the production chain.

39. In 2016, roughly 17,700 people worked directly in the lignite sector in Germany along with 1,300 trainees (Table 5). About a quarter of these jobs – 5,161 – are found in power plants. The remaining employees work in mines and processing. At present, 6,285 jobs are reported in German hard coal mining, which will end in 2018 (Statistik der Kohlenwirtschaft 2017). In contrast, no reliable data are available for the number of employees working in hard coal power plants. In an expert report based on a survey of members in 15 power plant blocks, labor union Verdi found that there were 330 jobs per gigawatt of capacity (enervis energy advisors 2016). That ratio would put the total number at some 9,000 employees. However, this number is far higher than the 5,000 employees spoken of by labor union Industriegewerkschaft Bergbau, Chemie, Energie (IG BCE 2014) in the context of possible restructuring of the hard coal sector.

In autumn 2016, both RWE and Steag announced additional operational job losses of 800 to 1,000 employees (Der Westen 12.09.2016). At RWE, one reason is the upcoming transfer of five older power plant blocks into the security reserve. After four years in reserve operation, these power plant blocks will be completely closed. Steag is closing numerous hard coal power plants for a lack of profitability. LEAG has also announced that 600 jobs will be cut related to the creation of the security reserve (Lausitzer Rundschau 20.03.2017). In total, the number of people directly employed in the lignite and hard coal industries can be expected to fall from 30,000 to around 20,000 in the next few years for business reasons. The growing number of employees working in the renewables sector would have to be added for a complete calculation of the direct job effects of the upcoming coal phaseout. The number of renewable energy jobs created in the past few years already far exceeds not only the coal jobs lost, but also the remaining jobs in the coal sector (DEHNEN et al. 2015; LEHR et al. 2015). However, the green jobs are spread across all of Germany, so that the Energiewende affects various regions differently („Rückenwind im Norden: Studie zeigt Verteilung der Erneuerbaren-Jobs in den Bundesländern", press release by the Agentur für Erneuerbare Energien on 26 June 2017).

3.2.2 Indirect and induced job effects

40. Studies that include indirect jobs generally use a factor of 1 to 2 (in reference to direct jobs) to estimate the total. In a study for Agora Energiewende, Öko-Institut (2017) points out that the additional share of indirect jobs increases the larger the area investigated. The factor for a coal region is given as 1. When commuters and suppliers are included, the factor increases to around 1.5 for the surrounding area and to 2 for all of Germany. The indirect job effects of power plants are roughly twice as great as those of mines. The exact number of these jobs is just as unclear as the question of whether the jobs would be lost completely if there were a coal phaseout. For instance, new jobs could be created due to changes already taking place in the regions as adjustment reactions. For example, new firms can be founded and existing business models converted, such as for the construction and maintenance of wind turbines or for alternative production processes for gypsum. Most economic labor market models cannot (fully) map such dynamic changes in the labor market. The numbers resulting from these model calculations therefore only concern direct and indirect jobs lost; they do not take into consideration that the market would adjust, thereby absorbing some of these jobs. When these adjustment effects are taken into account and the area and time investigated are expanded, the net job effects of a coal phaseout are even positive (DEHNEN et al. 2015; LEHR et al. 2015).

A study done by Prognos for Vattenfall and MIBRAG takes account of induced job effects along with direct and indirect jobs (HOBOHM et al. 2011). Induced job effects cover jobs created by the purchasing power of employees in the lignite sector. Various studies assume that these jobs would be completely lost if the number of jobs in the lignite sector were reduced. However, former employees from the lignite sector could find new jobs, which the study does not take into account. And even if they are temporarily looking for work while receiving funds from social transfers, they temporarily partly contribute to a retention of the induced jobs. Like a calculation of indirect employees, including induced jobs therefore overestimates the job effects of a coal phaseout because the focus is merely on the number of jobs lost without consideration of dynamic adjustment reactions.

Even greater effects on the job numbers are found when electricity price effects are included in the calculation (r2b energy consulting and HWWI 2014). The assumption is that the coal phaseout could increase power prices considerably, thereby leading to further job losses in energy-intensive industry. Numerous model calculations show, however, that a structured coal phaseout will only increase power prices on the exchange minimally (HERMANN et al. 2017; OEI et al. 2014; 2015a; 2015b; HORST et al. 2015). This minimal increase automatically reduces the renewable energy surcharge (as stipulated in the Renewable Energy Act), which reflects the difference between wholesale prices and feed-in tariff compensation. This arrangement means that any effect a coal phaseout might have on power prices will be dampened additionally for most private and industrial end consumers not exempt from the renewables surcharge. Even in the most energy-intensive businesses, power procurement costs only make up a very small share of total costs (PESCIA and REDL 2014; NEUHOFF et al. 2014; GERMESHAUSEN and LÖSCHEL 2015). Furthermore, power prices have continually dropped in the past few years for energy-intensive businesses, partly because they are exempt from the surcharge. A slight increase in power prices is therefore not expected to lead to job losses in energy-intensive industry (SRU 2016, ch. 2; ELMER et al. 2016). Because a clear calculation of indirect and induced jobs is not possible, the focus of the following is on the 20,000 to 30,000 jobs directly affected in the coal industry.

3.2.3 Age structure of employees in the coal sector

41. The age structure of the remaining direct employees in the lignite sector reveal a number of special aspects that suggest certain focal points for future labor market policies (Figure 4; Statistik der Kohlenwirtschaft 2016):

- Two thirds of all employees are currently older than 46. In 2030, they will be older than 60. If a coal phase-out takes place in the next 20 years, most of these employees could keep their jobs until they retire. Because the age of the power plant blocks does not correlate with the age of employees working there, employees could move to different positions within the regions, thereby compensating for lost expertise and ameliorating the social impact.
- In the past few years, employees older than 55 have been offered various early-retirement programs, which could cover an additional 10 % of employees after the coal phaseout.
- Targeted regional development would then have to create new jobs for the remaining quarter of the employees. Retraining costs might be incurred for some 5,000 to 7,500 people in Germany.
- If lignite were phased out, 300 to 400 trainee positions annually would be lost in these regions and need to be replaced.

42. The situation for hard coal is similar to the one for lignite in many ways. However, employees in hard coal mining are older on average than in the lignite sector (Statistik der Kohlenwirtschaft 2016). Furthermore, a

Table 5

Remaining direct jobs in the lignite and hard coal industries in Germany in thousands

