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301 Report by Leonard Göke, Martin Kittel, Claudia Kemfert, Casimir Lorenz, Pao-Yu Oei, and Christian von Hirschhausen

Successful climate protection via rapid coal phaseout in Germany and North Rhine-Westphalia

- Coal phaseout in Germany is necessary for climate protection and makes sense for the energy sector: lignite by 2030 and hard coal by 2040
- North Rhine-Westphalia, a traditional energy state, should phase out coal-based electricity generation and significantly increase its share of renewable energy in line with the climate protection plan



LEGAL AND EDITORIAL DETAILS



DIW Berlin — Deutsches Institut für Wirtschaftsforschung e. V.

Mohrenstraße 58, 10117 Berlin

www.diw.de

Phone: +49 30 897 89-0 Fax: -200

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DIW Berlin Leserservice, Postfach 74, 77649 Offenburg

leserservice@diw.de

Phone: +49 1806 14 00 50 25 (20 cents per phone call)

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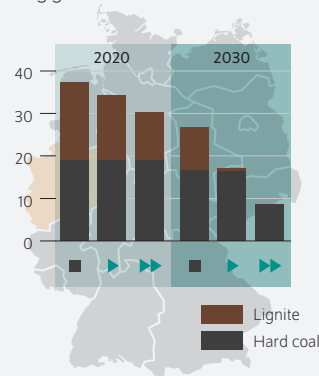
Successful climate protection via rapid coal phaseout in Germany and North Rhine-Westphalia

By Leonard Göke, Martin Kittel, Claudia Kemfert, Casimir Lorenz, Pao-Yu Oei, and Christian von Hirschhausen

- Energy economic model calculations on alternative paths for a coal phaseout up to 2030
- Only a rapid coal phaseout in Germany and North Rhine-Westphalia will satisfy the climate targets for 2030 advancing the decarbonization of Europe at the same time
- An adequate contribution to 2020 climate targets can only be achieved by an additional limit on annual operating of coal plants
- In the traditional energy state North Rhine-Westphalia, a coal phaseout will make a positive contribution to environmental protection in lignite regions
- Policymakers should create the conditions for a coal phaseout and transition to a flexible, renewable electricity system

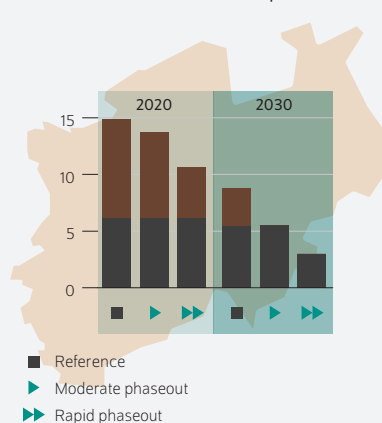
Possible paths for an accelerated coal phaseout in Germany and North Rhine-Westphalia and their effect on the fulfillment of the German climate targets in the electricity sector in 2030

Capacities of coal power plants in Germany... (in gigawatts)

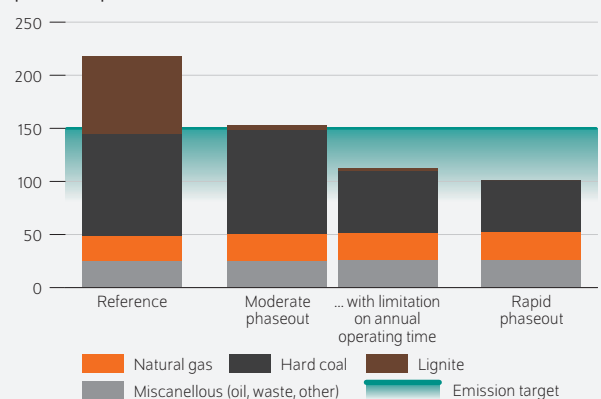


Source: Authors' own depiction, authors' own calculations

... and North Rhine-Westphalia



CO₂ emissions in the electricity sector in 2030 under the different phaseout paths (in million tons CO₂)



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FROM THE AUTHORS

"The coal phaseout in Germany is necessary for climate protection and makes sense for the energy sector."

— Claudia Kemfert, survey author —

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Audio interview with Claudia Kemfert (in German)
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Successful climate protection via rapid coal phaseout in Germany and North Rhine-Westphalia

By Leonard Göke, Martin Kittel, Claudia Kemfert, Casimir Lorenz, Pao-Yu Oei, and Christian von Hirschhausen

ABSTRACT

Power generation from lignite and hard coal was responsible for more than a quarter of German greenhouse gas emissions in 2016. Of all federal states, North Rhine-Westphalia is by far the largest carbon emitter. The Growth, Structural Change and Regional Development Commission (also known as "Coal Commission") among others are currently debating alternative pathways toward a coal phaseout to achieve the national climate targets. The Coal Commission has been tasked with submitting specific recommendations by the end of 2018. Supported by detailed model calculations, the present study shows that a rapid reduction in coal-fired power generation nationwide and in North Rhine-Westphalia is necessary to meet the climate targets in 2030. According to the German government's climate protection plan, emissions in the energy sector must fall by about 60 percent as compared to 1990. The analysis also shows that a German phaseout promotes decarbonization and the expansion of renewable energies throughout Europe. And in North Rhine-Westphalia, a rapid coal phaseout will be necessary to meet the climate protection targets. All lignite power plants and many plants that run on hard coal could be shut down by 2030. The phaseout of lignite mining in NRW could be designed such that surface mine Garzweiler II would no longer engulf any villages; the forest in the Hambach surface mine that is worth conserving would also be saved.

According to its climate protection targets, by 2020 the German government aspires to reduce greenhouse gas emissions in Germany by 40 percent, using 1990 as the base year.¹ There should be a 55 percent reduction by 2030.² The energy industry is slated to make a major contribution to the effort by switching to renewable energy.³ Greenhouse gas emissions are targeted to fall by slightly more than 60 percent as compared to 1990.⁴ Currently, the likelihood of meeting the targets is bleak: without any extra measures, Germany can expect a total reduction in greenhouse gas emissions of only 35.5 percent by 2020. One reason is that great quantities of lignite and hard coal continue to be used in generating electricity.⁵

Formed by the federal government to respond to the circumstances, the Growth, Structural Change and Regional Development Commission (more generally referred to as the "Coal Commission") has been working on its coal phaseout proposal since June 2018. The goal is a phaseout that reduces the climate target shortfall for 2020 and meets the target for 2030, while at the same time creating opportunities for future-proof jobs in the affected regions. By the end of this year, the commission is expected to present concrete policies.

