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Long-term impacts of a coal phase-out in Germany as part of a greenhouse gas mitigation strategy

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HIGHLIGHTS

- Different strategies for a coal phase-out in Germany are analyzed.
- Even in a BAU scenario, coal-fired power plants decline substantially by 2050.
- A GHG mitigation strategy without an early coal phase-out is more cost-efficient.

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ABSTRACT

Germany appears set to miss its CO_2 reduction target in 2020. As a result, ideas for additional political measures have been put forward. One such idea involves an early phase-out of coal-fired power plants. However, the possible impacts of such a phase-out on the energy system have not yet been fully analyzed. We therefore apply a German energy system model to analyze these impacts. To do so, we calculate three different scenarios. The first represents a business-as-usual scenario, while the second takes a coal phase-out into account. The third scenario has to achieve the same CO_2 reduction as the second without being forced to implement a coal phase-out. Our three scenarios show that a definitive coal phase-out by 2040 would result in only a relatively small amount of additional CO_2. However, an equal CO_2 reduction can be obtained using a different strategy and slightly lower costs. In the latter scenario, the additional costs are also distributed more evenly across the sectors. The sensitivities analyzed show the robustness of the conclusions drawn. In summary, this analysis outlines what consequences could arise by excluding several options in parallel from a technology portfolio.

1. Introduction

1.1. Motivation and background

The European Union aims to reduce its greenhouse gas emissions by 30% by 2020 and more than 80% by 2050 compared to 1990 levels. Currently, fossil-fuel power plants are the largest emitters in the EU, making up 37% of total CO_2 emissions [1]. In EU member countries with a high share of electricity production from fossil-fired power plants like in Poland, the Czech Republic, Greece or Germany [2], the percentage is even higher. Therefore, to meet the reduction goals, fossil-fired power plants play a key role in some national greenhouse gas mitigation strategies. The United Kingdom took the decision to phase out coal-fired electricity production by 2025 [3]. In other EU member countries (e.g. Denmark, Germany), the decommissioning of coal-fired power plants is still under discussion. An overview of EU mitigation strategies can be found in [4].

Efficiency improvements and increased use of renewables are the main pillars of the most greenhouse gas reduction strategies. Also CCS (Carbon Capture and Storage) technology or nuclear energy is often seen as important reduction measures [5]. Compared to these international trends Germany favors a strategy which is quite different. The German government decided to phase out of nuclear and the implementing of CCS technology is hardly possible due to legal obstacles. To meet the greenhouse gas emission goals as fast as possible different time schedules for a phase-out of coal are currently being discussed. A national overall mitigation strategy including all interactions and sectoral impacts is still missing. As Germany is the main emitter of greenhouse gases in Europe the success or failure of the German mitigation strategy will deeply affect the European greenhouse gas mitigation goals.

The German government aims to reduce greenhouse gas (GHG) emissions by 40% by 2020 and by 80–95% by 2050 compared to 1990 levels – which is more ambitious than the EU's targets. To

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Nomenclature

BAU	business-as-usual scenario
BMWi	Federal Ministry for Economic Affairs and Energy
BNetzA	Bundesnetzagentur (Federal Network Agency)
CAP	scenario with a CO_2 cap
CCS	Carbon Capture and Storage
CHP	combined heat and power
COUT	coal phase-out scenario
CP	Current Policies Scenario
CPLEX	optimizer based on the simplex method
ECOFYS	name of a German consulting firm
EEG	Renewable Energy Sources Act
EEWärmeG	Renewable Energy Heat Act
EnEV	renewable saving ordinance
EU-ETS	European emissions trading system
GDP	gross domestic product
GHG	greenhouse gas
HPV	high price variant scenario
IEA	International Energy Agency
IKARUS	instruments for greenhouse gas reduction strategies
LPV	low price variant scenario
NP	New Policies Scenario
RES	renewable energy sources
TIMES	the integrated MARKAL-EFOM system

achieve this goal, the government developed an energy concept [6,7] which encompasses a variety of measures and instruments. In addition, a nuclear phase-out will be completed by 2022, thus increasing the effort needed to achieve Germany's greenhouse gas emissions goals even further. At the same time, a monitoring process has been initiated, examining the progress and impact of the activities and measures implemented. Compared to 1990, German CO_2 emissions, which represent the major part of overall GHG in Germany, had been reduced by nearly 20% by 2012 [8]. Nevertheless, according to the second monitoring report [9], policy makers are concerned that the reduction goal for 2020 cannot be achieved. This sparked a debate about additional CO_2 reduction measures being considered and implemented. Due to the fact that nearly 38% of Germany's total CO_2 emissions originate from fossil-fired power plants [8], significant additional emissions reduction measures are expected [10]. Against this background, some political parties proposed an early phase-out of hard-coal- and lignite-fired power plants [11–13].