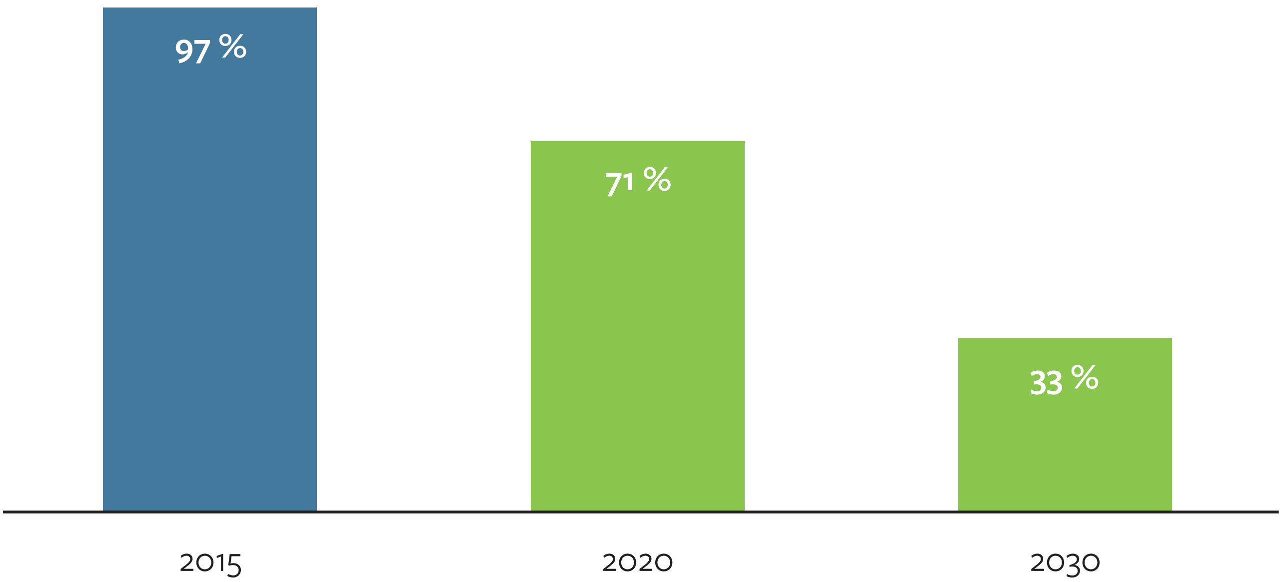
Direct employees in lignite regions	
Rhineland	9.0
+ Lausitz	8.3
+ Mitteldeutschland	2.4
+ Helmstedt	0.2
= Sum of direct employees in lignite regions	19.9
– Employees at LMBV (re-cultivation of GDR mines)	0.6
– Employees in Helmstedt (re-cultivation & reserve)	0.2
≈ Remaining direct employees in the lignite industry	19.0
– Trainees	1.3
≈ Employees in the lignite industry (power plants & mines)	**17.7**
+ Employees in hard coal mining	6.3
+ Employees in hard coal power plants	5.0–9.0
≈ Direct employees in the lignite and hard coal industries 2016	**29.0–33.0**
– End of hard coal mining in 2018	6.3
– Job losses at RWE (5 lignite power plant blocks in security reserve)	0.8–1.0
– Job losses at Steag (hard coal power plant closures)	0.8–1.0
– Job losses at LEAG (2 lignite power plant blocks in security reserve)	0.6
– possible further job losses at other companies from 2016 to 2019	?
≈ Remaining direct employees in the lignite and hard coal industries in 2019	**20.1–24.5 minus ?**

Inconsistencies in the sums are the result of rounding inaccuracies.

Sources: Statistik der Kohlenwirtschaft 2017; enervis energy advisors 2016; IG BCE 2014; Der Westen 12.09.2016; 25.10.2015; Lausitzer Rundschau 20.03.2017; WÖRLEN et al. 2017

Figure 4

Share of workers in the lignite sector in 2015 who are younger than 60 (in the respective years)



SRU 2017; data source: Statistik der Kohlenwirtschaft 2016

much smaller number of jobs would be lost in the hard coal sector, and the power plants are spread across more regions. The focus of structural support should therefore be in lignite regions.

3.2.4 Lessening the impact of structural developments

43. A large number of economic restructuring events have already taken place in Germany. For instance, 500,000 jobs were lost in the textile industry in Germany from 1970 to 1984 (FRÖBEL et al. 1986, p. 58), and nearly 300,000 jobs were lost in the steel industry from 1975 to 1984 (SCHUCHT 1998; BINDER and SCHUCHT 2001). There have also been numerous transformation processes in the energy sector in the past few decades. For instance, the number of people working in hard coal mining fell from more than 600,000 in 1957 to 250,000 in 1970 (Statistik der Kohlenwirtschaft 2016). In 2007, an agreement was reached between politicians and the collective bargainers for hard coal mining: the 35,000 direct jobs remaining at the time – and hence, all domestic hard coal mining in Germany – would be ended by 2018 (Gesetz zur Finanzierung der Beendigung des subventionierten Steinkohlebergbaus zum Jahr 2018). After 1990, the number of people employed in the lignite sector in the GDR fell from more than 100,000 to 10,000 within a decade (Statistik der Kohlenwirtschaft 2016). In the solar sector as well, more than 45,000 jobs were lost in a very short time (2012 and 2013) (BMWi 2014, p. 93). The effects of these job losses were sometimes also regionally concentrated.

As social policy support for these structural changes, a combination of the following instruments has proven useful both for the promotion of active structural development and to lessen possible detrimental local impacts:

- Regional economic support (such as within a joint task to improve regional economic structure) and complementary state programs,
- Social plans, especially to compensate for income losses for job losses before retirement,
- Avoiding operational layoffs and guarantees for substitution jobs and incomes,
- Early retirement with extensive salary compensation,

- Active labor market policy, sometimes even with job offers in the public sector,
- Re-training and qualification measures.

44. If the aforementioned major structural developments from previous decades are compared with the roughly 20,000 to 30,000 direct jobs endangered in the coal industry over the next 20 years, this reduction seems rather slight and possible to shape with industry and social policy. The main difference is that previous structural change processes resulted from (international) competition, which the upcoming lignite phaseout does not. The lignite phaseout is economically the result of the success of renewables; however, speeding up the rate of this phaseout would be a consequence of political decisions (SCHULZ and SCHWARTZKOPFF 2016). The state therefore has an additional responsibility to shape the change process in a socially responsible way.

The labor market in the energy sector is not developing in a unified fashion. While jobs are being cut in the coal sector, the number of employees overall has increased in the past ten years. The main reason is the expansion of renewables as a result of the Energiewende (BMWi 2014). However, when comparing job effects, the number of jobs is not the only factor to consider; salary levels and future employment perspectives should also be taken into consideration. Former employees of the lignite sector have far better future perspectives when they move to other industries, but on average their salaries drop considerably. In an analysis of eastern German employee data from 1998 to 2010, a study by the German Institute for Economic Research (DIW) found that people who switched sectors saw their income drop by 20 to 30 % on average (FRANKE et al. 2017). Older employees suffered the greatest income losses. No trend of employees moving to southern and western Germany was found, however.

One reason for the salary losses when people leave the sector is the high starting salary in the lignite industry. For instance, a study for labor union Verdi found that the average employee salary (gross salary including 21 % social insurance paid for by the employer) came in at around 68,000 euros (enervis energy advisors 2016). In particular, the work done by labor unions IG BCE and Verdi has brought about well-paid jobs in the coal sector in the past few decades. Unlike these very well organized industries, new fields of business – such as renewables – have only mustered much weaker labor representation up to now.