The federal state of North Rhine-Westphalia (NRW) plays a special part in these developments. On the one hand, the state parliament adopted a climate protection law in 2013 that prescribes a reduction in greenhouse gas emissions by 2020 of at least 25 percent and by 2050, at least 80 percent

¹ Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, "Klimaschutz in Zahlen – Fakten, Trends und Impulse deutsche Klimapolitik," (2018) (in German; available online, accessed: July 23, 2018; this applies to all other online sources in this report unless stated otherwise).

² Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, "Klimaschutzplan 2050 – Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung," (2016) (in German; available online).

³ In total, the proportion of greenhouse gas emissions from the energy industry was 86 percent of total emissions in 2016. See Federal Ministry for Economic Affairs and Energy, "Zahlen und Fakten. Energiedaten – Nationale und Internationale Entwicklung," (2018) (in German; available online).

⁴ Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, "Klimaschutzplan 2050." In the German government's climate protection targets for 2050, *Klimaschutzplan 2050*, electricity and heat generation are combined as the energy industry. The present study only tackles the power supply.

⁵ German Federal Environmental Agency, "Coal-fired power generation and climate protection until 2030," (2017) (available online).

compared to the base year 1990.⁶ This positions the state as one of the pioneers of climate protection policy – at least on paper. On the other hand, of all German federal states NRW is currently the largest emitter of greenhouse gases. Part of the reason is that at ten gigawatts and eight gigawatts respectively, half of the capacity of Germany's lignite power plants and almost one-third of power plants that run on hard coal are located in the state. The lignite power plants in NRW alone were responsible for ten percent of Germany's total carbon emissions in 2014.⁷ And the proportion of renewable energy in the power generation mix is currently 12.5 percent there – far below the nationwide average of 36 percent.⁸ For this reason, NRW is key to the successful implementation of the energy transition in Germany.⁹

The present study identifies three possible paths to the lignite and hard coal phaseout in Germany within the context of the European electricity system. For each path, a model calculation of the European electricity system analyzes the effect on carbon emissions for 2020 and 2030, describing the resulting mixture of generation technologies. Next, the study examines the impact of each path on NRW. We placed particular emphasis on power plants, carbon emissions, as well as surface mining and the environmental damage its operation causes.¹⁰

One reference scenario and two paths for an accelerated coal phaseout in Germany...

Based on a reference scenario and two accelerated paths for phaseout by 2030, the authors analyzed the effects of the coal phaseout on the German electricity sector's emissions and the European electricity market.¹¹ The reference scenario updates the power plant capacity that is currently available in the absence of any additional energy or environmental policy measures. The coal phaseout it envisions takes place as one power plant after the other is shut down upon reaching its technical service life – a comparatively slow process.¹² It excludes the option of retrofitting the power plants for operation beyond their technical service lives.

⁶ Ministerium des Innern des Landes Nordrhein-Westfalen, "Klimaschutzgesetz Nordrhein-Westfalen," *Gesetz- und Verordnungsblatt*, 2013 no. 4 (2013).

⁷ Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen, "Energiestatistik NRW, 2018." (in German; available online); and German Environment Agency, "Erneuerbare Energien in Deutschland – Daten zu Entwicklung im Jahr 2017," (2018) (in German; available online).

⁸ Landesverband Erneuerbare Energien Nordrhein-Westfalen, "Erneuerbare-Energien-Bilanz 2017 für NRW," (press release, Düsseldorf, 2018) (in German; available online).

⁹ Wolf-Peter Schill, Jochen Diekmann, and Andreas Püttner, "Fünfte Vergleichsstudie zu erneuerbaren Energien: Baden-Württemberg führt erstmals," *DIW Wochenbericht*, no. 46 (2017): 1029-1041. (in German; available online); and Jochen Diekmann et al., "Vergleich der Bundesländer: Analyse der Erfolgsfaktoren für den Ausbau Erneuerbarer Energien 2017," *DIW Politikberatung kompakt*, no. 125 (2017) (in German; available online).

¹⁰ This report draws on results provided by the junior research group „CoalExit – Economics of Coal Phase-Out – Identifying Building Blocks for Future Regional Transition Frameworks" funded by the Federal Ministry of Education and Research of Germany.

¹¹ A broader array of coal phaseout scenarios and their impact is presented in Pao-Yu Oei et al., "Szenarien zur Einhaltung der Deutschen Klimaziele – Auswirkungen und Chancen für NRW für eine umfassendere Betrachtung," *DIW Politikberatung kompakt*, no. 129 (in German; forthcoming); Martin Kittel and Leonard Göke, "Coal exit scenarios in Germany – A Model-Based Analysis and Implications in the European Context," *DIW Discussion Paper* (forthcoming).

¹² Previously adopted transfers to back-up status (*Sicherheitsbereitschaft*) are also taken into account.

Table 1

Possible paths for a coal phaseout in Germany Power plant capacities in gigawatts

Path	Technology	2015	2020	2030
Reference	Hard coal	24.7	19.1	16.5
	Lignite	21.0	18.2	10.2
Moderate phaseout	Hard coal	24.7	19.1	16.5
	Lignite	21.0	15.2	0.6
Rapid phaseout	Hard coal	24.7	19.1	8.6
	Lignite	21.0	11.2	0.0

Source: Authors' own depiction.

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Emission-intensive lignite power plants will be almost completely shut down by 2030; in a rapid phaseout, capacities of hard coal power plants are also significantly reduced.

The two accelerated paths follow proposals for the early shutdown of coal-fired power plants by 2020 that were discussed during the coalition talks in November 2017.¹³ The paths are determined such that depending on the targets, shutdown would be as evenly distributed as possible until 2040, and the majority of power plants would be out of operation by 2030 (see Table 1). In the *moderate phaseout*, an additional three gigawatts of power plant output in comparison to the reference scenario would be shut down by 2020 and total coal-fired capacity would be reduced to 17.1 gigawatts by 2030. This path initially focuses on phasing out lignite and would not begin shutting down hard coal power plants until after 2030. The *rapid phaseout* path would shut down coal-fired power plants by 2020, totaling seven gigawatts, and total capacity would be reduced to 8.6 gigawatts by 2030. Hard coal-fired power plants would be successively shut down before 2030 on this path, alongside lignite plants.

We also examined the effects of limiting the annual operating time of coal-fired power plants for the moderate phaseout path.¹⁴ In detail, this would mean limiting operation of all coal-fired power plants age 20 and over to a maximum of 4,000 full load hours per year.¹⁵ This measure would reduce emissions in a way that makes economic sense and at the same time, hardly impact the number of employees in the affected power plants.¹⁶

¹³ Parties FDP and CDU/CSU favored closing three to five gigawatts of lignite capacity until 2020; a proposal from the German Ministry for Economic Affairs and Energy suggested seven gigawatts. See "Grüne lehnen Kompromiss zum Kohleausstieg ab," *ZEIT online*, November 13, 2018 (in German; available online); Federal Ministry for Economic Affairs and Energy and Federal Network Agency, *Versorgungssicherheit in Deutschland*, (2017) (available online).

