Impacts of a UK and German coal phase-out on the electricity mix and CO_2 emissions in Europe

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Highlights

- An early phase-out of coal and lignite leads to higher imports and higher electricity wholesale prices in Germany. The carbon emissions are reduced in the long-term.
- The impact of a coal phase-out in the UK does not have a major impact on the UK electricity mix and wholesale prices.
- In a framework that is already suitable for energy transition, i.e. high CO_2 prices and renewable targets, a coal phase-out in Germany and the UK has very little additional impact on total European emissions.

Coal power in UK and Germany

In Germany and the United Kingdom, coal accounts for a significant share of the total electricity production. Transmission entry capacity of coal-fired plants in the UK was 20 GW in 2014, i.e. 26% of the total transmission entry capacity[1], and represents 30 % of the generation. In Germany, the production of lignite and coal power plants in 2015 represented respectively 24 % and 18 % of the total gross electricity generation[2]. In spite of this relative importance of coal, the Department of Energy and Climate Change of the United Kingdom (DECC) announced in November 2015 plans to close all coal-fired power stations by 2025 and a consultation will be launched in that regard in spring 2016[3]. The UK is the first major economy to put a date on shutting down coal-fired power plants.

According to the fourth monitoring report[4], Germany won't be able to reach its 2020 GHG emission reduction goal of a 40% reduction compared to 1990 and therefore considers an early phase-out of its coal-fired power plants. It has already been decided to move eight lignite power plants with a total capacity of 2.7 GW into a strategic reserve, the so-called climate reserve, and to decommission them until 2023. Therefore, a significant share of coal in the total energy production of both countries will have to be replaced by other production means. Considering this, questions arise regarding a coal phase-out:

- What could be the economic impacts of these decisions, e.g. on electricity prices?
- What is an ideal future electricity mix which is compatible with renewable energy (RES) targets while still

[1] Department of Energy and Climate Change (2015). Digest of United Kingdom Energy Statistics.
[2] AG Energibilanzen (2016).
[3] Department of Energy & Climate Change (18. November 2015). Government announces plans to close coal power stations by 2025.
[4] Federal Ministry for Economic Affairs and Energy (November 2015). Vierter Monitoring-Bericht zur Energiewende.

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ensuring the security of supply without relying on coal-fired power plants?

- What will be the role of European market integration in compensating for this missing production?
- How do these national measures really contribute to reaching the set GHG emissions targets on a European level?

None of the existing studies on coal phase-out[5][6][7][8] considers the whole European electricity system. Therefore, in this present study, the impacts of a German and UK coal phase-out will be assessed on a European level while integrating the potential "carbon leakages" to other countries.

Scenarios for total coal phase-out

A detailed schedule (Table 1) is integrated in the modelling analysis, for the decommissioning of UK's coal power plants.

Table 1: Expected decommissioning of coal-fired power plants in the UK

Station Name	Fuel	MW	Commissioning	Expected decommissioning
Slough	Coal / biomass / gas / waste derived fuel	35	1918	2015
Ferrybridge C	Coal / biomass	980	1966	2016
West Burton	Coal	2012	1967	1 unit in 2018 1 unit in 2019 2 units in 2023
Eggborough	Coal	1960	1967	2017
Ratcliffe	Coal	2000	1968	2025
Cottam	Coal	2008	1969	2025
Longannet	Coal	2260	1970	2016
Aberthaw B	Coal	1586	1971	2025
Fiddler's Ferry	Coal / biomass	1961	1971	3 units in 2016 1 unit in 2017
Rugeley	Coal	1006	1972	2016
Lynemouth	Coal	420	1972	2016
Drax	Coal / biomass	3870	1974	2020
Kilroot	Coal / oil	520	1981	2025

However, such a schedule has not yet been developed in Germany. Moreover, the high number of affected units makes a similar work very difficult. Therefore, several scenarios have been developed, implemented and analysed applying the Perseus-EU model[9]. The phase-out scenario considers a complete phase-out of the existing coal fired power plants in Germany until 2040 starting with the oldest plants as they are assumed to be less efficient and it is more likely that they have amortized a higher share of their capital costs already. A linear phase-out scenario with a fixed capacity of 2.3 GW from either lignite or coal power plants to be decommissioned each year is integrated. Alternative scenarios based on lifetime have also been considered but deemed not necessary.