3.2.5 New perspectives for coal regions

45. A phaseout of coal power has quite different effects on the various lignite regions. A number of studies have already dealt with the upcoming structural change in eastern Germany, especially Lausitz, because there is little other industry there at this time (MARKWARDT et al. 2016; SCHWARTZKOPFF and SCHULZ 2015; KUTZNER 2014; KLUGE et al. 2014; VALLENTIN et al. 2016; BOSHOLD 1999; HAUSER and LEPRICH 2008; BLANKE et al. 2010). The Rhine area, by contrast, has far more different industries and is close to such urban centers as Cologne, Düsseldorf, and Aachen; the area also has greater innovation potential (Regionomica 2013; IRR 2016; OPIELKA et al. 2014; SCHEUERMANN et al. 2012). On the other hand, a lot of municipalities in the Rheinisches Revier have holdings in RWE and are thus directly dependent on income from coal power. Furthermore, a number of municipalities are directly affected by lower trade tax income and additional social transfers for people looking for work.

In addition to the economic consequences for employees and firms, the interests of municipalities and federal states are thus also affected and must be kept in mind.

46. The lack of skilled workers could worsen in eastern German lignite regions, making it more difficult to set up new industries. Demographic effects are the main reason (MARKWARDT et al. 2016). For instance, the number of people employed in Lausitz is expected to drop by 36 % from 2015 to 2030 (IMU 2015), far above the western German level of 8 %. The Zukunftsatlas 2013 (Future Atlas 2013) of Prognos (Prognos AG 2013) speaks of “slight to high future risk” and “weak economic dynamics” for a large number of the affected counties in eastern Germany, also because of previous migration to southern and western Germany.

Possible alternative future fields that already exist include the chemicals and automotive sectors in central Germany along with several economic sectors in North Rhine-Westphalia (such as chemicals, automotive, logistics, and energy). Lausitz, however, is not highly diversified industrially, so the loss of the lignite industry will have a greater impact. In the past few years, the tourism sector in particular has therefore been supported. In the future, additional new, sustainable perspectives should be set up in a targeted manner in various economic sectors.

47. The wide range of opportunities for a socially responsible structural change should be part of the development of a supportive federal-state program for a coal phaseout. Such a program should be properly financed and cluster and coordinate various assistance programs to promote social acceptability. The think tank Agora Energiewende (2016a) proposes a "structural change fund for lignite regions" with an annual budget of 250 million euros. This amount is equivalent to just under a quarter of the current annual subsidies for hard coal (Deutscher Bundestag – Wissenschaftliche Dienste 2017). This funding is especially devoted to promoting sales and only secondarily to adjustments and the "miner's bonus". When hard coal mining and subsidies for it end in 2018, some of this funding could be devoted to structural development in lignite regions. It is crucial that the concept be developed with all affected stakeholders and adopted in a consensus (SRU 2015a). The goal of such a program should be to sustainably further develop current lignite regions – based on their individual strengths – in order to prevent possible deindustrialization. This goes in particular for the further development of Lausitz (Agora Energiewende 2017). In addition to protecting a sufficient number of jobs, a large number of various hard and soft factors must be taken into consideration. If these factors work together successfully, they can provide a high quality of life for people in the affected regions. The result can be greater positive identification with the region, which contributes to further development in the long term.

48. Suitable fields need to be identified and promoted in lignite regions based on local prerequisites and potential. In addition to traditional economic sectors, new future fields should be set up because it could be easier for lignite regions to play a pioneer role in such sectors. For instance, Innovationsregion Lausitz GmbH and IHK Cottbus have identified the following growth markets and fields of action for Lausitz (LANGE und KRÜGER 2017):

- renewable energy,
- urban Energiewende/district heat supply,
- XXL robots for automation technology,
- electric mobility, and
- expansion of infrastructure in the Berlin–Dresden–Leipzig triangle.

In identifying and promoting possible focal points for support in coal regions, account must always be taken of the extent to which the support is in line with Germany's long-term (climate protection) targets. For instance, sustainable future markets should be targeted for funding, such as renewable energy and electric mobility. Investment support for existing locations (brownfields) are better than support for completely new locations (greenfields) because existing infrastructure can be utilized so that no additional land needs to be consumed. Whenever additional transport infrastructure is built, the necessary mobility transition requiring a greater shift from roads to rails should be kept in mind (Agora Verkehrswende 2017).

49. For better structural development, an attempt should be made to support new firms and their employees settling directly in coal regions. To prevent excessive commuting to more distant cities (such as Berlin, Dresden, Düsseldorf, and Cologne), existing infrastructure within coal regions should be included in a targeted manner. For example, initiatives specifically for creating new jobs where universities are located will keep young employees in the region. In addition, setting up local research institutes and startup initiatives will help (further) develop expertise and solution approaches locally. As a result, proposals will meet with greater acceptance, and local expertise and regional identification will increase. Successful positive (re-)identification with lignite regions will only work, however, if additional – mainly soft – factors contribute to a positive living climate and greater quality of life along with the provision of well-paying jobs. One benefit is that the reduction of coal power will have a direct positive impact on health factors (see chapter 2.2). In addition, leisure and cultural facilities can be created for residents and to increase tourism when mining areas are re-cultivated.

50. Compared to earlier historical structural effects in Germany, it is clear that the social changes brought about by the upcoming coal phaseout will be limited in scope – and hence manageable. Nonetheless, these changes pose a serious challenge to individual counties, especially in Lausitz. Directly affected businesses therefore want the German government to provide more planning security by means of a fixed, concrete phaseout roadmap (MARKWARDT et al. 2016). Active structural policy specifically for these regions should therefore be worked up from the outset in parallel to phaseout scenarios for the energy sector. The upcoming change should also be understood as an opportunity to further develop these regions for the long term. The focus should move beyond purely monetary aspects – such as salaries for the remaining employees in the coal sector – to include additional important factors, such as the environment, health, social issues, and training. If an environment can be created that positively influences these aspects, (re-)identification with and in lignite regions can be successfully created. For the Energiewende's future, it is especially important that Germany demonstrate how such a planned structural development can succeed so that other sectors and other countries follow this example.

3.3 Ensuring supply security

51. In designing the future power market in compliance with (inter)national climate protection goals, sufficient adjustments must be made to ensure supply security in Germany. To this end, dispatchable generation capacity must be combined with the fluctuating share of renewable electricity at a given point in time and imports from neighboring countries so that domestic power demand can be met at all times. In the course of the German nuclear phaseout, the last nuclear reactors will be shut down by 31 December 2022 at the latest. In contrast, a phaseout of coal power will take longer and last into the 2030s. Within the next 20 years, more investments must therefore be made in setting up carbon-free generation capacity parallel with the reduction in coal power. As the share of renewable energy grows, reliance on fossil resources drops – and hence, the import quota for primary energy consumption (Agora Energiewende 2017).

In an energy system increasingly dominated by renewables, the remaining conventional facilities will be needed less and less. Still, most power plant operators hope that facilities run by their competition will be closed first, thereby improving the profitability of their own units when power scarcity raises prices. There is therefore significant excess baseload generation capacity in Europe currently, which contributes to low wholesale prices for electricity. According to the European Network of Transmission System Operators for Electricity (ENTSOE 2016), the excess came in at around 40 GW in the area of the power markets relevant for Germany. This area includes Germany, all neighboring countries directly connected by power lines, and Italy. German lignite power plants benefit in particular from low fuel costs compared with other fossil power generation systems in Europe. Electricity can therefore be exported to neighboring countries when renewable power covers a large share of the domestic market. In combination with the growing amount of renewable electricity, the nearly constant capacity utilization of coal plants has led to not only lower power prices, but also record power exports from Germany of 54 TWh in 2016 (AGEB 2017), equivalent to nearly 10 % of annual power generation.