¹⁴ Cornelia Ziem et al., "Entwurf und Erläuterung für ein Gesetz zur Festsetzung nationaler CO₂-Emissionsstandards für fossile Kraftwerke in Deutschland," *DIW Politikberatung kompakt*, no. 82 (2014) (in German; available online); Pao-Yu Oei et al., "Auswirkungen von CO₂-Grenzwerten für fossile Kraftwerke auf Strommarkt und Klimaschutz in Deutschland," *DIW Politikberatung kompakt*, no. 104 (2015) (in German; available online).

¹⁵ In other words, a power plant in that age group would produce a maximum of 4,000 of its 8,760 hours per year under full load. The amount could be distributed across several hours with correspondingly lower output.

¹⁶ See Pao-Yu Oei et al., "Effektive CO₂-Minderung im Stromsektor: Klima-, Preis- und Beschäftigungseffekte des Klimabeitrags und alternativer Instrumente," *DIW Politikberatung kompakt*, no. 98 (2015). (in German; available online); and German Advisory Council on the Environment, "Statement: Start coal phaseout now", 2017 (available online).

Box

The electricity sector model dynELMOD

dynELMOD, the dynamic investment and power plant utilization model, decides on optimal investments into plants that generate electricity using conventional and renewable energy sources, storage, demand-side management, and high-voltage transmission lines. After making the investment decision, it determines the re-

sulting power plant use and electricity flow among the European countries.¹

It bases its decision on current data for the European power plant fleet and electricity grid. Additional inputs include forecasts on European electricity consumption, the costs and properties of the technologies under consideration, the historical, hourly time series of electricity demand, and feed-in of renewable energy from the base year, 2013.

Under the specified conditions, the model minimizes the total system costs of providing electricity by 2050 in five-year steps across 33 European countries divided into five synchronous grid zones (see figure). dynELMOD simulates the European electricity market in the future years examined. One important condition is the extensive decarbonization of the European electricity supply by 2050. The model maps this as a linear reduction in greenhouse gas emissions from 1,300 million tons of carbon in 2015 to 20 million tons of carbon in 2050.²

And to keep the calculation period reasonable despite the large temporal and spatial horizons, investment decisions are determined in five-year steps; a special algorithm is used to reduce the annual period of observation. The seasonal characteristics and extremes of the demand for electricity and phases with lower electricity generation from renewable sources are all taken into consideration.

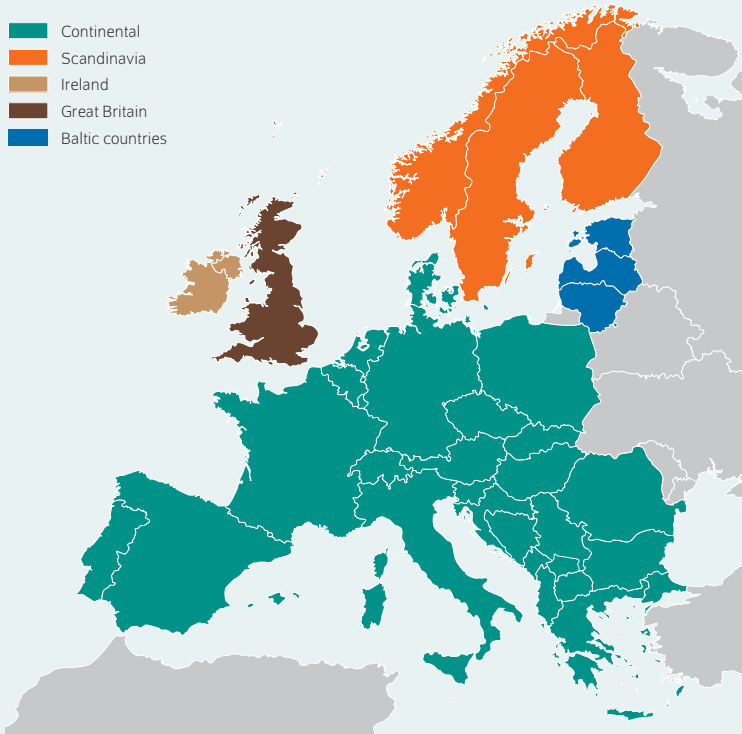
The model output encompasses the European mix of generation technologies and flexibility options consisting of power plants using conventional and renewable energy sources, storage systems, and demand-side management facilities and their deployment. dynELMOD also outputs the expansion of interconnection points for cross-border trade with electricity.

Figure

Geographical coverage of dynELMOD

Synchronous zones

- Continental
- Scandinavia
- Ireland
- Great Britain
- Baltic countries



Source: Gerbaulet and Lorenz, "dynELMOD."

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The investment model covers 32 European countries.

¹ Clemens Gerbaulet and Casimir Lorenz, "dynELMOD: A Dynamic Investment and Dispatch Model for the Future European Electricity Market," *DIW Data Documentation*, no. 88 (2017) (available online).

² To avoid a double restriction on carbon emissions, a price for carbon is not included in the model.

...meeting emission targets in the electricity sector

To examine the phaseout paths while considering the federal government's climate targets, we compared them to the specifications in the climate protection plan for 2050. The plan stipulated targets for reducing greenhouse gas emissions for individual sectors,¹⁷ but it did not define explicit climate targets for power provision because it considers only

the energy industry as a combination of electricity and heating. The energy industry target is a 60 percent reduction in greenhouse gas emissions against the base year 1990.

It should be noted that in the heating sector, decarbonization is held to be more difficult than in the electricity sector.¹⁸ Thus, the authors assumed that the emissions of elec-

¹⁷ Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, "Klimaschutzplan 2050."

¹⁸ Gerhard Stryi-Hipp et al., "Besonderheiten des Wärmemarktes und Konsequenzen für eine erfolgreiche Wärmewende," *Forschungsverbund Erneuerbare Energien: Forschung für die Wärmewende* 23–26 (2015) (in German; available online).

tricity generation must be reduced by at least 60 percent. In the spirit of dealing with the sector targets flexibly, the calculations also examine the conditions surrounding an 80 percent reduction in emissions from electricity generation. This takes into account the difficulty of decarbonizing the heating sector, which would not have reduce emissions substantially in this case, as well as likely shortcomings in other sectors.¹⁹

Since there are no sector targets for 2020, a reduction of 40 percent was applied to the electricity sector. This equals the target for overall greenhouse gas emissions.²⁰

A detailed model calculated the effect of the coal phaseout on emissions

The dynamic investment and power plant dispatch model dynELMOD (see box) was used to examine the phaseout paths. The model simulates the European electricity market in five-year steps by making cost-optimized investment decisions in different technologies for electricity generation, storage, and distribution, as well as determining their application. This report focuses on results for years 2020 and 2030.