[5] Agora Energiewende (2016), Elf Eckpunkte für einen Kohlenkonsens. Konzept zur schrittweisen Dekarbonisierung des deutschen Stromsektors (Langfassung).

[6] Heinrichs, H. U., & Markewitz, P. (2015). A coal phase-out in Germany - clean, efficient and affordable? Energy Procedia (75), 2541-2547.

[7] Gross, R., Speirs, J., Hawkes, A., Skillings, S., & Heptonstall, P. (2014). Could retaining coal lead to a policy own goal? Modelling the potential for coal fired power stations to undermine carbon targets in 2030. Imperial College London.

[8] Johnson, N., Krey, V., McCollum, D. L., Rao, S., Riahi, K., & Rogelj, J. (2014). Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants. *Technological Forecasting & Social Change* (90), 89-102.

[9] Heinrichs, H. U. (2014). Analyse der langfristigen Auswirkungen von Elektromobilität auf das deutsche Energiesystem im europäischen Energieverbund. Karlsruhe: KIT Scientific Publishing.

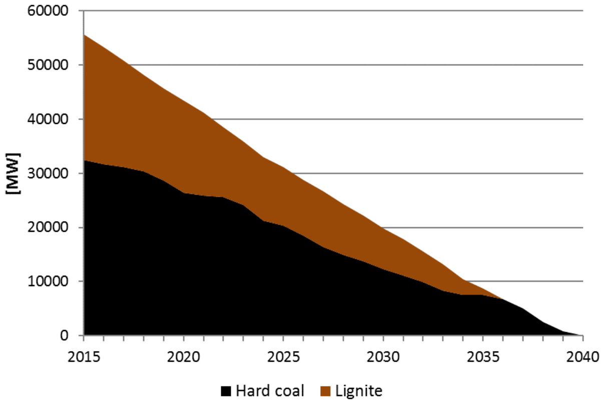

Figure 1 shows the framework assumptions for the decommissioning schedule of existing lignite and hard coal capacities in Germany.

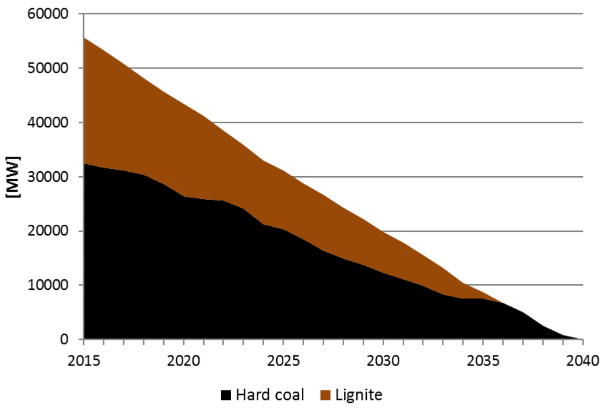

Figure 1: Coal phase-out assumptions in Germany

In addition to the phase-out scenario, a base scenario allowing investments in new lignite and coal fired power plants in Germany and a retrofit scenario are also modelled. In the retrofit scenario, it is assumed that the calculated lifetime (assumed to be 40 years for all steam turbines) of coal fired power plants can be extended for 10 years carrying out additional investments.

In the retrofit scenario, the lifetime extension option is endogenously chosen when it is economically feasible. These two scenarios, while not being necessarily realistic, are developed in order to comparatively assess the impacts of a coal phase-out.

