Munich Personal RePEc Archive

Stranded Asset Risk and Political Uncertainty: The Impact of the Coal Phase-out on the German Coal Industry

Breitenstein, Miriam and Anke, Carl-Philipp and Nguyen, Duc Khuong and Walther, Thomas

Faculty of Business and Economics, Technische Universität Dresden, Germany, Faculty of Business and Economics, Technische Universität Dresden, Germany, IPAG Business School, France International School, Vietnam National University, Vietnam, Utrecht School of Economics, University Utrecht, the Netherlands

October 2019

Online at https://mpra.ub.uni-muenchen.de/101763/
MPRA Paper No. 101763, posted 13 Jul 2020 05:59 UTC

Stranded Asset Risk and Political Uncertainty: The Impact of the Coal Phase-out on the German Coal Industry*

Miriam Breitenstein[1], Carl-Philipp Anke[1], Duc K. Nguyen[2,3,4], Thomas Walther[1,5,†]

[1] Faculty of Business and Economics, Technische Universität Dresden, Germany
[2] IPAG Business School, Paris, France
[3] VNU International School, Hanoi, Vietnam
[4] School of Public and Environmental Affairs, Indiana University, Bloomington, USA
[5] Utrecht School of Economics, University Utrecht, the Netherlands

Abstract

We assess the value of stranded coal-fired power plants in Germany due to the critical phase-out by 2038. Within a Monte Carlo simulation, the scenarios under consideration (a slow decommissioning at the end of the technical lifetime in 2061, the highly probable phase-out by 2038, and an accelerated phase-out by 2030) are additionally assigned distributions to display the uncertainty of future developments. The results show an overall stranded asset value of €0.4 billion given the phase-out by 2038 and additional €14.3 billion if the phase-out is brought forward by eight years. This study also depicts the impacts of carbon pricing and the feed-in from renewable energy sources on the merit order and eventually the deterioration in economic conditions for hard coal and lignite power plants. Lastly, we illustrate immediate concerns for share prices of affected companies and contributes to closing the research gap between stranded physical and financial assets.

Keywords: Coal Phase-out; Energy transition; Germany; Stranded Assets
JEL Classifications: C53, L13, L94, Q38

---

* We thank Sven Loßagk, Christian Opitz, Philipp Rubner, Wolf-Peter Schill, Philipp Thaler, and Rolf Wüstenhagen for their valuable remarks and discussion. Part of the work has been conducted during Thomas Walther's research time as Assistant Professor at the Institute for Operations Research and Computational Finance, School of Finance, University of St. Gallen. This publication is part of SCCER CREST (Swiss Competence Center for Energy Research), which is supported by Innosuisse (Swiss Innovation Agency). Thomas Walther is grateful for the funding received for conducting this research.

† Corresponding author's e-mail: t.walther@uu.nl.

1 Introduction

Under the 2015 Paris Agreement, the global community committed itself to keeping global warming well below 2.0°C (UNFCCC, 2015). In its 2018 report, the Intergovernmental Panel on Climate Change (IPCC) also raised alarms regarding the potential impacts of global warming greater than 1.5°C above pre-industrial levels. It endorses the obligations set within the Paris Agreement to keep the global warming below 2.0°C and, at best, limit it to 1.5°C (IPCC, 2018). One of the crucial steps towards mitigating climate change is thus phasing out coal-fired power generation (Zhao and Alexandroff, 2019). This is especially important for Germany because on the one hand it is failing to fulfill its voluntarily set obligations, most notably its greenhouse gas emissions target for 2020 (Heinrichs et al., 2017) and on the other hand coal is the largest source of CO_2 emissions of the German energy sector (Umweltbundesamt, 2019).[3]

In order to achieve the national climate targets the German government has appointed the German Commission on Growth, Structural Change and Employment, commonly referred to as Coal Commission, to develop a national emission reduction initiative. It presented its final report in early 2019 and the future of the coal industry in Germany is a major part. Within this final report, the coal commission, that included representatives of all major stakeholders, suggested to phase-out coal-fired generation by 2038. This phase-out design is, however, in conflict with the phase-out requirements by 2030, in order to meet the 2.0°C target established during the 2015 Paris Climate Agreement (Climate Analytics, 2018). While insisting on the national phase-out of coal power generation in 2038, the commission's recommendation contradicts German voters' preferences of an early coal phase-out. Across all political parties, German voters' favor an accelerated phase-out of coal within the next five to ten years, even if additional payments amounting to €8.5 billion arise (Rinscheid and Wüstenhagen, 2019).

These current political developments raise the question how the coal-phase-out will impact the German coal industry valuation. Thereby, arising costs adversely impacting the commitment to phase-out coal can be specified as stranded assets (Jewell et al., 2019), which refer, in this

---

[3] Germany's reliance on coal was politically driven in the past, despite the liberalization of the electricity markets. Coal-fired power generation proved to be well received by the broad political spectrum merely ten years ago (Pahle, 2010). The country has then been prone to the so-called 'carbon lock-in effect', the inability to facilitate the shift towards low-carbon technologies due to its coordinated energy market and historically strong political and institutional interest in coal-fired electricity generation (Rentier et al., 2019). Since 2007, however, power generation from fossils started to decrease and at the same time generation from renewable energy sources increased benefitting from continuous feed-in tariffs. Currently, Germany enters the next phase of its energy transition, where climate change urgency requires an advanced transition towards low-carbon technologies as well as the accelerated decline of electricity generation from fossil fuels (Markard, 2018). Thus, the phase-out of coal-fired power generation is in the light of discussion.

