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A coal phase-out in Germany – clean, efficient and affordable?

Heidi Ursula Heinrichs[a],*, Peter Markewitz[a]

[a]*Institute of Energy and Climate Research, System Analysis and Technology Evaluation (IEK-STE),Forschungszentrum Jülich, Wilhelm-Johnen-Straße,52425 Jülich, Germany*

Abstract

Germany seems to miss its CO_2 reduction target in 2020. Due to this, ideas for additional political measures arise. One of them is an early phase-out of coal power plants. However, possible impacts of such a phase-out on the energy system aren't fully analyzed yet. Therefore we apply a German energy system model to analyze those impacts. Our three scenarios show that a final coal phase-out until 2040 could reduce CO_2 to a certain extent, but increases total costs. However, an equal CO_2 reduction can be obtained with a different strategy and lower costs. In the latter scenario the additional costs are distributed in addition more evenly across the sectors. This analysis points out which consequences could arise by excluding several options in parallel from a technology portfolio.

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Keywords: coal phase-out; CO_2 reduction; energy system model; Energiewende

1. Introduction

The German Government aims to reduce the greenhouse gas emissions by 40% until 2020 and by 80% - 95% until 2050 compared to 1990. To achieve this goal the government developed an energy concept [1, 2] which describes a variety of measures and instruments. In parallel a monitoring process has been implemented which examines the progress and impacts of the implemented activities and measures. Compared to 1990 the German CO_2 emissions have been reduced by nearly 20% until 2012 [3]. Nevertheless according to the second monitoring report [4] the reduction goal for 2020 cannot be achieved. This brings up a debate about choosing and implementing additional CO_2 reduction measures. Due to the fact that nearly 38% of Germany's total CO_2 emissions originate from fossil fired power plants [3], some political parties proposed an early phase-out of hard coal and lignite fired power plants [5-7].

* Corresponding author. Tel.: +49-2461-619166; fax: +49-2461-612496.
E-mail address: h.heinrichs@fz-juelich.de.

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Nomenclature

IEA	International Energy Agency
IKARUS	Instrument for Climate Reduction Strategies
TIMES	The Integrated MARKAL-EFOM System
BAU	Business-as-usual scenario
COUT	Coal phase-out scenario
CAP	Scenario with a CO_2 cap

However, possible impacts of such a phase-out on the energy system aren't fully analyzed yet. Those impacts could affect for instance CO_2 emissions as well as system costs and their sectoral distribution due to interdependencies between the sectors of the energy system. That is highly relevant insofar as in an energy system beside affordability (economy) and security of supply are as important as climate protection (ecology) in the long run. Therefore we apply a full German energy system model described in section 2 to analyze those impacts of a coal phase-out. Section three addresses the coal phase-out strategies we take into account and the underlying assumptions. Subsequently we discuss the results of our model-based analysis regarding the adequacy of a coal phase-out against the background of the German energy system transformation process so called "Energiewende".