Methodology and assumptions

The scenarios are analysed by applying the Perseus-EU Model (Program package for Emission Reduction Strategies in Energy Use and Supply). Perseus-EU is a long term optimising energy system model following a bottom-up approach for energy supply and demand. Three typical days (for the seasons winter, summer and transition seasons), each consisting of 24 hourly time slices[10], are used to describe the demand and to optimise the power plant dispatch. The main objective of the model, however, is the optimal planning of long-term investments in the electricity sector minimizing the total system costs.

Perseus is particularly used for different scenario analyses, especially for the impact analysis of changing framework conditions caused by political or environmental reasons. The objective of the model is to minimize total system costs under a set of technical, ecological and political constraints. Examples of important cost parameters are fuel costs for all resources and energy carriers required for energy supply, variable and fixed operating costs of power plants as well as investments in new generation units or load variation costs.

The model is a material and energy flow model, representing the electricity sector of 28 European countries (EU28 without the islands of Cyprus and Malta but including Switzerland and Norway) with a multi-periodic linear optimization approach. The hierarchical structure of the model relies on a directed graph, where all nodes are connected to each other through energy flows and gather several energy conversion units (see Figure 2). A main restriction is the energy flow balance for each model node.

[10] The applied time structure does not enable the detailed representation of fluctuations of wind and PV power generation.

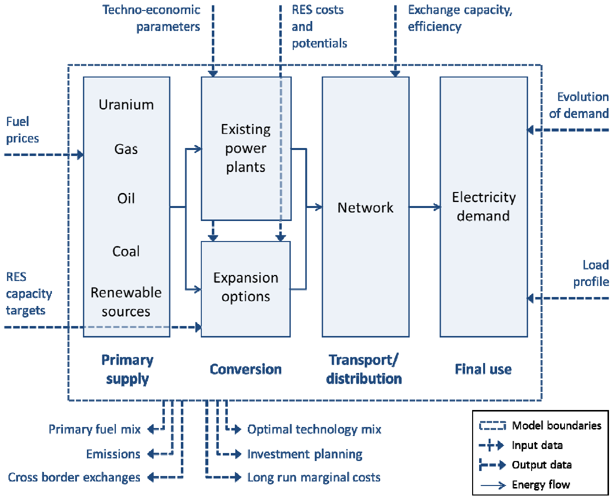

Figure 2: Structure of PERSEUS-EU

Technical parameters and equations ensure an appropriate representation of operating modes of electricity conversion processes, e.g. maximal full load hours, capacity and availability of power plants, efficiency and operation and maintenance costs. The results include among others details on the evolution of the optimal electricity mix in each country and the expected long term marginal costs of electricity generation.

Apart from those related to coal phase-out in the UK and Germany, the model framework includes a set of assumptions representing the current policy status in Europe, especially regarding RES development policies. A target of 80 % in 2050 was set for the share of renewable production in the total European electricity production. The allocation of this target among the different countries is based on cost-potentials[11]. Therefore, renewable energy sources are exploited where it is economically most feasible, regardless of national targets, in order to reach the overall European target. We chose to consider the EU ETS exogenously by integrating a CO_2 certificate price (see Figure 3) based on a reference long-term scenario for the European Union[12].

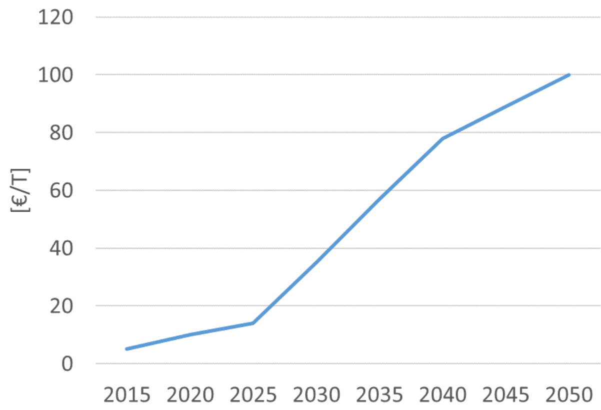

Figure 3: CO_2 price assumptions

Many uncertain parameters could not be considered in the scope of this study, which distinguishes between coal policy scenarios, but applies only one CO_2 price scenario[13].