context, to the decrease in valuation of the coal power generation industry in Germany. The decrease in valuation can be a basis for possible compensation payments that have been proposed by the coal commission to alleviate the financial impact of the coal phase out for the coal industry (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019). On the one hand, some studies argue that compensation is inevitable due to the size of the industry, which can be seen as "too big to fail" (Sen and von Schickfus, 2018). On the other hand, recent studies conclude that the coal phase-out is in line with the constitution and compensation payments are legally controversial (German Bundestag, 2018; Institute for Climate Protection, Energy and Mobility, 2018). While the industry is expecting considerable payments and is therefore against the coal phase-out,[4] especially the lawyers of environmental organizations assume that no compensation will be due (Client Earth, 2019; Leipprand and Flachsland, 2018). If no compensation payments are made to reimburse energy suppliers, the potential decrease in valuation is transferred onto financial assets. Accordingly, this study also highlights the impacts of stranded asset risk on the financial sector as well as estimates compensation payments resulting from the stranded asset value.[5]

In this study, we contribute to the related literature on stranded assets valuation by quantifying the economic, financial, and industrial impacts of the coal phase-out in Germany due to the growing concern over stranded assets. This issue is of paramount importance because the coal phase-out uncertainty would significantly affect the national energy transition policy and cost-benefit analysis of coal-related industries. To the extent that the likelihood and severity of assets stranding are strongly driven by economic (e.g. fuel and carbon prices) and political developments, a scenario analysis is proposed to examine the potential impact of the unanticipated early phase-out by 2030 (Enforcing Paris Agreement Scenario) and the scheduled phase-out of German coal-fired power plants by 2038 (Maintaining Climate Action Scenario). Our analysis also considers a reference scenario in which current hard coal and lignite power plants operate until the end of their technical lifetimes (Delaying Climate Action Scenario). For all three regulatory scenarios, the valuation of the German coal industry is estimated by the overall net present value derived from the cash flows of the coal power industry.

---

[4] Expecting claims for compensation, the Coal Commission recommends negotiations with energy utilities intending an orientation towards payments for reserve power around €0.6 billion per GW (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019). In January 2020, the Minister of Finance announced that utilities will receive compensation payments of €4.35 billion over the next years (German Government, 2020).

[5] According to applicable law, the German government can change regulatory policies and decommission certain power plants. However, the shareholders are entitled to compensation in the amount of the lost profits.

Under the assumption of moderate carbon and fuel prices, we find evidence that an accelerated coal phase-out by 2030 would lead to the lowest valuation of coal and lignite power plants, with an absolute stranded asset value (defined as the loss difference between the Delaying Climate Action and the Enforcing Paris Agreement Scenarios), reaching €14.72. Moreover, the stranded asset value for the scheduled phase-out by 2038 only amounts to €0.4 billion, which is however significantly below the approximated values by the Coal Commission and industry. In addition, we also point out that, if no compensation is paid, stranded asset risks affect share prices of listed companies in the utilities sector and, thus spill-over to the financial sector (Dietz et al., 2016). Finally, higher carbon and fuel prices as well as feed-in from renewable energy sources are found to be important factors that decrease the valuation for both hard coal and lignite.

The remainder of this paper is organized as follows. Section 2 briefly reviews the literature related to the financial assessment of stranded assets. Section 3 presents the underlying scenarios as well as methodology of the Monte Carlo simulation employed to conduct the scenario analysis. Section 4 reports the empirical findings and discusses their implications. Section 5 concludes this work and gives an outlook to policy implications. The Supplementary Material to our study provides further technical details, data, assumptions, and additional robustness checks.

2 Literature Review on Stranded Assets Assessment

Stranded assets generally describe economic losses resulting from assets becoming devalued or no longer earning economic return. Since political decisions on the phase-out will terminate and impair the running business with coal to differing extents, these devalued or stranded assets bear an uncertain risk for energy suppliers. Stranded assets eventually translate into a decrease in firm valuation (Carbon Tracker Initiative, 2011). The subject of stranded assets is associated with environmental risks, which was first brought up and publicly discussed by Meinshausen et al. (2009) published in *Nature*. The authors investigate the remaining carbon emissions and therefore possible energy resources that could be burned between 2000 and 2050 to not exceed the 2.0°C global warming carbon budget. They document that carbon reserves may not be fully exhausted. In this regard, the Carbon Tracker Initiative (2011) coins the terms of 'unburnable carbon' and the 'carbon bubble' therewith making stranded assets a subject of discussion.[6]

Stranded asset risk has, over the last decade, gained increased attention with growing topicality of climate change emergency, climate policy uncertainty, and financial implications through environmental hazards (Bloomberg New Energy Finance, 2013; Breitenstein et al., 2019; Caldecott, 2017). Beyond this, companies faced with the risk of valueless assets draw attention towards financial assets that will be directly affected.[7] For instance, Atanasova and Schwartz (2019) examine the North American oil industry and conclude that adverse effects between firm value and proved oil reserves exist. Thus, the higher the firm's oil reserves the higher their exposure to climate policy risk. Van der Ploeg and Rezai (2019) find that immediate climate action, e.g. a carbon tax, reduces the societal cost in terms of CO_2 emissions and increase the value of stranded assets for exposed firms.

Current research on stranded asset is mainly driven by academic and non-academic research initiatives including, among others, the Stranded Assets Programme at the University of Oxford's Smith School of Enterprise and the Environment (introduced by the Carbon Tracker Initiative), the World Resources Institute and the United Nations Environment Programme Finance Initiative, the International Renewable Energy Agency, and the Economist Intelligence Unit. The branches of institutional investment and investment consulting (e.g. HSBC, Bloomberg, and Mercer Consulting) are also concerned by assets becoming stranded and have addressed the financial assessment of stranded assets. However, the overall quantitative results show that financial assessment research, especially academic research, except for contributions published by the Oxford's Smith School, remains quite rare. The relevant literature on this subject is aggregated through the previously identified research institutions, proceeding snowball literature research and selected scientific journals instead of a comprehensive systematic literature research, as common databases depict only few scientific research concerning practices and tools of assessment.