2. The energy system model IKARUS

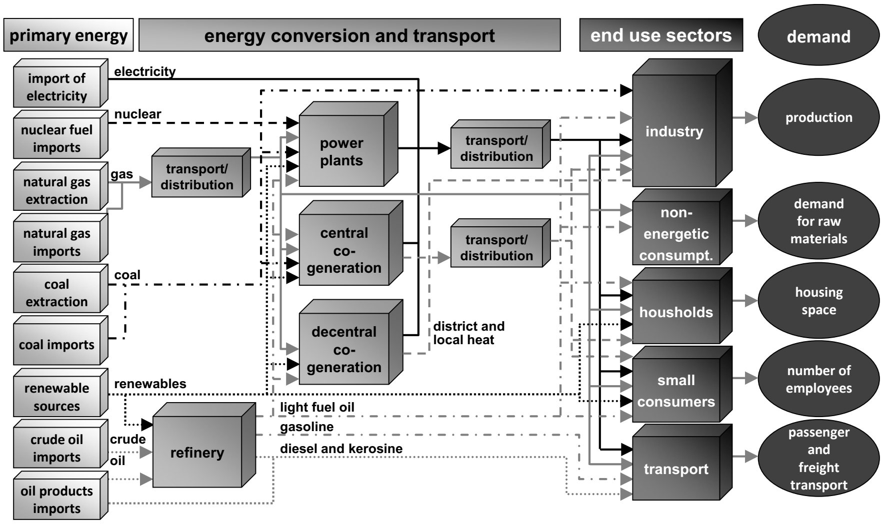

Fig 1. Schematic of the model structure in IKARUS

IKARUS is a techno-economic bottom-up model of the German energy system comparable to TIMES models [8]. It maps the energy system as a chain of transformations regarding technical, economic and ecological parameters to satisfy demands for energy services. This energy chain shows a detailed representations of the technological options and ranges from the primary energy supply to energy services and covers all intermediary sectors as shown in Fig. 1. The demands for energy services constitute the driving forces of this linear optimization model. The objective function of this optimization minimizes the discounted global costs of the energy system. The covered time horizon till 2050 is divided into 5-year intervals which are optimized sequentially. This means that this myopic optimization considers the provided results of the previous periods (i.e. capacity expansions), but does not take into account full information till 2050 in each time step. A full documentation of IKARUS can be read up in [9] while applications to some specific themes are described in [10-11].

3. Coal phase-out scenarios and basic assumptions

In the following we analyze three different strategies regarding hard coal and lignite power plants. We assume in all scenarios that power plants which are actually under construction will be commissioned in the near future. In addition we expect that no new plants will be constructed. In the first scenario BAU the power plant will be decommissioned according to their typical technical lifetimes of 50 years for lignite power plants and 45 years for hard coal power plants respectively. These lifespans have been typical in the recent decades in Germany. This leads to a remaining coal based capacity of approximately 13 GW (4,5 GW lignite, 8 GW hard coal) in 2050 (cf. Fig. 2). In scenario COUT we describe a phase-out strategy according to [14], because this strategy has been used by some political decision makers arguing for a phase-out ahead of schedule [5,7]. The decommissioning strategy in [14] is based on allocations rules for residual amounts of electricity from coal fired power plants. This strategy takes into account the efficiency and the level of heat extraction for each power plant. In COUT lignite power plants phase out till 2030 and hard coal power plants till 2040. The third scenario (CAP) is based on the achieved CO_2 emission reductions in scenario COUT which are used as a CO_2 cap in this scenario. All other assumptions in CAP are the same compared to the BAU scenario.

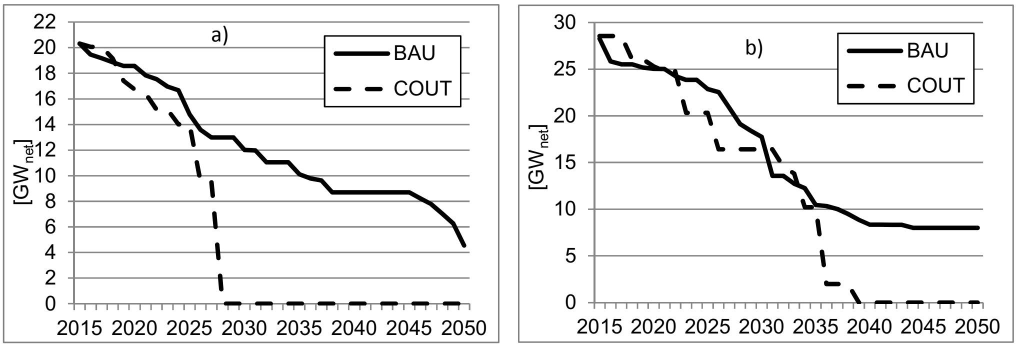

Fig. 2. Decommisioning of power plants in Germany a) lignite; b) hard coal

All three scenarios are based on the same general assumptions. One of the most important assumptions is the development of the overall population which is taken from [15] and decreases from nearly 81 million today to nearly 74 million in 2050. In addition to this a yearly growth of the German GDP of approx. 1% is assumed which distributes heterogeneously across the different industry branches and is derived from a macroeconomic input-output model. In the transport sector an increase in freight transport of roughly 50% until 2050 compared to 2020 is assumed while the demand for passenger transport remains nearly the same. The real energy carrier prices for crude oil, hard coal and natural gas are derived from [16,17] by applying the growth rate of the "current policies" IEA scenario to the current prices which leads for example to a real crude oil price of $105€_{2000}$/bbl in 2050. The underlying price of CO_2 certificates is also taken from [16] and increases to nearly $30€_{2000}$/t until 2050. Beside the nuclear phase-out [18] we apply a lower boundary for the development of renewable energy sources in accordance to the amendment to the national renewable energy act in 2014 [19].