In 2014, approximately 44% of national electricity was produced in coal-fired power plants [14]. The capacity of coal-fired power plants amounts to 47 GW (lignite: 21 GW, hard coal: 26 GW), which represents 24% of total installed capacity in Germany [14]. Lignite power plants conventionally operate in base load mode, whereas hard coal power plants mainly operate in medium load. After the Fukushima disaster, the German government decided to phase out nuclear electricity production (2014: 97 TW h, 12 GW) by 2022. The phasing-out of coal and nuclear power (until 2022) means that 60% (370 TW h) of current total electricity production [2] must be replaced by alternative energy sources over the next decades.

1.2. Literature overview

Many studies have analyzed how to meet the ambitious goals of the German energy concept. A differentiation can be made between studies taking into account all sector interdependencies (end use, energy) [15–22] and studies [23–28] which focus only on the electricity sector. The studies taking into account all sectors focus on special topics, such as the nuclear phase-out, the role of renewables, and the role of efficiency measures. All studies include normative scenarios, which assume reduction targets over time. Ambitious CO_2 reduction goals (e.g. 80% CO_2 reduction by 2050) can be interpreted as a decarbonization of the whole energy system. To this end, reduction strategies assumed for these scenarios also include a long-term phase-out of coal electricity production. However, no study analyzes an early phase-out taking into account the different temporal developments of coal-fired power plant capacities. For these intersectoral analyses, bottom-up models are usually applied. Almost all of these models are energy system models with an underlying optimization approach (e.g. TIMES and IKARUS) which represent the whole national energy system and are able to calculate a cost-optimal GHG mitigation strategy [15,21]. In other studies [17–20,22,29], several sectoral simulation models are utilized in which the results of single sectors are combined into an integrated result. A detailed description of the model approaches applied in these studies can be found in [30].

Over the course of the recent discussion regarding the coal power phase-out, a multitude of detailed studies have been carried out focusing solely on the electricity sector and neglecting feedback to the whole energy system. Most studies apply electricity market models to analyze the impacts of a coal phase-out (cf. [24–28]), some of which do not show the underlying method used for the applied model in full detail (cf. [24,26]). In [31], no model is applied and the study focuses mainly on careful considerations as well as simulation-based estimations regarding the electricity market. Only [25] combines an electricity market model with a unit commitment model and [28] additionally analyzes the impact on the European electricity market as well as the related GHG emissions. The development of existing power plants is determined exogenously in these studies. In contrast to analyses based on energy system models, demand for electricity and district heat are also not model variables but have to be determined exogenously. The advantages of such sectoral approaches consist in a high level of detail (per single unit) in electricity generation. Admittedly, a conclusion on how to classify a measure (e.g. a coal phase-out) and its impacts as part of a national CO_2 mitigation strategy cannot be drawn. As none of the studies discussed addresses the entire energy system in Germany, they are therefore unable to analyze the impacts that may arise due to the interdependencies of the various sectors within the energy system.

1.3. Contribution of the study and paper organization

Against this background, we decided to use the optimization model IKARUS, which simulates the whole national energy system covering among others all end use sectors and the electricity generation sector. In contrast to the approaches of recent studies, which combine different models, the consistency of the results is always ensured. For example, electricity demand is an endogenous variable instead of an exogenous one. Moreover, IKARUS is suitable for calculating different decommissioning strategies of coal electricity production with a particular focus on interdependencies with other energy sectors. This allows the impacts on a national mitigation strategy to be investigated in detail.

The possible impacts of an early phase-out of coal on the entire energy system have not been analyzed in detail before. These impacts could influence, for instance, CO_2 emissions as well as system costs and their sectoral distribution due to interdependencies