---

[6] It is to be noted that the concept of stranded assets originates in the late 1980s. Krause et al. (1989) firstly outlined the relationship between unburnable carbon, fossil fuel assets and the adverse financial impacts to financial markets. Michaels (1994) also discussed possibilities of stranding assets for the utilities sector. These ideas, however, did not receive enough attention due to the common perception of climate change as neglectable at the time. A comprehensive recap of this study can be found in Caldecott (2017).

[7] The Bank of England has announced stranded assets to be a material risk to financial stability given the exposure of the financial sector to the vast risk of assets becoming stranded following climate change (Carney, 2015). In his speech, the Bank of England's Governor, Mark Carney, outlined that 19% of the Financial Times Stock Exchange 100 Index value are invested in natural resource and extraction sectors of oil, gas, and coal; and 11% are invested in power utilities or other industrial sectors that depend on these natural resources (Carney, 2015). The IPCC (2015) have also voiced concerns about future impacts of stranded asset risk for the financial sector and advocated emissions to the G7 finance ministers in the group.

Table 1 provides main features of the relevant literature that recently assesses and estimates the financial impact of stranded assets. Most studies featured are case studies with the exception of Ansar et al. (2013), Silver (2017), and World Resources Institute and UNEP Finance Initiative (2016) who provide theoretical frameworks on the financial assessment. The remaining are mostly motivated by climate change and its impacts on high-carbon commodities and sectors. The analyses were conducted on different levels: the financial portfolio level or the industry/company/asset level. First, the financial portfolio level includes Integrated Assessment Models (IAM) such as the macroeconomic Dynamic Integrated Climate–Economy (DICE) or E3ME-FTT-GENIE models. A quarter of the studies assesses cumulated losses for financial assets with exposure to carbon-intensive industries. There is interestingly the large amount of case studies employing the Discounted Cash Flow (DCF) method in order to assess the stranded asset value on the industry, company or asset levels. Noteworthily, most studies estimate valuation impacts through the Net Present Value (NPV) of cash flows and the primary fossil fuel industries form the core of the sectors considered within the analyses.

All case studies are scenario analyses in order to estimate the potential value of prospective stranding assets, over the short- to medium-terms, with respect to impending policy, technology, and physical climate change hazards. For most studies, however, the recognition of assets stranding is poorly pronounced and not directly considered in the construction of the different scenarios. Instead, the macroeconomic models do not allow for the disaggregation of financial assets or industry-specific impacts of stranded assets (The Economist Intelligence Unit, 2015). Moreover, the focus on cross-industrial and global estimates induces simplification and insignificance for specific industries. Finally, research considering financial impairment along the stranding of physical assets is rare.

Our study, while focusing on stranded asset risks for the German coal industry, argues that the estimation of the extent of negative implications for the valuation of industry-specific financial assets is a necessary step to further advance research on stranded assets. Doing so thus stresses on the necessity of institutional investors, asset manager, and asset owners to incorporate climate risks into their overall governance and risk management frameworks (Breitenstein et al., 2019; Ernst & Young, 2016).

Author	**Type**	**Model**	**Outcome Metrics**	**Sector**	**Geographic Coverage**
HSBC Global Research (2012)	Lobby group report	DCF	NPV (of industry cash flows)	Coal mining	United Kingdom
Ansar et al. (2013)	Academic publication	DCF	NPV (intrinsic value of stock)	-	-
Bloomberg New Energy Finance (2013)	Lobby group report	DCF	NPV, shareholder value	Oil	Global
HSBC Global Research (2013)	Lobby group report	DCF	VaR	Oil	Europe
Caldecott et al. (2013)	Academic publication	-	VaR	Agriculture	Global
Kepler Cheuvreux (2014)	Lobby group report	DCF	NPV (of revenues)	Oil, gas, coal	Global
Mercer Investment Consulting (2015)	Lobby group report	IAM (FUND, DICE)	10-year asset return impacts	Utilities, coal, oil	Global
The Economist Intelligence Unit (2015)	Non-academic publication	IAM	NPV of global financial asset losses	All sectors	Global
Dietz et al. (2016)	Academic publication	IAM (DICE)	NPV of global financial asset losses, 'climate VaR'	All sectors	Global
UBS (2016)	Lobby group report	DCF	NPV (of Industry/peer group cash flows) / EV	Oil, gas	Global, focus U.S. and Canada
World Resources Institute and UNEP Finance Initiative (2016)	Non-academic publication	DCF, IRR, break-even price	NPV (of cashflows)	-	-
Caldecott et al. (2017)	Academic publication	DCF	NPV (total coal stranded plant value)	Coal	China
International Renewable Energy Agency (2017)	Non-academic publication	-	Undiscounted stranded plant value	All sectors	Global
Silver (2017)	Academic publication	DCF	NPV, shareholder value	-	-
Byrd and Cooperman (2018)	Academic publication	CAPM-based return model	Shareholder value in response to stranded asset risk news	Coal	Global
Mercure et al. (2018)	Academic publication	IAM (E3ME-FTT-GENIE)	NPV of global financial asset losses, GDP	Oil, gas, coal	Global
Atanasova and Schwartz (2019)	Academic publication	Panel regression model	Tobin's Q (firm value)	Oil	U.S. and Canada
Van der Ploeg and Rezai (2019)	Academic publication	Pyndick's canonical model	NPV (market valuation)	Oil, gas	Global

The models are Discounted Cash Flow (DCF), Integrated Assessment Models (IAM) such as the Dynamic Integrated Climate–Economy (DICE) and Framework for Uncertainty, Negotiation and Distribution (FUND), and E3ME-FTT-GENIE models, Internal Rate of Return (IRR), and Capital Asset Pricing Model (CAPM). The outcome metrics are the Net Present Value (NPV), also in relation to the Enterprice Value (EV), the Gross Domestic Product (GDP), or the Value-at-Risk (VaR).