4. Impacts of a coal-phase-out on the German energy system

In this section we show our modelling results focusing on the aspects related to a coal phase-out and its adequacy to contribute to the Energiewende. To identify the differences between the three scenarios we first look at the electricity production in coal power plants compared to the BAU scenario until the final coal phase-out in COUT in 2040 (cf. Fig. 3). While in the beginning COUT as well as CAP show a higher utilization of hard coal power plants, both scenarios show a lower electricity production in hard coal and lignite power plants in later periods. These differences between 2015 and 2050 sum up to 3,427 TWh (COUT) and 1,726 TWh (CAP) less electricity production in coal power plants compared to the BAU scenario. In the BAU and CAP scenario lignite power plants phase out in 2045 and 2040 while hard coal power plants show a substantial decline although no final phase-out. However, these results can't be translated directly into CO_2 emission reductions obtained in the COUT and CAP scenario due to the intersectoral interdependencies.

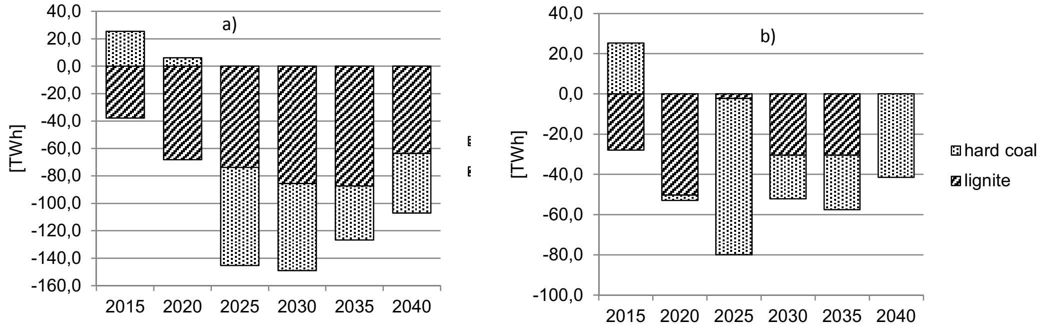

Fig 3. Differences in electricity production in coal power plants compared to BAU (a) COUT; (b) CAP

Therefore we analyze the sectoral differences in CO_2 emissions (cf. Fig. 4). The total achieved CO_2 reduction are approx. -34% (BAU) and -36% (COUT/CAP) in 2020 as well as -59% (BAU) and -60% (COUT/CAP) in 2050 compared to 1990. Though the coal phase-out in COUT (and the alternative in CAP) contributes to an additional CO_2 reduction of -2% in 2020 and -1% in 2050. The cumulative

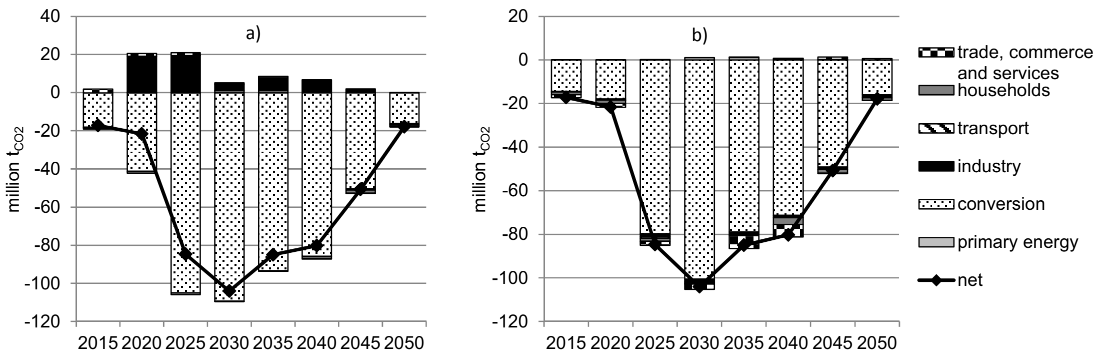

Fig 4. Sectoral differences in CO2 emissions in COUT (a) and CAP (b) compared to BAU

additional CO_2 reduction over the considered time horizon sums up to nearly 2.3 billion t_{CO2} in the COUT as well as in the CAP scenario compared to the BAU scenario. While the CO_2 reduction in COUT mainly occurs in the conversion sector due to the coal phase-out, the industry sector emits more CO_2 as a result of a shift to more decentralized generation of process heat. In CAP the other sectors also contribute in a certain extent to the CO_2 reduction even though the main part is still reduced in the conversion sector. This is also related to the additional costs occurring in COUT and CAP and their distribution across the sectors of the energy system.