The fuel prices are also considered exogenously based on the latest projections of the Department of Energy and Climate Change[14]. CCS has not been considered as an investment option in this study.

Selected results

We observe an increase of electricity wholesale prices over time in all scenarios for Germany (see Figure 4), mostly because of the assumptions on CO_2 certificate prices as well as higher fuel prices. The increase is more significant in the coal phase-out scenario, especially from 2025 on. However, the main drivers of the increase remain higher fuel and CO_2 prices.

[11] Scholz, Y (2010). Potenziale zusätzlicher erneuerbarer Elektrizität für einen Ausbau der Elektromobilität in Deutschland - Endbericht.

[12] European Commission. (2013). EU Energy, transport and GHG emissions - Trends to 2050 - Reference scenario 2013.

[13] Although there is a wide range of carbon price scenarios, we choose to only consider this official scenario of the European Union as the "best" assumption available.

[14] Department of Energy & Climate Change. (2015). DECC 2015 Fossil Fuel Price Assumptions.

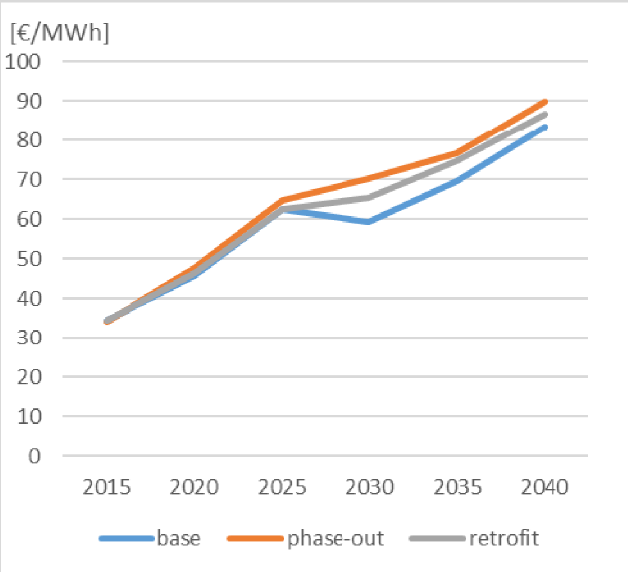

Figure 4: Electricity generation prices in Germany

The retrofit and the phase-out scenarios converge in the long-term. In the retrofit scenario, the investments for lifetime extension of power plants are carried out only in the first periods (until 2030). Afterwards, high CO_2 certificate prices deter any investments in coal and lignite fired power plants. In the base scenario, however, prices are lower as Germany can still produce electricity with existing coal power plants as well as old and new lignite capacity.

Overall, it can be stated that in all scenarios, fossil generation is progressively replaced with renewable energy sources, mostly with wind power (both onshore and offshore) as well as with higher imports (see Figure 5). Hence, the European integration plays an important role in compensating the German coal phase-out. Higher imports are a plausible result in light of the high environmentally related constraints in all scenarios, i.e. high CO_2 certificate prices and renewable targets. It should be reminded on the latter that in the modeling approach only a European, technology-neutral target is applied and no specific targets for each country and each energy carrier, except for already installed capacity. Therefore, wind is usually the preferred option, while PV is only developed in countries where the insolation is more favorable to PV generation. If we consider specific targets for PV in Germany, it could change the result that Germany becomes an import country.