The expansion of renewable energy capacity in Germany is specified as a constraint in the model – at least according to the paths for expansion included in the Renewable Energy Sources Act (*Gesetz für den Ausbau erneuerbarer Energien*, EEG) and the current coalition agreement, which stipulates a proportion of 45 percent of German electricity consumption in 2025 and 65 percent in 2030.²¹ The model also mandates an overall reduction of greenhouse gas emissions by 95 percent until 2050 in Europe. A third assumption was that Belgium would completely shut down its remaining nuclear power plants by 2020 since they frequently malfunction and are, thus, unavailable.²²

Accelerated coal phaseout would significantly reduce emissions

The model results show that, even along the ambitious phaseout paths, the sectoral climate target for 2020 can only be achieved if the operating times of older, more emission-intensive power plants are limited (see Figure 1). Under a limitation of annual operating time, the moderate phaseout path would surpass the carbon savings goal in the electricity sector, at just below six million tons, and could compensate for foreseeable shortfalls in other sectors.

Like the year 2020, the minimum decarbonization target in the electricity sector for 2030 would be missed without any

¹⁹ For example, current forecasts predict a shortfall of 40 to 50 million tons of CO₂ by 2030 in the transport sector. See Ifeu, "Aktualisierung Daten- und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960–2035 (TREMOT) für die Emissionsberichterstattung 2016 (Berichtsperiode 1990–2014)," (2016) (in German; available online).

²⁰ Federal Network Agency, "Sechster Monitoringbericht zur Energiewende – Berichtsjahr 2016," (2018) (in German; available online).

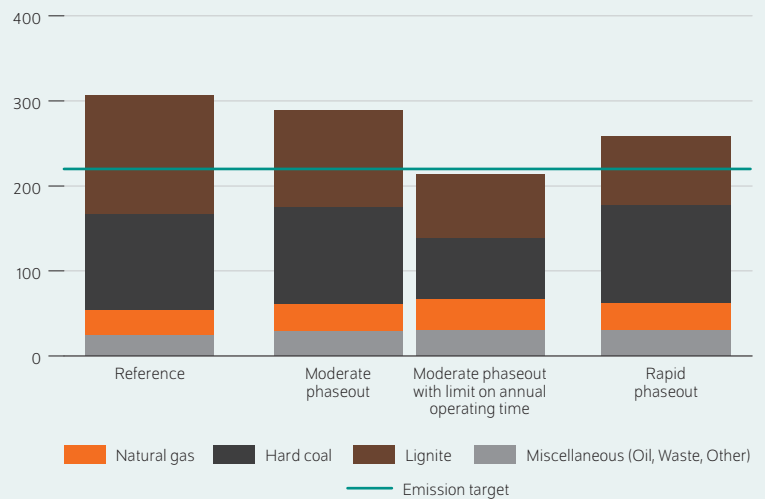
²¹ German government, "Coalition Agreement of March 14, 2018," (2018) (in German; available online).

²² Westdeutscher Rundfunk, "AKW Tihange deutlich gefährlicher als bislang bekannt," (2018) (in German; available online).

Figure 1

CO₂ emissions in the electricity sector in 2020 under the different phaseout paths

In million tons CO₂



Source: Authors' own calculations.

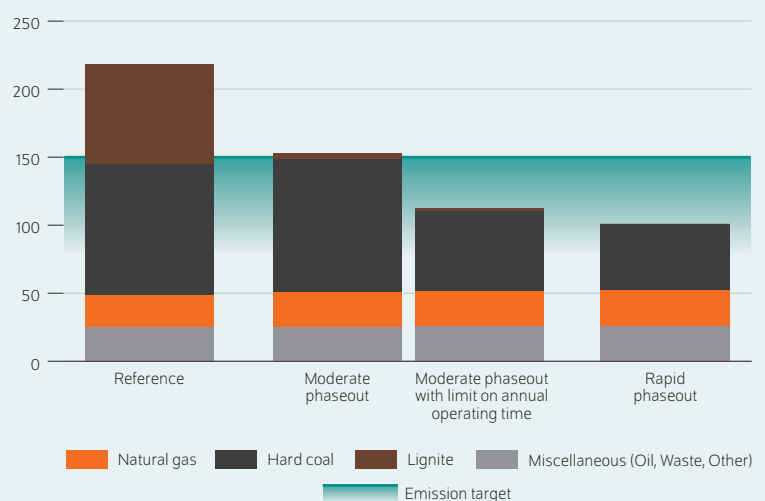
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Only an ambitious coal phaseout can lower emissions substantially by 2020.

Figure 2

CO₂ emissions in the electricity sector in 2030 under the different phaseout paths

In million tons CO₂



Source: Authors' own calculations.

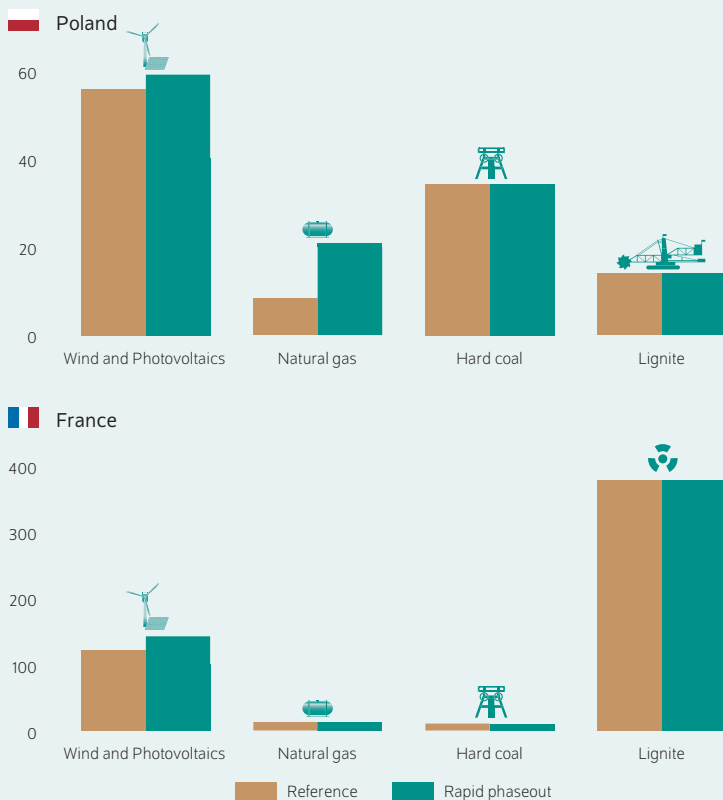
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Only an accelerated phaseout complies with the 2030 climate targets and could additionally compensate for foreseeable shortfalls in other sectors.