Table 1: Overview of case and theoretical studies on financial assessment.

3 Methodology

Generally, risks initially concerned with climate change are uncertain and driven by policy and market developments. Therefore, historical or parametric data do not provide sufficient use cases and, as mentioned in Section 2, scenario analyses are more suitable (World Resources Institute and UNEP Finance Initiative, 2016). Hence, our study relies on a scenario analysis which is conducted on the industry level or, more specifically, for the hard coal and lignite power generation industry in Germany.

3.1 Scenario Description

Three scenarios are set out in order to for the assessment of different levels of stranded assets. Throughout the years 2019 to 2061, different estimates of future input data are included to match the scenarios constructed along the World Energy Outlook published by the International Energy Agency (2018). Thereby, the coal business includes mining, power plants and the supply chain, including sales, to the consumer. The scenario analysis focuses on hard coal and lignite power plants in Germany that belong to energy utilities, municipal energy utilities and mining companies. This limitation is mainly driven by the inaccessibility of relevant data on the costs of the sales processes in utility and mining companies. The power plants considered within the analysis also do not account for revenues from heat cogeneration.

3.1.1 Delaying Climate Action: “Back to Normality”

The Delaying Climate Action Scenario (hereafter, DCAS) serves as the benchmark for the assessment of the stranded asset value. For this purpose, the scenario depicts the hypothetical valuation of the coal industry knowing it would be possible to keep coal and lignite power generation in operation past 2038. The DCAS represents the status quo with no additional policies to change current emission levels and consequently an electricity production from coal that decreases depending on the lifetime-determined decommissioning of all power plants. Furthermore, the DCAS does not include retro fits and new power plants starting operation. Addressing the key factors, the scenario is driven by socio-economic and economic key factors such as the expectation that fossil fuels are needed to sustain the increasing energy demand.

This scenario presumes that short-term physical climate change hazards are not as evident and threatening. Consequently, society and policymakers feel no urgency to further mitigate and adapt to climate change. Therefore, the scenario at hand includes no further policy action in response to climate change and is, instead, the reversal of the commission's proposal on the German coal phase-out in 2038. However, the pan-European policy instrument Emissions Trading System (ETS) is not abolished which implies a moderate increase in carbon prices.

Due to current public discussions about climate change brought up by the Fridays for Future movement in society (Institut für Protest- und Bewegungsforschung, 2019) and new political developments like the European "New Green Deal" (European Commission, 2018), this scenario is highly improbable. Nonetheless, it is of great relevance to the later assessment of valuation impacts of the coal-fired power generation industry.

3.1.2 Maintaining Climate Action Scenario: Current Pathway

Our second scenario, the Maintaining Climate Action Scenario (MCAS), relies on the announcements of the Commission on Growth, Structural Change, and Employment that Germany will decrease its installed capacities of coal electricity production to 8 GW for hard coal and 9 GW for lignite (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019). Even though the proposal has not yet been legally decided on by the German parliament, it is most likely to present the current pathway of the coal phase-out.[8] A key driving force, again, is found in the policy perspective. The current policy for Germany is included in the MCAS, but no further climate action on limiting greenhouse gas emissions. However, certificate prices are expected to increase due to the additional deletion of certificates. The expansion of renewable energy increases moderately according to the planned reductions in energy from coal. Other key driving forces are a moderate urgency of climate change to society and politics and an increase in climate change related physical events.

This scenario resembles the Current Policies Scenario from the World Energy Outlook by the International Energy Agency (2018). It is constructed along the planned decommissioning published by the Bundesnetzagentur (2019). Overall the MCAS has a low degree of uncertainty. However, the pathway does not follow the Paris Agreement and, therefore further actions are

---

[8] As of January 2020, a possible pathway to lignite coal phase-out is presented, but not yet confirmed. The MCAS is slightly more progressive than the announced possible decommission plan, i.e. while we assume an almost straightly linear decommission, the plan by the Coal Commission is slower in the early years and accelerates in the years after 2030.

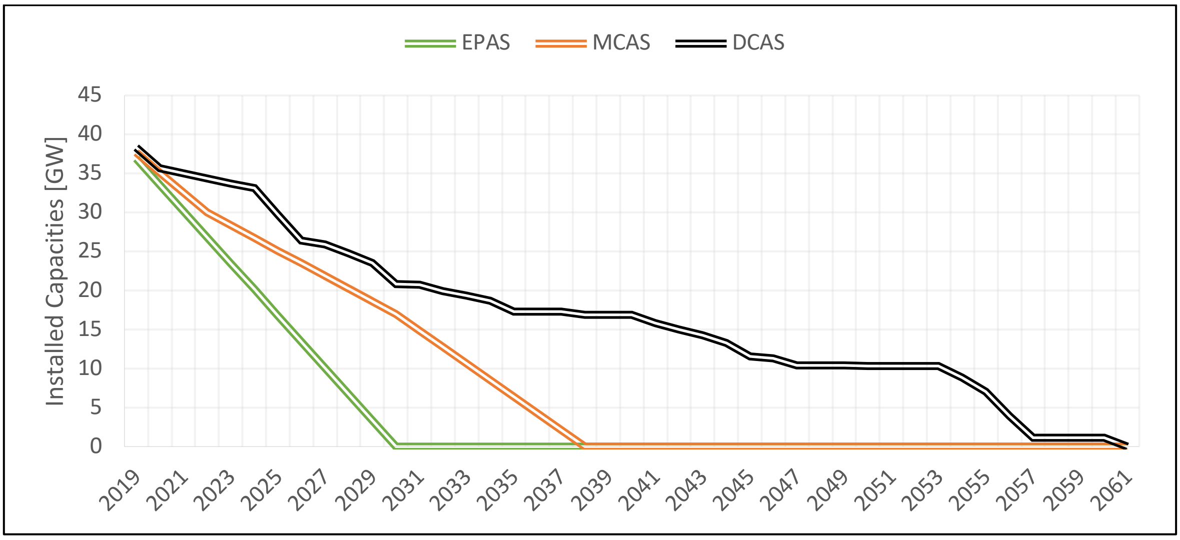
required to meet the international climate goals. The MCAS reflects the current policy framework in place.