At present, peak domestic power demand comes in at 86 GW. Additional demand from the transport and heat sectors can increase power demand when they are electrified as expected (KUNZ and MAIER 2017). At the same time, this trend will offer new potential for peak shaving to compensate for fluctuating renewable energy. Overall, some 190 GW of conventional and renewable generation capacity (net) is installed in Germany, not all of which is available all the time. The conventional energy sources have high availability; there is 76 GW of fossil energy sources (gas, oil, lignite, and hard coal) and 11 GW of nuclear power plants. In addition, there is a total of 22 GW of partly dispatchable energy sources (pumped storage, hydropower, biomass, and waste) along with 83 GW of fluctuating renewable energy (wind and photovoltaics) (Bundesnetzagentur 2015). Calculations made by the Institute for Future Energy Systems (IZES) (HORST et al. 2015) show that there are enough dispatchable generation units on the grid to ensure supply security in the form of combined-cycle gas turbines (CCGT) up to 2040 even with a coal phaseout. Renewable generators will continue to be built in large numbers and their availability will increase to provide greater support in this area through a combination of

- technical system innovations (such as higher capacity factors for wind turbines and tracking photovoltaic arrays),
- improved storage options (such as lower battery prices and power-to-X as a medium to long-term option), and
- additional demand management (from digitalization, efficiency improvements, demand reduction, etc.).

52. In addition to the question of sufficient installed capacity, all necessary ancillary services must be ensured in order to guarantee grid stability. Despite the great growth in renewables, the German electricity grid has become even more reliable in the past few years. For instance, the SAIDI (System Average Interruption Duration Index) number has been reduced by half over the past decade, to a new low of 12 minutes per year (Bundesnetzagentur 2016). This value is far below that of the US (a factor of 18) and other European countries. However, coal power still plays a decisive role for operations and the maintenance of frequency and voltage in particular. Alternative technologies therefore need to replace these functions. At present, no single technological solution on the horizon can replace all of these functions completely, so various solutions will need to be cleverly combined with each other. Table 6 provides a summary of the options for alternative ancillary services with a growing share of renewables presented by the German Energy Agency (dena 2014). The table shows that a wide range of alternative technological options is

Table 6

Provision of ancillary services in a system based on renewables

	Frequency control Instantaneous reserve	Frequency control Provision of balancing energy	Voltage control Provision of reactive power	Voltage control Provision of short circuit power	System restoration	System control
Requirements for 2030	Significantly lower contribution by conventional power plants Without alternative providers, support from the European integrated grid would be required	Demand for secondary balancing energy and minute reserve increases At times, conventional power plants will not be able to meet this demand	The demand for reactive power in the transmission and distribution grids increases Increased demand for reactive power control in the distribution grid	Bandwidth of the short circuit power available in future will hardly change Major time-dependent fluctuation at all grid levels due to decentralised energy units	There are sufficient black start capable power plants to retain the central power supply re-establishment concept	Increasing complexity Increased need for congestion and feed in management Increased need for coordination between transmission and distribution system operators
Alternative providers	Wind turbines Large-scale ground-mounted solar power plants Storage capacities	There are alternative providers for all types of balancing energy, which can cover the future demand	Reactive power compensators HVDC inverter stations Phase shifters Power plants in phase shift operation Provision from decentralised energy plants in the distribution grid	Retooling the inverters in renewable energy plants to allow them to provide short circuit power even without feeding active power	Decentralised system restoration is technically feasible but not macroeconomically efficient	Conventional control technology is sufficient initially to utilise ancillary service potential Broad-based standardised ICT is required to utilise smaller potential Costs/benefits must be evaluated
Recommended action	Use of the inertia of wind turbines Long-term: Review of the use of potential from throttling decentralised energy plants and storage facilities	Adaptation of product characteristics and pre-qualification requirements Check implementation of adaptive demand calculation for balancing energy	Develop coordinated balancing energy provision from decentralised energy plants in the distribution grid Check alternative use of reactive power from high voltage for extra high voltage in individual cases	Option for distribution system operators to request short circuit power from decentralised energy plants without active power Effect on protection concepts must be eval uated in individual cases	Weather and other generation-relevant forecasts must be incorporated in the future concept It must be possible to control RE systems during system restoration	Esp. distribution system operators must be able to choose between grid expansion and optimised system control Rapid implementation of the “energy information network”

Source: dena 2014, Annex Table 3

already available for the provision of ancillary services. Further study is needed, however, to determine the extent to which the coal phaseout will require adjustments to specific ancillary service products. There may be a need for further new technological solutions and adjustments for the provision of affordable, reliable ancillary services needed for a secure, stable power supply. For instance, market access criteria – such as minimum bid levels – can be lowered and the scope for the provision of ancillary services can be expanded across national borders in order to ensure that this potential is better tapped (CE Delft and Microeconomics 2016; LORENZ 2017; LORENZ and GERBAULET 2017).

53. If an incremental coal phaseout is planned early on, it will create economic incentives for market players to come up with alternatives. In addition to low-emission generation capacity, such alternatives could include progress in demand management and power storage. Digitalization allows for this “prosumage” concept of production, consumption, and storage to be synchronized. The expected slight increase in wholesale power prices as a result of the closure of coal plants will facilitate this trend. However, the price increase will not come all at once, and it will be moderate, basically compensating for the drop in wholesale power prices over the past few years. Furthermore, the renewables surcharge will drop for retail customers and industrial firms not exempt from the surcharge, thereby dampening the impact of rising wholesale prices (OEI et al. 2015a; HERMANN et al. 2017). German industry and the German economy as a whole are therefore not expected to be substantially weakened (SRU 2016, ch. 2; ELMER et al. 2016).

54. Overall, sufficient power generation capacity is currently available in Germany and Europe for a significant number of coal plants to be closed in the short term. Within the next 20 years, an incremental closure of all coal plants can also be designed so that supply security is not detrimentally affected. A wide range of alternative technological applications is already available to ensure various ancillary services (Table 6). This would be facilitated if some of the emissions reductions came from coal plants running at lower capacity. In that case, a larger number of power plant capacities could be maintained in the system at lower capacity utilization. If European interaction with neighboring countries is increased, the demand for ancillary services can also be adjusted and greatly reduced. This increases the extent to which the potential of renewables can be tapped, thereby strengthening national and European energy and climate protection targets.

4 Designing a coal phaseout

55. In the upcoming legislative period, a phaseout of coal power should be decided and laws and regulations for it should be designed, all as quickly as possible. The SRU believes that a consensus supported by broad sectors of society and agreed in a dialogue with representatives of regions, companies, and labor unions should be reached prior to the formulation of laws and regulations (cf. SRU 2015a).

4.1 Steps to reduce coal power

56. Both European and national climate and environmental protection tools can be used to implement a reduction of coal power. Combining various tools makes implementation of a structured coal phaseout even smoother for Germany.

4.1.1 The European climate policy context

57. The European Emissions Trading System (EU-ETS) is the EU’s main climate protection instrument, but it has considerable weaknesses (SRU 2015a). The SRU therefore welcomes the German government’s aims to impose additional national measures within the Climate Action Plan 2050.