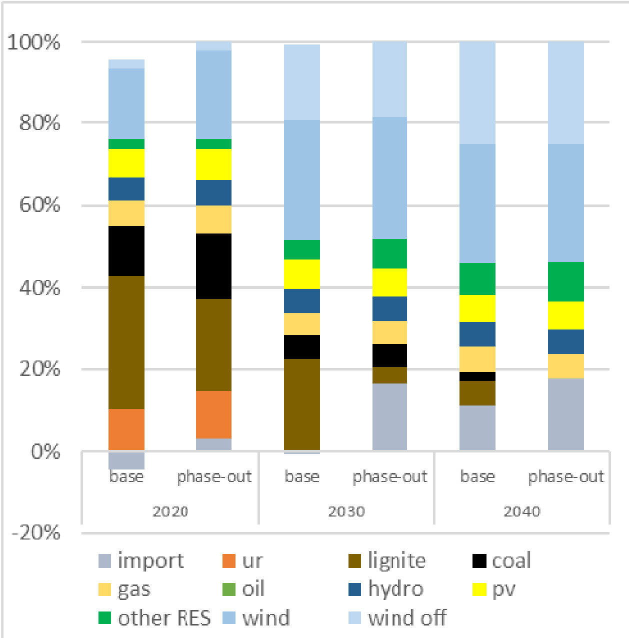

Figure 5: Electricity production mix in Germany

Germany's emission reduction targets are 40 % until 2020 compared to the levels of 1990 and the electricity sector is expected to contribute at most. But in all scenarios, the German electricity sector will not reach a 40% emission reduction in 2020 (see Figure 6). However, in the long-term, emission reductions are clearly higher in the phase-out scenario. Finally, it is worth mentioning that this result has to be interpreted taking into account the assumptions made for CO_2 certificate prices.

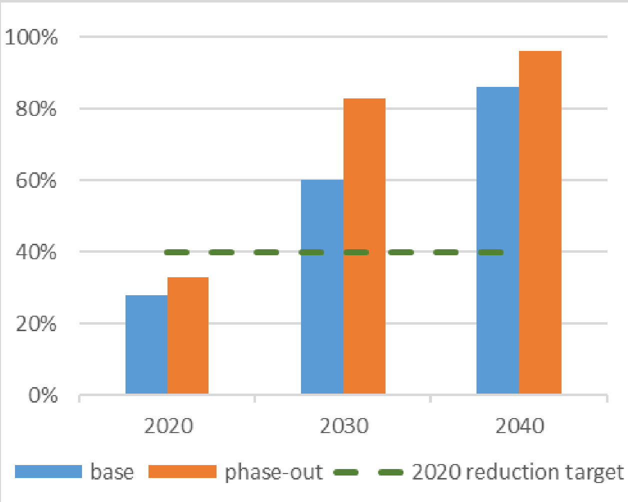

Figure 6: CO_2 emission reductions in the German electricity sector compared to 1990 levels

The impact of a coal phase-out in the UK has far less significance than in Germany. The affected capacity is only 20 GW in comparison to 57 GW in Germany. Moreover, coal power plants are older on average.

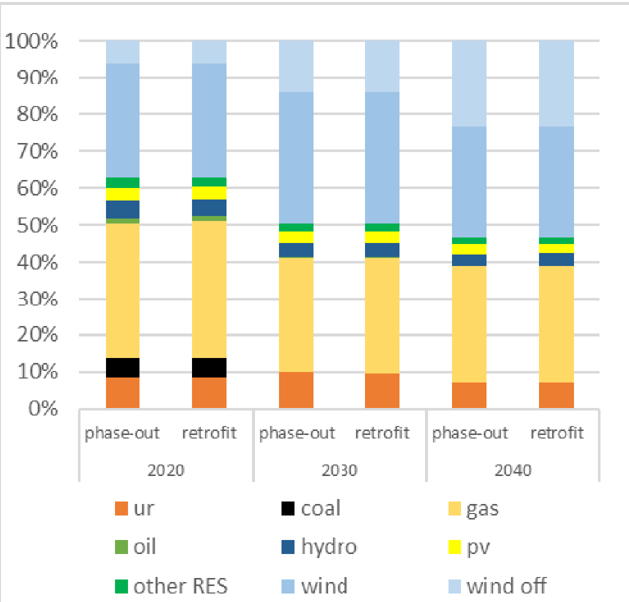

Figure 7: Electricity capacity mix in United Kingdom

In the retrofit scenario no coal power plants are retrofitted due to high fuel and carbon prices. Coal is mostly replaced by wind generation (see Figure 7), while gas power plants are used as back-up capacity. Under the chosen framework conditions and model assumptions, some additional nuclear power plants are also commissioned. In general, differences between scenarios are not significant in the UK. Prices are very similar throughout the time horizon and the amount of CO_2 emissions is more or less identical as well.