3.1.3 Enforcing the Paris Agreement: Limiting Global Warming to 2.0°C

The last scenario, the Enforcing Paris Agreement Scenario (hereafter, EPAS), is consistent with the 2015 Paris Agreement on limiting the average global increase in temperature to below 2.0°C by decreasing the concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2 equivalent. It includes a 42% decrease of CO_2 emissions from coal in the power sector by 2020 and a 100% decrease by 2030 in comparison to 2017 levels (Climate Analytics, 2018). Since there have been no adequate reductions in installed capacity of coal-fired power plants, under the EPAS, Germany must reduce installed capacity from around 97% in 2018 to zero in 11 years. Hence, the construction of the scenario to speed up coal phase-out until 2030 is designed along the Paris Agreement self-set goals. Key drivers in this envisioned scenario are short-term physical climate change hazards that are evident and threatening to society, economy, and policymakers.

The EPAS provides strong climate change mitigation action and resembles the Sustainable Development Scenario built by International Energy Agency (2018). Moreover, the scenario is in line with preferences of German voters as well as a wider public who favor the early coal phase-out within the next 10 years (Rinscheid and Wüstenhagen, 2019). In comparison to the MCAS, the phase-out by 2030 is not scheduled within the proposal by the Coal Commission. Given voters’ preferences and current debates, it is moderately predictable and exposes a high level of policy action in response to an impeding climate change magnitude.

The respective annual development in terms of installed capacities of hard coal and lignite for each scenario is illustrated in Figure 1.



Source: Own presentation based on Bundesnetzagentur (2019), Climate Analytics (2018), and Federal Ministry for the Environment, Nature Conservation and Nuclear Safety(2019).

Figure 1: Development of installed capacities of hard coal and lignite combined.

3.2 Monte Carlo Analysis

The analysis at hand covers a long-time span from 2019 until 2061 and therefore uncertainty places a substantial role. As previous studies such as Barnett et al. (2019) and Cai et al. (2017) note, climate-change-related uncertainties largely impact the obtained output parameters of macroeconomic models. To some extent, uncertainty in this study is covered by the scenario approach, but even within the scenarios, input parameters could vary greatly. Thus, a Monte Carlo simulation for each scenario is carried out. It allows to assign specific input parameters with uncertainty and a distribution of the uncertainty.

The outcomes of the analysis exhibit an impact on future cash flows since cash flows resulting from the coal power generation business are then reduced by lost profits. For this purpose, the EBIT is calculated as the differential between revenues from the clearing price and operation costs and depreciation. The cost variables consist of fuel, carbon, variable, and fixed costs described and determined for all years of the scenarios within the Supplementary Material. Revenues are the output variable of a further complex modelling itself. It is assumed that power plants operators hedge positions and therefore receive either the prices for base or peak load. The prices for base and peak load are determined by applying a simplified merit-order. Figure 2 depicts the modelling procedure of estimating the revenues for all scenarios.

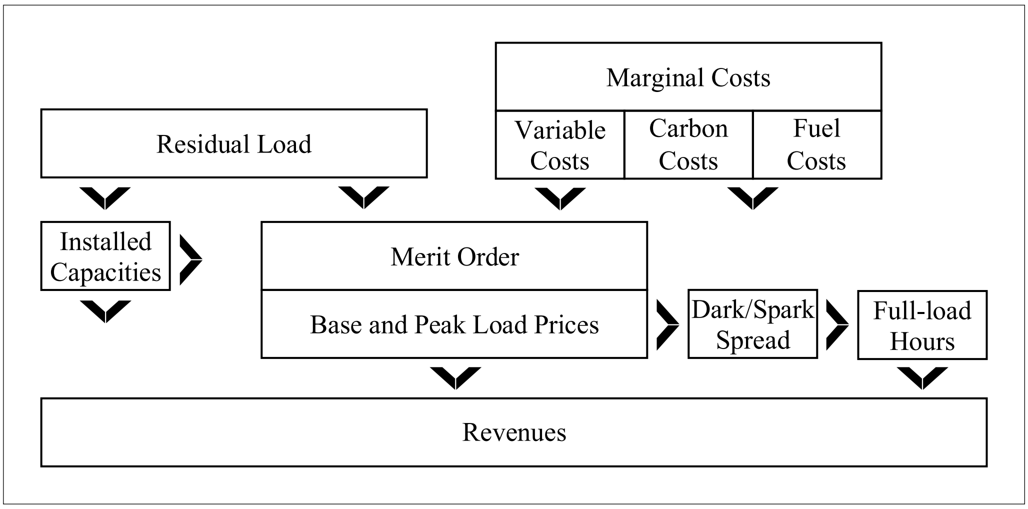


Figure 2: Modelling procedure of the determination of revenues.