Figure 3

Power generation in Poland and France by technology in 2030, under the reference scenario and rapid phaseout

In terawatt hours



Source: Authors' own calculations.

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A rapid phaseout in Germany would not lead to intensified use of nuclear power in France or coal in Poland.

limitation on annual operating time along the moderate phaseout path. If annual operating time were limited along the moderate phaseout path or in case of the rapid path, the objective is exceeded by around 50 million tons of CO₂ (see Figure 2).²³ This might be necessary in order to compensate for lower emission reductions in other sectors and thus reach the climate target for 2030 with high cost efficiency. In all cases, the climate targets can only be reached by intensifying the coal phaseout. Without any additional energy policy measures, Germany would miss its mark.

Energy mix in neighboring countries becomes more renewable

The fear that a coal phaseout in Germany could shift electricity generation to other technologies in neighboring

countries – such as French nuclear power or Polish lignite – is unfounded. On the contrary, the coal phaseout would also advance the decarbonization of Europe.

Currently, part of Germany's coal-fired electricity is being exported abroad. Such imports are only economical for purchasing countries if the imported electricity cannot be generated more cheaply domestically. This is why this electricity does not compete with domestic nuclear or lignite power plants. Instead, it primarily replaces the lower-emission gas power plants in purchasing countries.²⁴ A decline in German coal-fired power generation is therefore likely to cause additional generation from gas power plants in Europe outside Germany, but not from nuclear or lignite power plants, which are already running at full capacity. In addition, there is extra incentive for expanding renewable energy because the option of cheap imported German coal-fired electricity would no longer be available.

The model results reflect this market mechanism (see Figure 3). It becomes obvious that even a rapid coal phaseout in Germany in 2030 would not lead to intensified use of nuclear power in France or coal in Poland, for example. Instead, more gas power plants would be used, forcing an expansion of renewable energy capacity and demand-side flexibility and storage – neither represented here. The same applies to the other neighboring countries. In sum, an accelerated coal phaseout in Germany would yield only a negligible increase of coal-fired generation in neighboring countries in 2030 – equal to around 0.6 to 2.1 percent of the German reduction of coal use.

Accordingly, the emissions from power generation within the European Union would also change. In comparison to the reference scenario, carbon emissions would be reduced by around ten percent to 465 million tons or 15 percent to 435 million tons via the moderate path, with a simultaneous reduction in annual operating time. Via the rapid path, a reduction by 17 percent in comparison to the reference would be possible.²⁵

Technology mix with renewable energy and demand-side management instead of coal

The two accelerated paths for German coal phaseout have effects on the cost-efficient mix of generation technologies calculated in the model.

Until 2020, the proportion of variable renewable electricity generation from wind and photovoltaics in Germany will increase as assumed. The benefit of flexibility in the electricity system will increase, resulting in an expansion of facilities that provide demand-side flexibility (demand-side

²³ A small proportion of the CO₂ emissions assigned to "others" likely stems from small distributed resources and cannot be attributed to a specific source. This proportion enters the model exogenously, extrapolated to 2020 and 2030 according to the German government's reduction targets. See Federal Environment Agency, "Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990 – 2016," (2017) (in German; available online).

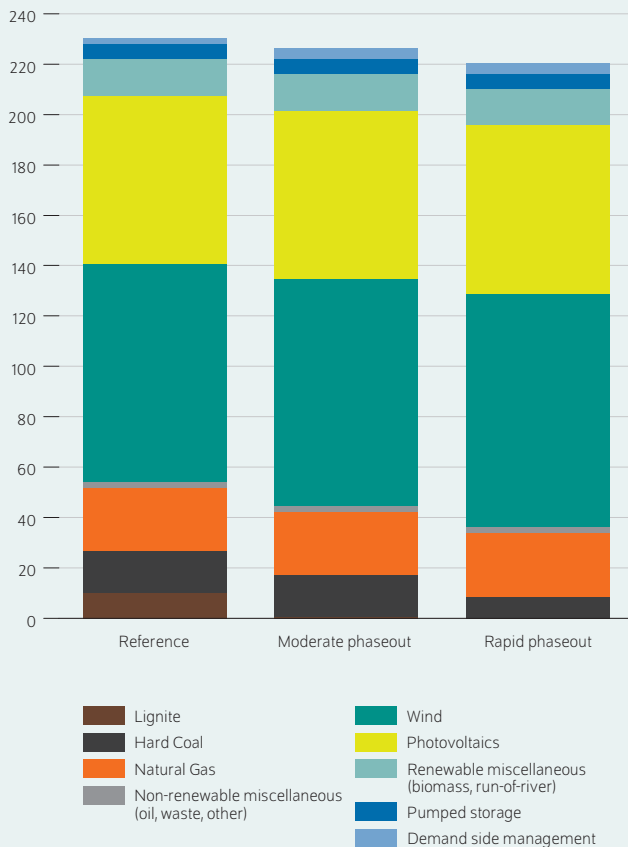
²⁴ Agora Energiewende, "Kohleausstieg, Stromimporte und -exporte sowie Versorgungssicherheit," (2017) (in German; available online).

²⁵ This is a combination of a reduction in emissions by 116.7 million tons of carbon in Germany and a slight increase of 26.0 million tons of carbon abroad caused by the shift in generation to low-emission technologies.

Figure 4

Capacity mix in Germany in 2030, under the reference scenario and the two accelerated phaseout paths

In gigawatts



Source: Authors' own calculations.

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Renewables, storage, and demand side management support an accelerated coal phaseout.

management) by around two gigawatts. In comparison to today's situation, none of the phaseout paths considered includes an expansion of thermal power plants, but old plants totaling 3.9 gigawatts will be shut down due to age.²⁶

The trend will continue in 2030 (see Figure 4). As a result of the age-based culling of plants, the complete phaseout of nuclear power, and switching off coal-fired power plants in accordance with the phaseout paths, output from conventional generation will continue to decline in Germany.²⁷ There is also a degree of interaction between the phaseout paths and expanding the capacities to provide flexibility: the proportion of variable renewable capacities increases, and the output of controllable generation units declines. This

boosts the cost-optimized potential of load management on the accelerated phaseout paths by a further two gigawatts to arrive at a total of four.²⁸

Instead of continued coal-based electricity, the energy system will expand towards renewable energy sources. According to the model, the calculated mix of technologies for generation and flexibility options in Germany and Europe will cover total European demand for electricity and Germany's peak load as well. In order to safeguard the supply of electricity for possible extreme situations that exceed what we already mapped in the model, a number of further energy policy instruments are available.