Reforms of the EU-ETS – including the implementation of a market stability reserve and an adjustment of the annual reduction factor – are expected to at least slowly draw down the current number of excess certificates in the course of the 2020s (MATTHES 2017; COWART et al. 2017). The reform will gradually move excess certificates into the market stability reserve starting in 2019. Emission reductions from additional climate protection steps taken nationally will thus not (or only to a limited extent) directly lead to greater carbon emissions abroad, but rather increase the number of certificates in the market stability reserve. This strengthens the short and midterm effectiveness of ambitious national steps for climate policy.

A large number of certificates in the market stability reserve will also provide leeway with which to increase the ambition level of European climate policy in the future, thereby allowing the additional national climate protection efforts to also remain effective over the long term (SRU 2015a; ELMER et al. 2015). One suitable way to situation-based increase the ambition level would be introducing an absolute limit on the number of certificates in the reserve. Certificates beyond that limit should then be nullified for good (IWR 2017). Additional rule-based mechanisms for the nullification of excess certificates in the market stability reserve are also being discussed (MATTHES 2017; COWART et al. 2017). The joint goal of such proposals is to prevent excess certificates from being kept in the reserve over the long term (and later returned to circulation) and instead to ensure a scarcity of certificates that will produce an effective emissions price signal.

In addition to approaches to permanently remove certificates stored in the market stability reserve, there are other ways to protect the climate-policy effectiveness of national measures. For instance, member states could directly compensate for a reduction in domestic demand for certificates by reducing their auction volume. Also, the emissions cap in the EU-ETS could be regularly adjusted based on additional national climate protection efforts (UBA 2017f).

4.1.2 National carbon reduction approaches

58. In principle, there are three ways to carefully reduce coal power in Germany:

- Switch off the oldest lignite power plants constructed before 1990, which have the greatest specific carbon emissions (s. Item 29). Roughly 50 % of the lignite coal plants still active fall into this category.
- Switch off the oldest lignite and hard coal power plants: if the emissions to be reduced are spread across lignite and hard coal power plants, the lignite phaseout can be slower. It would then be easier to dampen the structural effects occurring over a longer time frame in the lignite regions. Because hard coal power plants are less locally concentrated and hard coal mining will terminate in Germany in 2018, there will only be slight local structural effects in the hard coal sector.
- Limit on annual capacity factor for coal plants by means of maximum generation volume (MWh) or maximum CO_2 volume (t CO_2) annually: this reduces emissions without necessitating a direct closure of a site. Most employees can therefore continue working until the site is completely closed. However, individual sites could become unprofitable if possible revenue is reduced too much.

59. A number of different tools have been proposed in the public debate about how these paths could be taken (OEI et al. 2014; 2015a; 2015b; Agora Energiewende 2016a; HORST et al. 2015; OEI 2016; HERMANN et al. 2017):

- The national climate protection contribution proposed by the German Economics Ministry at the beginning of 2015 took up various options previously discussed. The proposal aimed to put an additional price on CO_2 emissions from coal plants in order to reduce the capacity utilization of older coal plants.
- Instead, a security reserve – also called the “coal reserve” – was launched in 2016. This instrument is comparable to a “cash for clunkers” program for the oldest lignite power plants; the German government will pay them to shut down after four years in the reserve.
- Specific CO_2 limits have been adopted for new construction in a number of states in the United States and Canadian provinces to limit the amount of CO_2 emitted per megawatt-hour of electricity generated. The limits, which reflect the specific emissions of modern gas-fired power plants, effectively prevent the construction of coal plants. In Germany, this approach could prevent RWE’s plans to construct another BoA Plus lignite plant in Niederaußem (1,100 MW).
- Absolute, volume-based CO_2 limits have been adopted in the UK. They cap the maximum annual amount of CO_2 per installed megawatt of output. As a result, the parameters chosen mean that affected coal plants cannot run at more than around 50 % of their maximum annual capacity.
- Minimum requirements for efficiency (or comparable technical requirements) have also been discussed because a lot of coal plants have worse efficiency levels or longer ramp-up times than gas-fired power plants. The effectiveness of such tools is, however, harder to ensure than for the other instruments described here because the various gas turbine types have quite different values. For instance, combined-cycle power plants are very efficient but far slower than open-cycle gas turbines when ramping up; indeed, they are comparable to modern coal plants in that respect.
- An additional option could be a coal phaseout law that, like Germany’s nuclear consensus from 2000, would specify the remaining amount of electricity or CO_2 emissions for the remaining coal plants. Plant operators could also be allowed to transfer these commissions from one block or mining region to another – or even between companies – to give them additional leeway without changing overall emissions.

Table 7 shows the possible tools presented above along with a summary of the resulting paths for a reduction of coal power and their financial effects. Analyses by Öko-Institut and the Büro für Energiewirtschaft und technische Planung (BET) for UBA (HERMANN et al. 2017) show that the tools chosen have much greater distribution effects than the impact on overall generation costs in power supply, especially concerning the shifting of profits between operators of the conventional power plant fleet. Furthermore, a number of tools (such as the climate contribution) could provide the state with an additional source of revenue, which could then be devoted to structural development programs or the annulment of emission certificates.

The authors conclude that switching off the oldest lignite and hard coal plants in parallel would have the least macroeconomic and distribution effects.

60. In the Climate Action Plan 2050, the German government envisions discussions with all stakeholders towards composing a resolution on a coal phaseout based on broad acceptance in society (see chapter 4.2). The path to a complete coal phaseout can be implemented through various regulatory tools, each of which are equally appropriate if the parameters are properly set. A combination of various tools is also imaginable towards ensuring that Germany stays on the structured phaseout path. This statement does not delve deeper into an assessment of the content and legality of possible tools for the implementation of a phaseout (for various legal assessments, see HORST et al. 2015; ZIEHM 2014). Section 4.1.4 presents a recommendation for a structured coal phaseout path based on social and energy-policy considerations that combines various ways of reducing coal power.

4.1.3 New European standards for nitrogen oxide emissions from coal plants

61. Most of the coal plants used to generate electricity in Germany are large combustion plants, with a thermal output exceeding 300 megawatts thermal (MWth). Large combustion plants must comply with the EU Directive on Industrial Emissions 2010/75/EU (IE Directive), which requires the best available techniques (BATs) to be used in order to avoid and reduce environmental pollution. Member states and representatives of interested parties discuss these BATs in an informational exchange; they are then specified and described in BAT reference documents. The emissions spectrums described in the conclusions on best available techniques are binding for member states (Article 15 para 3

Table 7

Possible climate protection tools and their financial effects

Options to reduce coal power State budget		financial effect (effect: + positive; o neutral; – negative)	
		State budget	Coal firms
Tools for a shutdown of oldest power plants	Security reserve/“Coal reserve”	–	+
	CO_2 limit (specific)	o	–
	Minimum efficiency	o	–
	Coal phaseout law	o	–
Tools to limit annual capacity factors	Climate protection contribution	+	–
	Volume-based CO_2 limits (absolute)	o	–

SRU 2017; data sources: HERMANN et al. 2017; OEI et al. 2014; 2015a; 2015b; HORST et al. 2015; OEI 2016

IE Directive) and can serve as the basis for a continuation or specification of EU-wide emission requirements.