In order to calculate the cash flows, we first assess the amount of taxes (via EBIT). Secondly, we subtract taxes and other cash-effective expenditures from EBITDA to yield the yearly free cash flows, which are the relevant data for the DCF model. We use the Weighted Average Cost of Capital (WACC) to discount the yearly free cash flows and derive the NPVs.

As seen in Section 2, the DCF model is widely used for the physical asset level, operator level, and financial asset level because it includes a prospective perspective on valuation. Different NPVs allow for the comparison of hypothetical and potential prospective industry valuations across the chosen scenarios.

Due to the increasing installation of and feed-in from fluctuating renewable energy sources, the German residual load composition will experience major changes. Base, mid, and peak load become less distinct and the base load may decrease highlighting the need of flexible power plants to replace continuously running base load power plants (Brunner et al., 2019). As the assumed base load depends heavily on the expectation of future renewable energy installations, the Monte Carlo analysis is conducted four times. Thereby, the upper limit of the base load serves as the baseline analysis. In order to assess the sensitivity of the upper limit base load assumption, the Monte Carlo analysis is repeated by setting the base load to its lower limit, its mean, or by assuming an underlying stochastic triangular distribution based on the given lower, mean, and upper limits. The upper limit depicts the current base load of 44.5 GW, the lower limit amounts to 30 GW for DCAS, 20 GW for the MCAS, and 10 GW for EPAS. The mean base load thus varies for each scenario as well. The determined and randomly sampled base load remains constant for all years of each scenario.[9]

Data, assumptions, and detailed descriptions concerning the Monte Carlo simulation are presented in Supplementary Material appendix to our study.

4 Valuation of the Lignite and Hard Coal Power Generation in Germany

The results for valuation for lignite and hard coal are presented in Table 2 which shows the NPV distributions and their respective summary statistics. Overall in all scenarios lignite has a much higher valuation as hard coal even though both industries are comparable in size. The difference is caused by lignite's lower variable costs and higher full load hours which increase the profitability of lignite. In the following the results for lignite and hard coal are separately presented and analyzed.

Parameter	DCAS Hard Coal	Lignite	MCAS Hard Coal	Lignite	EPAS Hard Coal	Lignite
Minimum	-4.52	11.59	-1.70	8.83	-4.78	-2.13
Maximum	-3.12	16.41	-0.52	12.97	-3.39	1.03
Mean	-3.79	13.97	-1.12	10.90	-4.11	-0.48
Range	1.40	4.83	1.17	4.14	1.39	3.17
VaR (α=0.05)	-4.06	12.68	-1.34	9.79	-4.32	-1.24
VaR (α=0.01)	-4.17	12.32	-1.44	9.44	-4.41	-1.51
STDEV	0.1641	0.7760	0.1370	0.6554	0.1324	0.4549
Rel. STDEV	0.0434	0.0555	0.1225	0.0601	0.0322	0.9466

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). We denote VaR as the Value-at-Risk and STDEV as standard deviation. Numbers with the exception of the relative STDEV are in billion €.

Table 2: Summary statistics of hard coal and lignite using the upper base load assumption.

4.1 Results of the Valuation of Lignite and Hard Coal Power Plants

4.1.1 Lignite Power Plants

As presented in Table 2, the valuations for lignite range between the scenarios from €-2.13 to €16.41 billion (from minimum EPAS to maximum DCAS). Across the scenarios, the mean NPV decreases gradually from €13.97 billion in the DCAS to €-0.48 billion € in the EPAS,

---

[9] In addition to the sensitivity analysis of the base load (Section 4.1.3), further robustness is checked by a sensitivity analysis on the WACC. While a higher (lower) WACC leads to lower (higher) NPVs in each scenario, the differences between the scenarios and, thus, the stranded assets value remains almost the same. The results are presented in the Supplementary Material.

which results in a loss in valuation of 104%. It is worth noting an absolute decrease of €3.07 billion between the DCAS and MCAS in comparison to the absolute decrease of €11.38 billion between the MCAS and EPAS as evident also in Figure 3. On the one hand, this suggests less profitable conditions for lignite past 2038. On the other hand, the strong valuation impacts resulting from high carbon and fuel prices combined with the strong decline in installed capacity in the EPAS.

Within the DCAS, lignite profits from the substantially higher marginal costs of the price-setting power plant technology. Due to low fuel and carbon prices, the current merit order remains unchanged and lignite receives revenues based upon the marginal costs of hard coal and with decreasing installed capacities from combined cycle gas turbines. Therefore, a scenario with no further regulatory measures and decommissioning after a plant's technical lifetime hypothetically presents the highest valuation of the lignite industry. Nonetheless, the profitability after 2038 diminishes and cash flows decrease to and even out at zero. This results in close NPVs for lignite within the DCAS and MCAS and therefore no changes in the merit order.