First, lawmakers can boost supply- and demand-side potential to make the market more flexible. Large-scale battery storage systems are one example and similar demand-side management instruments can also be applied.²⁹ Synergy effects in the European electricity grid could be mined as an additional means of safeguarding Germany's supply. In the calculated, cost-optimized energy system and other calculations,³⁰ Germany's import level at the borders to its neighboring countries will rise significantly by 2030. Both peak electricity demand and electricity generation from photovoltaic systems and wind turbines appear in different countries at different points in time. For this reason, neighboring countries with excess electricity would do well to export it to Germany. These inter-European compensatory effects can create synergies through closer electricity market integration.

And there is also the option of installing a strategic reserve³¹ – similar to the existing capacity reserve – based on mothballing the power plants that are disconnected from the grid before 2030 due to their technical age. The power plants whose fuel procurement chain could be reactivated at short notice would be the most preferable candidates. Lignite power plants are unsuitable for such a reserve mechanism because their surface mines are typically close to the plant, and when the power plant is shut down early in its life cycle, the adjacent mines are also closed and renaturated.³²

Due to politically desirable sector coupling, the future trends of electricity demand and peak load are marked by a certain level of uncertainty. In the wake of increased electrification of the power, heating and transport sectors, annual peak electricity demand could rise accordingly. To offset the effect, the rise in electrification should be supported by an appropriate

²⁸ To reach the specified target of 65 percent renewable energy for electricity demand, all paths showed an increase in photovoltaic capacity to 67 gigawatts by 2030. The expansion in wind power varies depending on the coal phaseout path. In the reference scenario, an additional 19.2 gigawatts of capacity will be installed, and for an accelerated phaseout of coal-based electricity 22.8 gigawatts will be added on the moderate path and 25.5 gigawatts on the rapid phaseout path.

²⁹ Federal Network Agency, "Genehmigung des Szenariorahmens 2019 – 2030," (2018) (in German; available online).

³⁰ F. Huneke, C. Perez Linkenheil, and M. Niggemeier, *Kalte Dunkelflaute – Robustheit des Stromsystems bei Extremwetter*, (2017) (in German; available online).

³¹ Karsten Neuhoﬀ et al., "Strategische Reserve zur Absicherung des Strommarkts," *DIW Wochenbericht*, no. 48 (2013): 5–15 (in German; available online).

³² From the economic viewpoint, using this instrument to safeguard against extremely rare weather situations should be subjected to a cost-benefit analysis.

²⁶ A detailed current account for 2020 is discussed in Pao-Yu Oei et al., "Effektive CO₂-Minderung im Stromsektor."

²⁷ Only the rapid path delivered a moderate addition of gas power plants with a total of 165 megawatts in comparison to the reference scenario.

Table 2

Plant-specific phaseout paths for NRW, lignite

	Reference	Moderate phaseout	Rapid phaseout
Niederaußem C	until 2025	until 2020	until 2020
Niederaußem D	until 2025	until 2020	until 2020
Weisweiler E	until 2030	until 2020	until 2020
Weisweiler F	until 2030	until 2020	until 2020
Weisweiler G	until 2030	until 2025	until 2020
Weisweiler H	until 2030	until 2025	until 2020
Neurath A	until 2030	until 2025	until 2020
Neurath B	until 2030	until 2025	until 2020
Niederaußem G	until 2030	until 2025	until 2020
Niederaußem H	until 2030	until 2025	until 2020
Neurath D	until 2030	until 2025	until 2025
Neurath E	until 2030	until 2030	until 2025
Niederaußem K	after 2030	until 2030	until 2025
BoA 2 / Neurath F	after 2040	until 2030	until 2030
BoA 3 / Neurath G	after 2040	until 2030	until 2030

Source: Authors' own depiction.

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On the accelerated paths, almost all lignite power plants in NRW will be shut down by 2030.

Table 3

Plant-specific phaseout paths for NRW, hard coal

	Reference	Moderate phaseout	Rapid phaseout
Gersteinwerk K2	until 2020	until 2020	until 2020
Bergkamen A	until 2030	until 2030	until 2025
Ibbenbüren B	until 2035	until 2035	until 2030
Heyden 4	until 2035	until 2035	until 2030
Walsum 9	until 2035	until 2035	until 2030
Herne 4	until 2035	until 2035	until 2030
Walsum 10	after 2040	until 2040	until 2040
Trianel-Kraftwerk Lünen	after 2040	until 2040	until 2040
Westfalen D	after 2040	until 2040	until 2040
Westfalen E	after 2040	until 2040	until 2040

Source: Authors' own depiction.

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On the accelerated paths, most hard coal power plants in NRW will be shut down by 2030.

technological, market-related, and regulatory framework. By avoiding simultaneously high demand for electricity from multiple sectors, an increase in peak load could be minimized or prevented entirely.³³

North Rhine-Westphalia, a key state for the energy transition, not tapping its full potential

As a traditional energy sector player, the state of North Rhine-Westphalia is key for the energy transition. Despite the high standards set by its climate protection laws, their effective

implementation has fallen short of their full potential. This is reflected in the state's apparent unwillingness to let go of coal-based electricity and its reluctance to expand its renewable energy capacity. In particular, the state's government is following an initiative that would severely restrict the land available for wind farms by implementing strict rules on location.³⁴

Climate protection in North Rhine-Westphalia requires intensified expansion of renewable energy...

However, energy economic calculations based on the state's climate protection show that to reach the climate protection targets in NRW, the electricity sector must be converted from fossil fuels to renewable technologies to the greatest possible extent.³⁵ The climate protection target for 2050 – an emission reduction of 80 percent against the base year 1990³⁶ – can only be met by expanding renewable energy to at least 80 percent of power generation in the year 2050.³⁷

Under Article 6 of the climate protection law, the climate protection plan must be updated every five years. The government of NRW will have to present an update in 2019. Right now, it is not clear how the planned climate protection targets will be met.

...and an accelerated phaseout of coal

The coal phaseout paths described above can be directly applied to the federal state level. In the area of lignite, first the older, more emission-intensive power plants will be shut down and the retirements will affect Germany's three lignite regions equally. This means that on the moderate path, all lignite power plants in the Rhine region in NRW should be shut down by 2025 at the latest, with the exception of three comparatively new power plant blocks Niederaußem K and Neurath E, BoA 2, and BoA 3. Via the rapid phaseout path, only the two most modern blocks in Niederaußem (BoA 2 and 3) would be operated until 2030 (see Table 2).