The final draft of the updated BAT reference document for large combustion plants was presented in June 2016 (EIPPC 2016). At the end of April 2017, the committee adopted the Commission's resolution on the BAT conclusions with individual changes with the required qualified majority in accordance with article 72 para 2 IE Directive. The committee thus adopted new environmental standards for large combustion plants, including stricter standards for emissions of particles, sulfur oxides, and nitrogen oxides along with the first European legal standards for emissions of mercury (European Commission 2017). This decision was published in August 2017 as an implementing act in the EU Official Journal. The new environmental standards must be ratified in national law and reached by existing facilities within four years, so by 2021. The SRU welcomes the stricter EU-wide environmental standards for large combustion plants and the adoption of standards for mercury emissions.

Reducing emissions of particles, sulfur oxides, nitrogen oxides, and mercury in Europe can minimize their detrimental input in the environment (see chapter 2.2).

62. Operation values for sulfur oxides and particles from large combustion plants in Germany already largely comply with the emissions spectrums in the updated BAT reference document (European Commission 2017), but the new standards for both mercury and nitrogen oxides will influence the emissions reduction for German coal plants. For mercury, the average annual limit of 10 µg/m^3 set for large combustion plants in Germany starting in 2019 (Article 11 para 1 in combination with article 30 para 1 no. 213 of the Federal Emission Control Act (BImSchV)) is reduced to a spectrum of < 1–4 µg/m^3 for hard coal plants and < 1–7 µg/Nm^3 for lignite plants (European Commission 2017, Table 10.7).

For nitrogen oxides, coal plants with a thermal output exceeding 300 MWth will have to remain within an annual spectrum of < 85–150 mg/m^3 on average in addition to the daily average of 200 mg/m^3 (article 4 para 8 no. 4 13th BImSchV) starting in 2021. However, a footnote for existing plants fired with pulverized lignite and with a thermal output exceeding 300 MWth waters down this requirement: for them, the emissions spectrum is < 85–175 mg/m^3 (European Commission 2017, Table 10.3). In Germany, the annual average values of most existing large lignite power plants come in between 160 and 190 mg/m^3. All of these facilities use only primary combustion measures (such as optimizing combustion conditions) to reduce nitrogen oxide emissions (Deutscher Bundestag 2017). The UBA estimates that only four lignite power plant blocks would reliably comply with a national annual average of 175 mg/m^3. The rest of the lignite power plants affected would have to be revamped, some of them with (secondary) flue gas measures, while others could make do with improving the primary combustion measures without additional flue gas purification to comply with the requirement. An annual average of 175 mg/m^3 would reduce the nitrogen oxide emissions of lignite power plants operated in Germany by around 5 % (written communiqué from the UBA on 13 July 2017) or by 7 % according to a different estimate (DNV GL – Energy 2016).

63. Two techniques are available to reduce nitrogen oxide emissions from flue gas: selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) SCR is more effective in reducing nitrogen oxides (generally 80–95 %, compared to 30–50 % for SNCR), but also far more expensive than SNCR (EIPPC 2016, p. 215 ff.). A European study found that the investment costs for SNCR flue gas purification (including primary measures) is 50 euros per installed kilowatt of electric output (kWel), whereas the cost of SCR flue gas purification (without primary measures) is estimated at 120 euros per kWel (DNV GL – Energy 2016). The aforementioned draft of the BAT reference document lists both flue gas purification technologies as BATs for large combustion plants exceeding 300 MWth running under full load (with a few technical exceptions for SNCR technology). If an SCR system is installed, as is already common in German hard coal plants larger than 300 MWth, lignite power plants can reach annual average values below 100 mg/m^3. Reducing the current nitrogen oxide limits for large lignite units from 200 to 100 mg/m^3 could reduce nitrogen oxide emissions by around 26 % (SRU 2015b, Item 549).

64. For environmental and health reasons, it makes sense and is necessary to further reduce nitrogen oxide emissions significantly (chapter 2.2). The SRU therefore believes retrofitting existing lignite plants in Germany with SCR technology is justified. For this to happen, the German government would have to make the limits on nitrogen oxide emissions from lignite plants more ambitious in the course of implementing the new EU standards for large combustion plants – to around 85 to 100 mg/m^3; if merely the upper limit for the emissions spectrum in the EU is complied with, the level would be 175 mg/m^3. However, reduction measures for coal plants always have to be discussed in combination with the required phaseout of coal power (SCHAIBLE 2017). In a structured phaseout, there will be lignite plants that will go off-line in a few years at any rate or see operating hours reduced as a result of limited remaining commissions. For these units, the investment costs for flue gas purification, such as SCR, would be excessive. In these cases, exceptions to the ambitious limits on nitrogen oxide should be possible, but the units should use the available primary combustion techniques to limit nitrogen oxide emissions up to the end of their commissions.

4.1.4 Recommendation for a coal phaseout in three phases

65. A structured path to end coal power that takes climate-policy urgency seriously and considers regional, social, and technical challenges can be divided into three phases for a simplified understanding (see Figure 5). To prevent structural discontinuations, a coal phaseout should be launched as quickly as possible based on the following phases in light of the planning timeframe of up to ten years for adjustments in lignite excavation at mines:

Phase 1: The oldest units are switched off by 2020 to close part of the gap towards a 40 % reduction in carbon emissions by that year. This would simultaneously achieve the goal of taking older lignite plants off-line as they would not be able to comply with the ambitious NO_x limit applicable starting in 2021 (see Section 4.1.3) because retrofitting with flue gas purification (SCR or SNCR) would not pay for itself. Existing excess capacity ensures that there will be no shortfall in supply.

Phase 2: Reduction in the capacity utilization of the remaining coal plants in the 2020s to continuously reduce coal power. If they are not already equipped with flue gas purification technologies (SCR or SNCR), these more modern units would need to be in order to comply with the ambitious nitrogen oxide limit. Only facilities scheduled to be closed in a few years anyway or only expected to run for a reduced number of hours due to limited residual commissions would be exempt from this retrofitting obligation. However, these facilities should use available primary combustion technologies to limit nitrogen oxide emissions as long as they are running. Because these facilities will provide reserve capacity, supply security will not be endangered even after the nuclear phaseout. Furthermore, most employees will be able to keep their jobs because the blocks will continue operation. A possible climate protection tool here would be a specific carbon emissions budget for each power plant block, similar to the volume-based carbon limits (emissions performance standards) implemented in the UK (see Item 59; ZIEHM et al. 2014; OEI et al. 2015a). One advantage of this tool is that it allows the volume of lignite still needed to be assessed per power plant and mine. The final spatial extent of open-cast mines can then be specified early on, thereby providing benefits for residents (certainty about possible relocation), operators (planning of re-cultivation efforts), and authorities (permitting processes for changes to lignite plans).

Phase 3: The remaining coal plants are successively closed in the 2030s. Continued operation of individual remaining power plant blocks is only profitable if power prices and capacity factors are very high, since the fixed costs of mines are high. For each region, the last facilities will be closed simultaneously for technical and economic reasons. By the 2030s, sufficient renewable energy generators should be added to the grid if the Energiewende is ambitiously pursued so that, in combination with power storage and demand management options, supply security can be ensured.

Figure 5, which depicts the three phases, shows total CO_2 emissions and power generation from coal plants in order to simplify the overview. If there were a differentiation, the greater specific emissions of older plants would cause emissions to drop slightly more quickly at the beginning and flatten off more at the end in return.