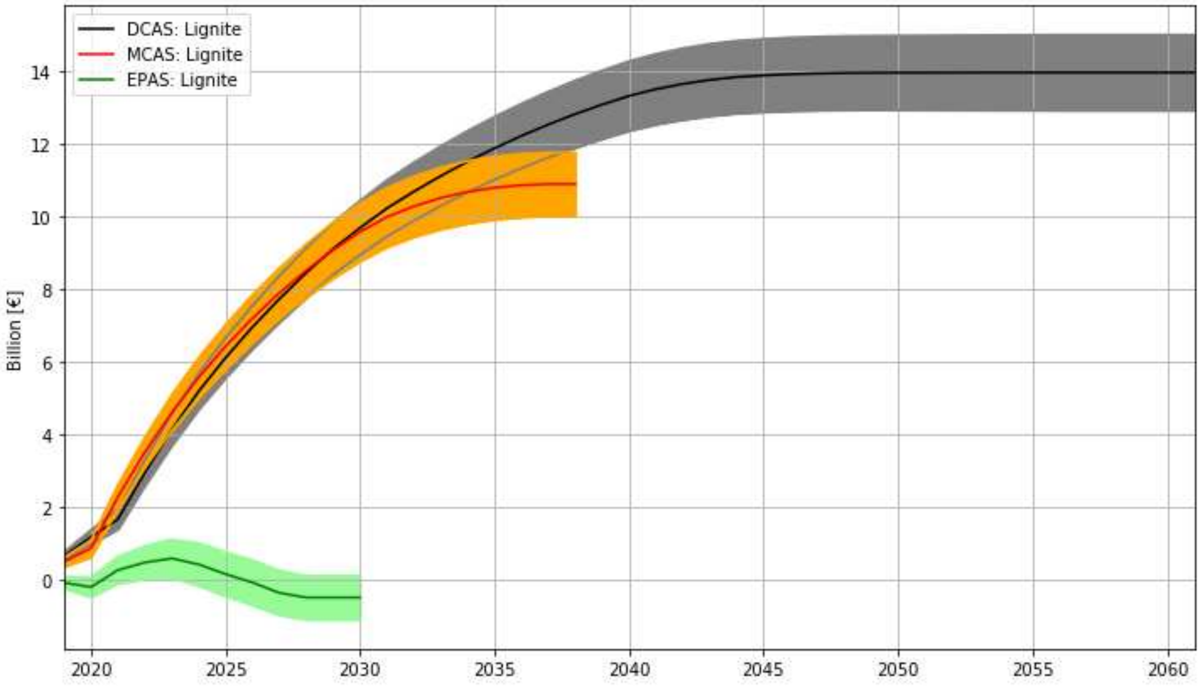


Figure 3: Evolvement of the Net Present Value of the Lignite industry under each scenario with 80% confidence intervals around the mean values.

In the EPAS, a higher carbon price is assumed and leads to the assimilation of the marginal costs of all technologies and in the end to a change in the merit-order where gas replaces lignite at the front. Therefore, lignite provides mostly peak load which reduces the full load hours.

Additionally, the installed capacity of combined cycle gas turbines increases over time so that it also covers the averaged peak load. Thus, the large profits of lignite are cut and result in lower mean NPVs previously outlined. However, the change within the merit order also raises the question whether it is technically feasible for lignite to operate in the peak load. This could eventually result in lignite power plants becoming uncompetitive by 2024 or 2025.

Furthermore, the risk measure Value-at-Risk (VaR) is estimated to determine the downside risk of the distribution. The VaRs at the 5% and 1% quantiles depict the severe decrease from the MCAS to the EPAS reducing by 113% and 116%, respectively. The mean NPV and the VaRs turn negative in the EPAS indicating that, by a probability of 99%, the lignite NPV does not fall short of €-1.51 billion. The standard deviation (STDEV) of the empirical NPV distributions for each technology varies within the three scenarios depicting differences in the risk-return profiles. As the standard deviation is compared to the mean of the NPV distribution, the relative standard deviation refines the comparability between the scenarios and the technologies themselves. In the DCAS, the relative standard deviation remains moderate at 0.0555 and increases only slightly to 0.0601 in the MCAS. In the EPAS, with risky fuel and carbon prices, the relative standard deviation of 0.9466 shows a strong increase of relative variance and is highly exposed to the downside variation of the mean NPV.

Overall, the value of the lignite industry decreases due to the coal phase out. Figure 3 depicts the evolvement of the mean NPVs under scenario. We see that a phase-out by 2038 limits the loss in valuation to about €3 billion while an earlier phase out leads to further losses in the valuation of about €11 billion. Hence the coal phase-out possesses a risk for stranded assets in the lignite industry.

4.1.2 Hard Coal Power Plants

The NPVs of the hard coal power generation industry range between €-4.78 billion and €-0.52 billion (from minimum EPAS to maximum MCAS). This generally perceptible pattern of negative NPVs is caused by the alignment of the marginal costs of hard coal with the ones of combined cycle gas turbines. Depending on the rapidity of decommissioning and the merit order, hard coal is the price-determining power plant later being replaced by combined cycle gas turbines. However, given the low positive spreads throughout most of the scenarios, hard coal power plants are not able to fully cover their fixed costs with the predetermined low number of full-load hours of 3,387.5 hours/year. Nevertheless, the MCAS reveals the highest valuation in comparison to the almost equally negative NPVs in the DCAS and EPAS (see also Figure 4). In order to generate positive cash flows a clean dark spread of at least 16 €/MWh is required. This can indicate that assumed fixed costs are too high. Nonetheless, the economic profitability remains compromised, as marginal power plants in an energy only market cannot cover their fixed costs due to the missing money problem.

Although the results of the DCAS and EPAS are almost the same the reasons for that are quite contrary. In the EPAS, high carbon prices increase variable costs of hard coal over those of gas and therefore these technologies switch their position by 2024 or 2025 in the merit order. Hence, earnings as well as full load hours decrease, since they act as peak load power plants, which leads to lower NPV compared to MCAS. On the other side in the DCAS as well as in the MCAS the cash flows are negative, which leads to lower NPVs because of the longer running time of the hard coal. Again, the technical feasibility of hard coal's peak load capability remains a further point of attention.