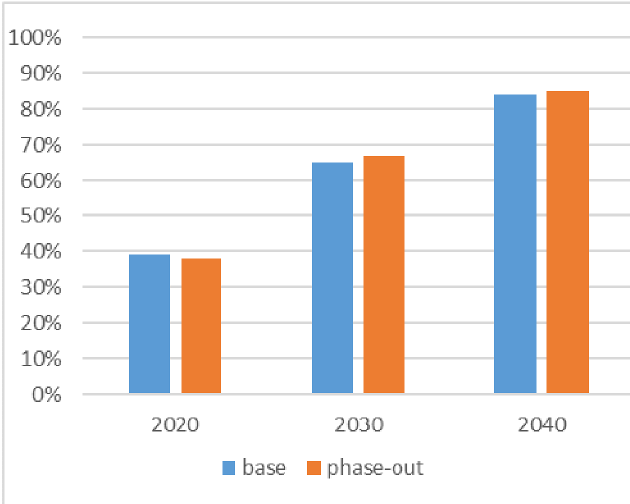

Figure 8: Emissions reductions in the European electricity sector compared to 1990 levels

Without considering the European cap, but using a CO_2 price path, there is only a very little additional reduction of total European CO_2 emissions in the phase-out scenario (see Figure 8). The decrease of the German emissions is partly compensated by increased emissions in other countries. 50% to 70% of the CO_2 emissions that are additionally reduced in Germany between 2020 and 2040 due to a coal phase-out are replaced by higher emissions elsewhere.

Conclusions

Based on the modelling results, it can be concluded that renewable generation increases and represents the highest share of electricity generation in Europe in 2040, in all scenarios, with or without a coal phase-out. Fossil production becomes more and more expensive due to environmental constraints and higher fuel prices. Thus, electricity wholesale prices increase over the time horizon in all scenarios.

The price increase is higher for Germany, as an early phase-out of coal and lignite leads to higher production costs forcing Germany either to build new power plants or to cover its demand by imports. New investments in coal-based generation are not encouraged in the long-term, even in the scenario without coal phase-out because of the assumed high CO_2 price path and limited full load hours due to high renewable feed-in. In the applied phase-out scenario, the 2020 targets cannot be reached, but the emission reductions in Germany are higher in the long-term. Therefore, it can be stated that a German phase-out would have a significant effect on the national emissions.

In the UK, a coal phase-out has a lower influence on the market. Coal power plants are expected to be replaced mainly by higher wind generation and gas power plants as back-up capacity. Under the chosen framework conditions, also some nuclear capacity is constructed. However, retrofit options (with different cost and efficiency rates) and other investments options including CCS should be addressed by future research.

Furthermore, it can be concluded that in a framework which is already suitable for energy transition, i.e. high CO_2 prices and renewable targets, a coal and lignite phase-out in Germany and the UK has very little additional impact on overall European emissions. The coal phase-out in these two countries leads to a "carbon leakage" within Europe. To reach an additional reduction of total emissions, a coordinated carbon or coal policy should be followed at European level.

Finally, it is worth mentioning that another set of assumptions may lead to different model results, e.g. more significant deviations of the total European carbon emissions in the different scenarios. Therefore, this study could be extended in order to analyze the sensitivity of the results depending on some important and particularly uncertain parameters. Renewable extension targets of the countries could be integrated and different framework assumptions could be used for carbon emissions, such as different price paths or a more constraining CO_2 cap.