4.2 A consensus for a coal phaseout

66. Coal power has become a major field of social conflict. In comparable situations, such as the phaseout of hard coal mining and the nuclear phaseout, agreements reached between politicians and stakeholders have proven useful. It thus seems proper to strive for a basic agreement with stakeholders for the coal phaseout process, as well, and launch a consultative process to that end.

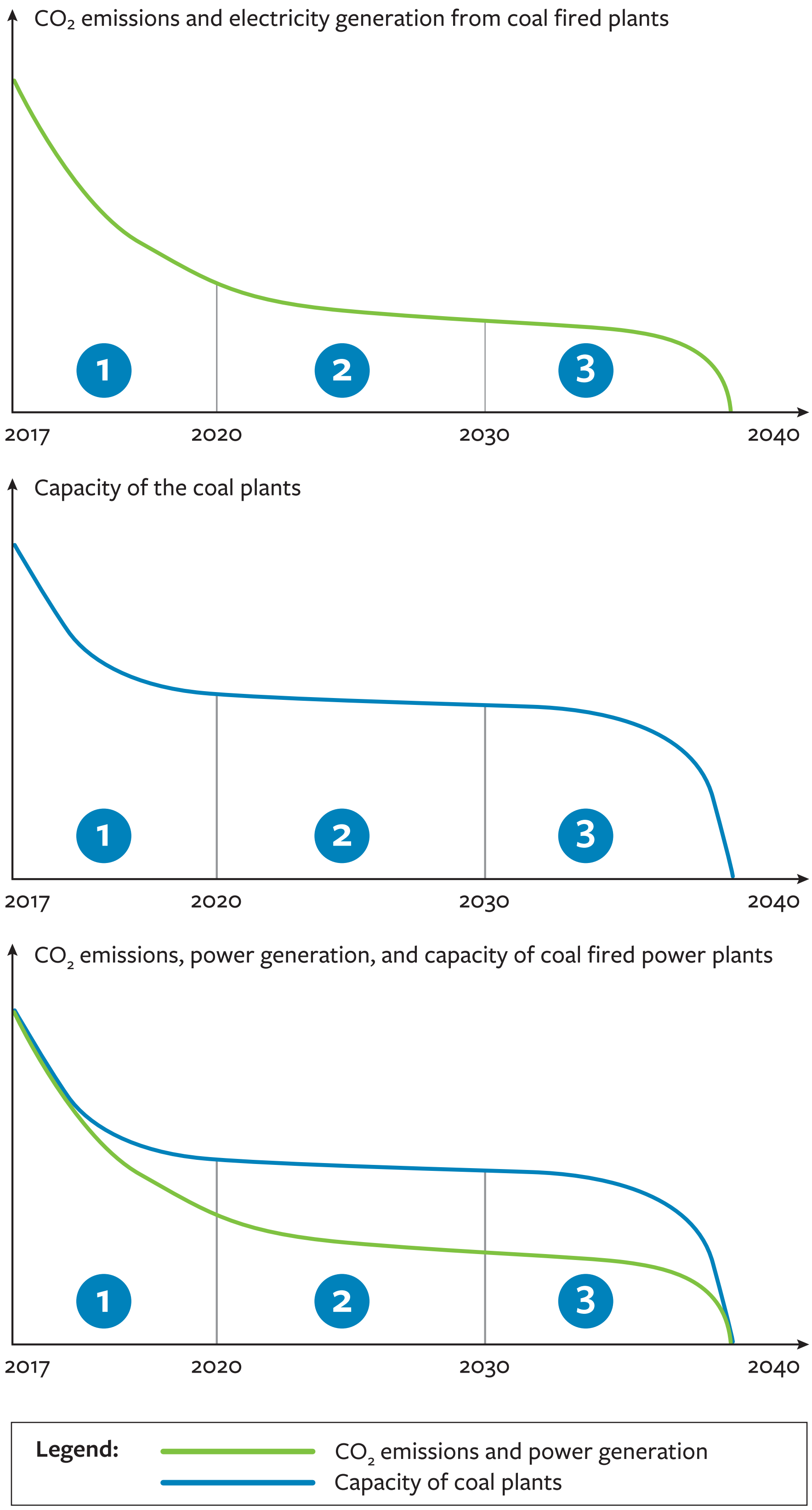
4.2.1 Added value of a coal consensus

67. A consensus for an end to coal power that describes a phaseout path worked up jointly would have a number of benefits:

- A consensus would provide stable foundations for economic planning and hence investment security. Legislative risk would be minimized, as would the danger of expensive lawsuits for affected firms. A possibly polarizing conflict over the future of coal could reach a peaceful end, and political and social trust in the seriousness of the Energiewende would improve.

Figure 5

Step-wise shutdown of coal plants in three phases



Maintaining a coal phaseout for Germany in three phases in compliance with an emissions budget of 2,000 MT CO_2

Phase 1: (1)
Switching off the oldest units as quickly as possible

→ Compliance with the 2020 climate protection targets and the new EU pollution limit

Phase 2: (2)
Reduction in electricity generation while capacity is maintained

→ Protecting jobs and supporting supply security

Phase 3: (3)
Coal phaseout

→ A structured coal phaseout gives stakeholders planning security

SRU 2017

- The reduction in coal power could be closely linked to specific measures that dampen social and economic consequences at affected locations. New economic perspectives could be opened and approaches developed for an effective use of support funding in a dialogue with the federal states, companies, and labor unions.

- With participation from representatives of the main companies and employees affected, a detailed phase-out path could be drawn up for an emissions reduction that is as cost-efficient as possible and focuses on targeted structural development in the individual lignite mining regions.

Distribution issues between, on the one hand, hard coal and lignite and, on the other, individual lignite regions could then be negotiated in order to produce compromises.

68. In its "Impulspapier Strom 2030", the German Economics Ministry already recognized the need for a dialogue towards implementing climate targets in the power sector after 2020 (BMWi 2016, p. 12). The Climate Action Plan 2050 included a plan to set up a commission in early 2018 tasked with "developing a toolbox that combines economic development, structural change, social responsibility, and climate protection in order to support structural change" (BMUB 2016, p. 36). By establishing a coal commission, the German government would take up a recommendation from the dialogue process for the Climate Action Plan 2050 supported by the forum of federal states, the citizens' forum, and other stakeholders ("KSP-E-07a: Ausstieg aus der Stromerzeugung durch Kohlekraftwerke – Dialogprozess", Wuppertal Institut für Klima, Umwelt, Energie et al. 2016, p. 39 ff.). Other actors have also previously proposed developing a phaseout of coal power in a broad societal consensus (cf. SRU 2015a; Agora Energiewende 2016a). The SRU welcomes the plan to set up the commission and makes the following proposals for its design.

4.2.2 A coal commission's task

69. The SRU believes that a commission for a phaseout of coal power will only be successful if it works on the basis of a clear political mandate and politicians clearly define its task. The commission can help clarify the large number of open questions about a coal phaseout in a consensus to the extent possible. The focus is on not only the business interests of affected firms, protecting jobs, and structure-policy design options, but also ensuring that the climate and environment are protected.