The phaseout of coal-based electricity in NRW is accompanied by the end of mining for hard coal, whose fate will finally be sealed in December 2018 when the last two mines (Ibbenbüren and Prosper-Haniel in Bottrop) will close. Since the 1950s, hard coal production in NRW and Germany's other regions has not been economical, requiring significant support from government subsidies.³⁸ The remaining

³⁴ The cabinet has resolved changes to the state development plan (*Landesentwicklungsplan*, LEP), including one that stipulates a minimum distance of 1,500 meters from residential areas for wind turbines – "to the extent such a restriction is permitted by federal law." The duty to earmark wind priority zones (*Windvorrangzonen*) was repealed and restrictions were put on setting up wind turbines in forests. See Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen, "Kabinett billigt Änderungen am Landesentwicklungsplan," (2018) (in German; available online).

³⁵ See Wuppertal Institute, "Zusammenfassung der Szenarioberechnungen des Beteiligungsprozesses," (2014) (in German; available online).

³⁶ Ministerium des Innern des Landes Nordrhein-Westfalen, "Klimaschutzgesetz Nordrhein-Westfalen."

³⁷ The upper target of the climate protection law can be met with electricity generated by renewable energy sources only, which would mean a 95-percent reduction in greenhouse gas emissions.

³⁸ Philipp Herpich, Hanna Brauers, and Pao-Yu Oei, "An historical case study on previous coal transitions in Germany," (2018) (available online).

³³ Federal Network Agency, "Sechster Monitoringbericht."

hard coal-fired power plants will be supplied with imported coal only as of 2019.

The paths for the hard coal phaseout in NRW indicate step-by-step closure between 2030 and 2040 (moderate phaseout) or between 2020 and 2040 (rapid phaseout) (see Table 3). This largely corresponds to the age-related phaseout along the reference scenario such that deviations from it which would require special policy measures are practically non-existent. Due to the lower carbon emissions in comparison to lignite and the lower number of expected full-load hours, hard coal power plants make a limited contribution to carbon emissions.

Significant climate protection effect of coal phaseout in North Rhine-Westphalia

Because total coal combustion is responsible for around 56 percent of energy-related emissions in NRW,³⁹ a shutdown would significantly improve the state's climate footprint.⁴⁰ Shutting down lignite power plants via the moderate phaseout path would reduce the emissions due to coal combustion by approx. 40 percent by 2030 in comparison to the reference scenario. An additional limit on the annual operating time of the remaining coal-fired power plants would bring a 64-percent reduction. At approx. 69 percent, this result would be surpassed only slightly by a rapid phaseout. Compared to 2014, this implies a 75 percent reduction of coal-related emissions on the moderate phaseout path, 87 percent on moderate phaseout path with a limit on annual operating time, and 90 percent on the rapid phaseout path.

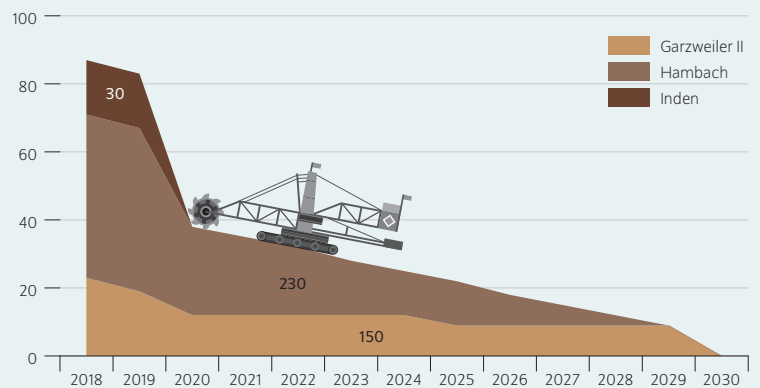
Lignite phaseout would benefit landscape and environmental protection

In addition to emissions, the coal phaseout would reduce the negative effects involved in mining lignite. In this regard, due to the current plans for surface mines Garzweiler II and Hambach, the proper volume of removal is a topic of heated debate. An accelerated coal phaseout in North Rhine-Westphalia would also mean a reduction in the amount of lignite mined. In total, a coal phaseout would sharply reduce demand for lignite, eliminating the need to mine the total lignite supply in the Inden, Garzweiler II, and Hambach surface mines (see Figure 5).

The rapid phaseout path would extend Garzweiler II only to highway A61 in order to mine another 150 million tons of lignite in total by 2025 (see Figure 6). As a result, only around one-fifth of the original volume of coal would be mined. Realizing the path would mean that the villages of Keyenberg, Kuckum, Unterwestrich, Oberwestrich, and Berwerath would not be engulfed by the progress of the mine after all. In Hambach as well, lignite surface mining would be limited

Figure 5

Amount of lignite mined in NRW on the rapid phaseout path in million tons



Source: Authors' own depiction, based on Pao-Yu Oei et al., "Braunkohleausstieg – Gestaltungsoptionen im Rahmen der Energiewende," DIW Berlin Politikberatung kompakt, no. 84 (2014) (available online).

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Mines Inden, Garzweiler II, and Hambach can provide the amount of coal required until the complete phaseout.

to 230 million tons via the rapid phaseout path. The coal would be used to supply the Neurath and Niederaußem power plants, as well as other smaller ones. A reduction in the volume mined would mean that Hambach Forest would not have to be cleared, avoiding a highly controversial measure from the viewpoint of environmental protection.⁴¹ Since Inden only serves the supply of the Weisweiler plant, the mine can be closed when the power plants shut down in 2020 on the rapid phaseout path.

Conclusions

Without a coal phaseout in Germany, the country will neither meet its climate targets nor can the required conversion to an electricity and energy system based on renewable energy succeed to the greatest extent possible. For these reasons, the coal phaseout is currently a subject of intense political debate. The Coal Commission is expected to present concrete recommendations by the end of this year.

Given these circumstances, the present report examines paths toward coal phaseout in Germany with different targets, visualizing its effect on carbon emissions based on detailed model calculations. The calculations show that if no power plants are shut down other than the ones that have completed their technical service life, Germany will miss its targets for reducing carbon emissions in the energy industry in both 2020 and 2030.