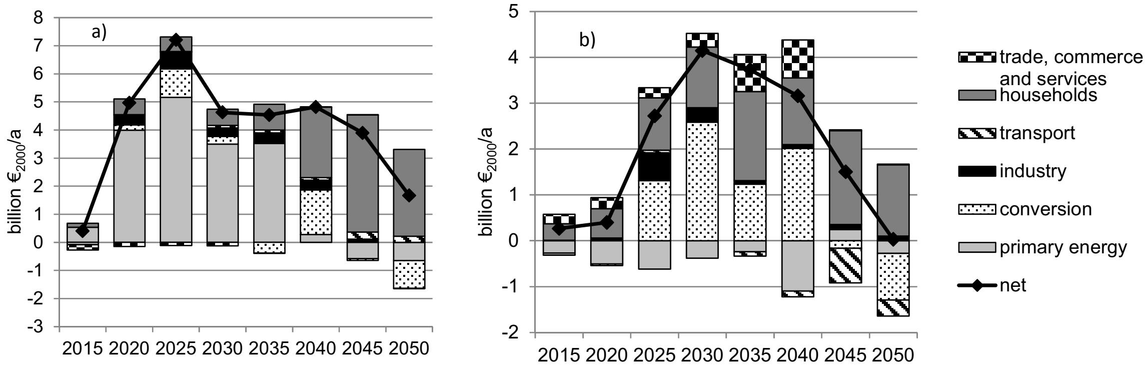

Fig 5. Sectoral differences in costs in COUT (a) and CAP (b) compared to BAU

The cumulative additional costs compared to the BAU scenario sum up to roughly 156 billion € (COUT) and 80 billion € (CAP) until 2050. These additional costs correspond to the 5.5-fold of Germany's yearly GDP growth or ~0.6% of Germany's GDP_{2013} in the COUT scenario. While in COUT the primary energy sector is mainly affected in the first periods, this changes in later periods towards the residential sector. The reasons for this are mainly an increasing demand for natural gas (substitution of coal) and more energy saving measures in the residential sector. In contrast to this, the additional costs are lower as well as more evenly distributed in the CAP scenario and mainly the conversion and residential sector are affected. Both scenarios show a peak in 2025/2030 which correlates with the nuclear phase-out in Germany in 2022.

5. Conclusions

The model-based analysis shows that an early coal phase-out in accordance with [14] can further reduce CO_2 emissions. The achieved additional CO_2 reduction in coal power plants only sums up to approx. 3 billion t_{CO2}. However, the total additional CO_2 reduction reaches 2.3 billion t_{CO2}. Beside this we also calculate an alternative scenario (CAP) with the same amount of total CO_2 reduction resulting in less system cost. This indicates that an early coal phase-out doesn't seem to be the most cost efficient way to achieve a further CO_2 reduction in Germany. This also shows the importance to analyze the energy system as a whole.

In all three scenarios a decline in electricity production in hard coal and lignite power plants can be observed until 2050. While lignite power plants even phase out in the BAU and CAP scenario (BAU:2050, CAP:2040), hard coal power plants are operated until 2050. Against this background all three scenarios can be classified as (partly) coal phase-out scenarios and COUT represents a moved up coal phase-out. However, in all scenarios the CO_2 reduction doesn't suffice for the national reduction targets of Germany. Therefore improving or extending already implemented measures like the EU emission trading system could be more promising compared to an early coal phase-out.

In this analysis we only focus on the direct impacts of a coal phase-out on the energy system. Beside those impacts it is most likely that a coal phase-out will influence other sectors as well, particularly the regional labor markets near the lignite mining sites or the share of income spent on electricity. Those impacts and barriers should also be taken into account by policy makers. These aspects exemplify which consequences could arise by excluding several options from a technology portfolio. Such measures should be chosen carefully and need a profound argument which holds true independently from the case study Germany.

6. Copyright

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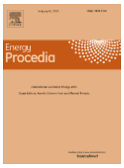

Biography

Heidi U. Heinrichs is a research associate at the Institute of Energy and Climate Research - Systems Analysis and Technology Evaluation at the Forschungszentrum Juelich. She obtained her doctoral degree at the Karlsruhe Institute of Technology and studied mechanical engineering at the RWTH Aachen University. Her main field of research is energy system analysis.