The requirements for future structural policy depend, both overall and in terms of the affected regions, on the exact phaseout roadmap and the final date for the coal phaseout. Unlike in the Climate Action Plan 2050 up to now, it therefore seems to make sense to include the coal phaseout path from the outset in the talks of the commission for growth, structural change, and regional development. This process could prevent the possible formulation of an agreement motivated by structural policy that doesn't meet climate-policy needs. In light of the urgent need for action, the climate protection targets, and the remaining carbon emissions budget, the SRU argues that not only should a resolution for a phaseout of coal power be made in the beginning legislation period, but a binding phaseout path should also be agreed. The German government should therefore specify the coal sector's binding contribution to climate protection in advance, specifically what part of the remaining carbon emissions budget is allocated to coal power. The required contribution of coal power to the Energiewende can thus be calculated from the context of an overall strategy for long-term climate protection. This decision will necessarily go beyond such a coal commission's mandate. The participating parties then no longer have to decide "whether" and can instead focus on "how" a coal phaseout can take place.

The SRU therefore recommends that the governing parties make a coal phaseout a priority task in the coalition agreement. It should include a binding carbon emissions budget for coal power from 2015 to 2040 in compliance with national and international climate protection targets (Section 2.1.3). Another benefit of the budget approach is that the mining areas still needed in the future for lignite can be calculated. The citizens threatened by relocation would then have more planning security, as would mining firms for re-cultivation projects.

Based on this specified overall budget, the commission's tasks could be to:

- develop a path that is macro-economically efficient and acceptable in terms of distribution equity for a gradual reduction of electricity from lignite and hard coal. The path should keep the number of job losses in lignite mining, in power plants, and along the value chain as low as possible even as it ensures supply security (SRU 2015a).

- identify investment fields in the lignite regions affected, develop overriding strategies to support regional structural change, and estimate the need for financing for these measures. In the process, it should include expertise from the affected regions and from research.

In addition, it should identify measures to mitigate the social impact of the coal phaseout.

- have a study done to determine the extent to which the provisions set aside cover long-term costs of coal mining (re-cultivation and other long-term costs; cf. Section 3.1.4). It should identify ways for mining firms to cover long-term costs as expected by the legislature so that they are not passed on to public budgets.

70. The commission should not be overburdened with a mandate that is too broad in subject. Such a commission cannot answer all of the questions that a coal phaseout raises. For instance, a national coal commission cannot provide final answers to all of the questions surrounding structural change. The consequences of the agreed coal phaseout path and the necessary structure-policy strategies should therefore be further discussed in more detail in regional processes with stakeholder input. The future design of the power market should not be a part of this dialogue process, either. Rather, future negotiations for power market design can only take place based on a binding decision about the end of coal power and the resulting coal phaseout path.

4.2.3 Who will be in the commission, and how will they work?

71. The legitimacy and stability of negotiation results depend not only on their content and effects, but also largely on whether the process is considered socially legitimate. Who sits in such a commission and how it works is therefore important. Ministerial departments in charge of energy policy and climate protection (currently the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and the Federal Ministry for Economic Affairs and Energy) should therefore head the commission jointly. Other relevant ministries – finance, health, labor, and social issues – should take part from early on, as should the federal states.

While the number of commission members should be limited, the commission also needs to represent the most important stakeholders. Only then will it be possible to reach a broadly accepted consensus. Representatives of the following groups should take part: federal government, state governments, affected regions, the lignite and hard coal sectors, environmental organizations, labor unions, and researchers (cf. SRU 2015a, Item 41 f.). Up to now, the commission called for in the Climate Action Plan does not specify any input from civil society aside from regional stakeholders. The SRU believes that the participation of environmental associations is required for widespread social acceptance and the commission's legitimacy because the phaseout of coal power serves environmental-policy goals (SRU 2015a). Allowing affected firms to send joint representatives would also make the committee more balanced. In this way, the interests of both power plant operators and mines could also be better kept in mind. Labor union representatives should be selected on similar lines to represent the interests of employees at both power plants and mines.

72. The dialogue process initiated by the commission offers stakeholders an opportunity to negotiate "in the shadow of hierarchy" (MAYNTZ and SCHARPF 1995), as was done, for instance, with the original nuclear phaseout (cf. TÖLLER 2012). Mining companies, labor unions, power plant operators, and representatives of affected regions are not, however, expected to be greatly interested in reaching an amicable solution, since they tend to prefer the status quo and would be primarily negatively affected by a coal phaseout. The consequences that could result from the commission's failure will be decisive for stakeholders' conduct (BENZ 2007, p. 113 ff.). It should therefore be made clear that the commission allows stakeholders the possibility of co-designing the phaseout roadmap with their own proposals. If the commission does not reach amicable proposals, it will be the task of the German government to set forth a phaseout roadmap compatible with the carbon emissions budget. In the end, the German Bundestag will have to support the coal phaseout by making it law with the greatest possible majority.

73. The commission should receive support from a small scientific advisory group that studies the legal and political compliance of the positions discussed. In particular, the advisory group should ensure that the agreed phaseout path is consistent with the carbon emissions budget specified by the German government. Expertise will probably also be needed at short notice concerning provisions for long-term costs.

74. The commission's work should be transparent from the perspective of both negotiation and democratic theory. In terms of democracy, transparency generally increases the legitimacy of proceedings. Transparency also makes bargaining less important because the public demands arguments – deliberative negotiations oriented on understanding – from participants (ELSTER 1998, p. 111). On the other hand, negotiations behind closed doors tend to increase leeway for participants (PUTNAM 1988). The SRU holds that a minimum of transparency must be ensured without endangering the commission's cooperation based on trust in order to protect the commission's legitimacy. For instance, agendas and minutes of resolution could be published for each meeting of the commission. Statements made by the scientific advisory group should be made public to allow for a transparent, comprehensive social and political debate about the negotiations.

5 Recommended actions

75. To make an appropriate contribution to global climate protection, Germany must quickly reduce the combustion of fossil fuels and make its economy almost greenhouse-gas neutral by 2050. Germany runs the risk, however, of missing its national climate protection targets for 2020 and 2030. The new German government should therefore immediately launch a coal phaseout in order to take an important step in the right direction. A fast reduction of coal power would not only reduce emissions greatly at relatively low cost, but would also have considerable positive effects on the environment and human health along with energy-economic benefits.

76. The SRU therefore proposes a phaseout of coal power in three phases. By 2020, the oldest, most inefficient and carbon-intensive coal plants should be closed. In the second phase up to 2030, the remaining coal plants should run at lower capacity utilization rates but largely remain on the grid to ensure supply security. In the third phase, the remaining coal plants should be successively closed in the course of the 2030s. The German government must determine the exact year in which the last coal plant will be shut down, but the specific date is not as important as compliance with a carbon budget that fulfills the Paris Climate Agreement. The challenges the phaseout entails for supply security and economic development in the lignite regions are to be taken seriously but can be managed.

77. As called for in the Climate Action Plan 2050, the new German government should establish a commission that makes the necessary decisions in consultation with stakeholders. Such a commission should have a clear political mandate. A central starting point and boundary condition for the commission is a remaining carbon budget allocated to coal power. From the scientific perspective, cumulative emissions from coal power should not exceed 2,000 MT CO_2 before the last unit has closed. The commission should make recommendations for a specific phaseout path, its instrumental design, and ways to mitigate its social and economic impacts in the regions affected.

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