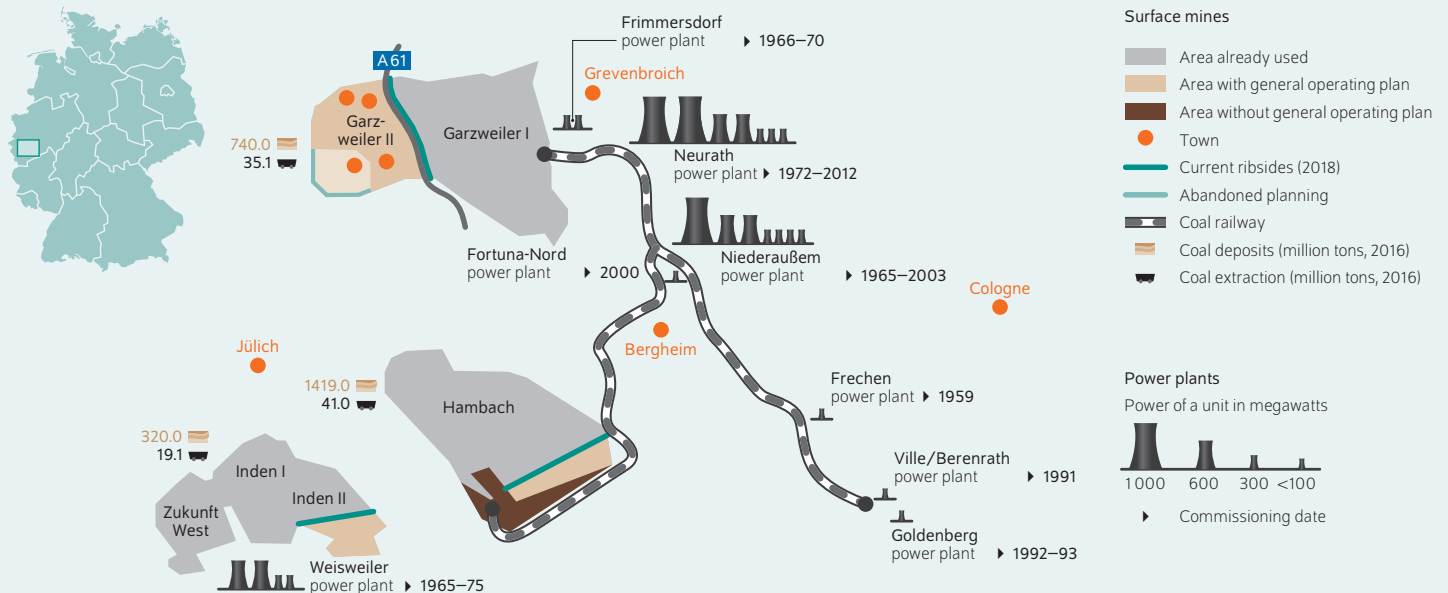
³⁹ Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen, Energiestatistik NRW, 2018 (in German).

⁴⁰ The figures refer to a comparison with 2014 since emissions figures were not published for subsequent years.

⁴¹ BUND, Friends of the Earth Germany, is currently petitioning to declare Hambach Forest a Natura 2000 region because the forest meets all the technical criteria included in the European Union's Habitats Directive (in German; available online).

Figure 6

Rhineland lignite mining area, current ribsides of surface mines Garzweiler, Hambach, and Inden, and future development according to current plans without a coal phaseout in North Rhine-Westphalia



Source: Authors' own depiction, based on Clemens Gerbaulet et al., "Die Zukunft der Braunkohle in Deutschland im Rahmen der Energiewende," DIW Politikberatung kompakt, no. 69 (2012) (available online); Öko-Institut, "Die deutsche Braunkohlenwirtschaft. Historische Entwicklungen, Ressourcen, Technik, wirtschaftliche Strukturen und Umweltauswirkungen," Study on behalf of Agora Energiewende and European Climate Foundation (2017) (available online).

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The coal phaseout can be designed such that the mine Garzweiler II would not absorb any villages and the forest in Hambach would be saved.

In an accelerated, moderate phaseout, an additional three gigawatts of power plant capacity would be shut down by 2020 and total coal capacity would be reduced to 17.1 gigawatts in 2030. In an accelerated, rapid phaseout, coal power plants with a total capacity of seven gigawatts would be shut down and total capacity reduced to 8.6 percent by 2030. The rapid path enables the climate targets in the energy sector to be met by 2030. The moderate path only enables this if in addition, the annual operating time of old coal plants is limited. At the same time, the more ambitious the path, the better it can compensate for missed targets in other sectors and contribute to meeting cross-sectoral emissions targets.

Contrary to frequently expressed concerns, the positive effects will hardly be evened out by opposing effects in other European countries. On the contrary, the model results indicate that an accelerated coal phaseout would create incentives for energy system decarbonization. In total, an accelerated coal phaseout would reduce carbon emissions in Europe by up to 17 percent in 2030.

In the framework of the energy transition, the federal state of North Rhine-Westphalia plays a special role. First, the majority of coal-fired power plants are located in NRW and the state is the largest carbon emitter in Germany. For these reasons, NRW should be actively committed to a coal phaseout. Lignite-fired power plants should be shut down by

2030 and those fired by hard coal by 2040 at the latest. And the potential of renewable energy should be tapped much more intensively than is currently the case. Depending on the accelerated path, coal emissions would decline by between 75 and 90 percent in comparison to 2014, in turn causing an up to 50-percent decrease in the energy-related emission of greenhouse gases in NRW. The state government should take these findings into consideration for its 2019 update of the climate protection plan and accelerate its expansion of renewable energy sources.

In addition to reducing emissions, the coal phaseout would reduce the negative effects of mining lignite. The phaseout of lignite mining in NRW should be designed such that surface mine Garzweiler II would no longer absorb any villages and the forest in the Hambach surface mine, which is worthy of conservation, would also be saved.

It would be economically beneficial to phase out coal-based electricity due to the high negative externalities associated with coal mining and electricity. The framework conditions for converting Germany's supply of electricity should be created now. The federal government should mandate an accelerated coal phaseout accompanied by the accelerated conversion of the electricity system to accommodate renewable energy sources. It will be necessary to include storage, potential demand-side management, and intensified European integration in the considerations.

Leonard Göke is a guest researcher at the Department of Energy, Transportation, Environment at DIW Berlin and a research associate at the Workgroup for Economic and Infrastructure Policy at Technische Universität Berlin | lgoeke@diw.de

Martin Kittel is a guest researcher at the Department of Energy, Transportation, Environment at DIW Berlin and a research associate at the Workgroup for Economic and Infrastructure Policy at Technische Universität Berlin | mkittel@diw.de

Claudia Kemfert is head of the Department of Energy, Transportation, Environment at DIW Berlin and Professor of Energy Economics and Sustainability at the Hertie School of Governance | ckemfert@diw.de

Casimir Lorenz is a research associate at the Department of Energy, Transportation, Environment at DIW Berlin | clorenz@diw.de

Pao-Yu Oei is a guest researcher at the Department of Energy, Transportation, Environment at DIW Berlin and a researcher at the Workgroup for Economic and Infrastructure Policy at Technische Universität Berlin | poei@diw.de

Christian von Hirschhausen is research director at DIW Berlin and a professor of Economic and Infrastructure Policy at Technische Universität Berlin | chirschhausen@diw.de

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