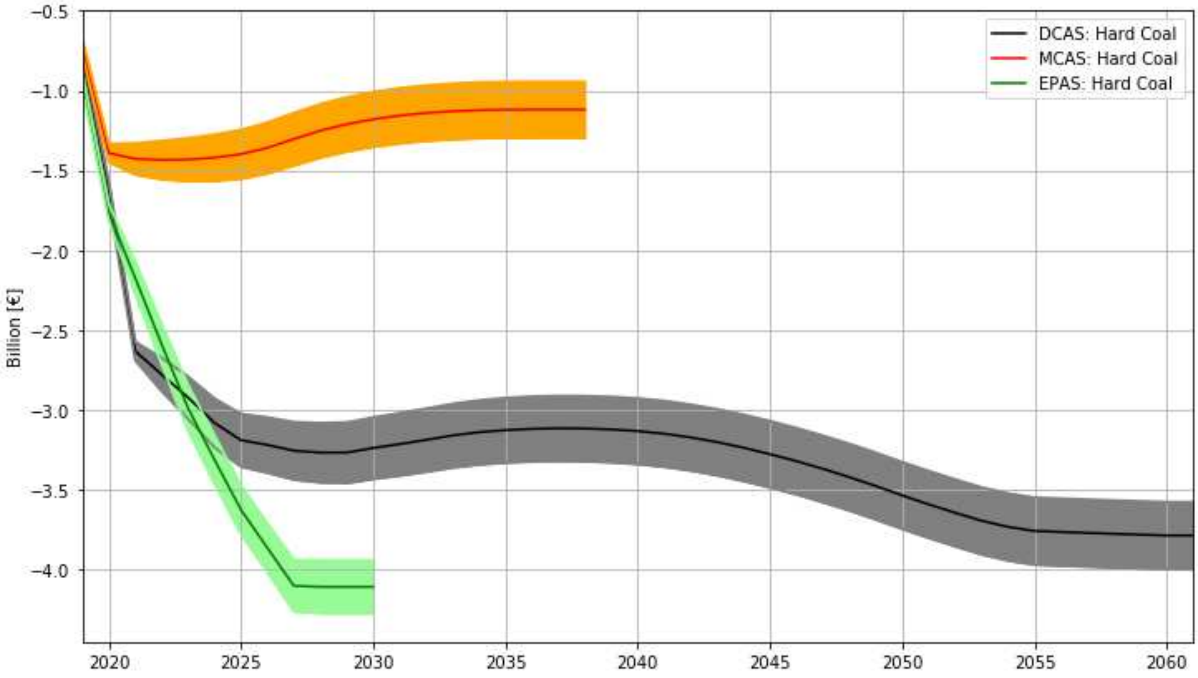


Figure 4: Evolvement of the Net Present Value of the Hard Coal industry under each scenario with 80% confidence intervals around the mean values.

This is further corroborated by the VaRs which display similar values in the DCAS and EPAS of €-4.17 and €-4.41 billion at the 1% quantile, respectively. A strong incline of the VaRs, however, is visible in the MCAS. The MCAS suggests that, by a probability of 99%, the NPV does not fall below €-1.44 billion economizing around €2.7 billion in losses in comparison to the DCAS. The MCAS has the highest relative standard deviation of 0.1225. In comparison, the relative standard deviations of DCAS and EPAS are 0.0434 and 0.0322, respectively.

Summarizing, a coal phase-out increases the valuation of hard coal (from €-3.79 to €-1.12 billion) due to a shorter period of negative cash flows. Although, in reality when companies expect future negative cash flows they would decommission their assets to minimize their losses. However, the coal phase-out does not create a risk for stranded assets from the hard coal industry.

4.1.3 Sensitivity Analysis of the Base Load

Base load constitutes a crucial input factor and can have a great impact on the profitability and thus on the NPVs of the two technologies. In this study, base load is to be understood as the minimum residual load for 7,000 hours per year. Hence, lowering the residual load accounts for the impact of a further expansion of renewable energies. Therefore, we repeat our Monte Carlo analysis to test for the sensitivity of the base load level. In our previous calculations, we assumed the current residual load (2019) to which we refer as 'upper limit'. The further analysis employs a lower limit, a mean, and a stochastic load level. For the latter, we employ a triangular distribution for the base load (from lower limit to mean to upper limit).[10]

The results for the different base load assumptions are presented in Table 3. Overall, the structure of the previous results remains the same, i.e. lignite has its highest valuation in the DCAS which decreases over the MCAS to the EPAS. Furthermore, the valuation for lignite follows the intuitive logic that the valuation decreases when base load is lower. In contrast, for hard coal, the valuation does not necessarily decrease with the load, thus its lowest valuation is derived for the mean base load assumption. This is due to the fact that hard coal can generate comparatively good cash flows in case of low base load in the first years.

Base Load	**DCAS**		**MCAS**		**EPAS**	
	Hard Coal	**Lignite**	**Hard Coal**	**Lignite**	**Hard Coal**	**Lignite**
Upper	-3.79	13.97	-1.12	10.90	-4.11	-0.48
Mean	-5.18	11.00	-2.03	4.00	-3.64	-2.33
Lower	-4.59	6.66	-0.59	2.52	-3.31	-1.28
Stochastic	-4.74	11.27	-1.67	5.92	-3.62	-1.68

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). Numbers are in billion €.

Table 3: Mean NPVs of the simulation employing different base load assumptions.

Furthermore, the absolute differences in the valuation between the different base load assumptions are much smaller for hard coal than for lignite. This result is explained by the fact, that hard coal has already negative cash flows with high base load assumptions and with the

---

[10] For technical details, we refer to the Supplementary Material to this study.

decreasing base load level more capacity is decommissioned earlier, which limits the loss in valuation. In contrast, with less load, lignite accrues fewer positive cash flows which lowers its valuation.

Summarizing, the level of the base load has a great impact on the valuation, especially for lignite. The impact for hard coal is much smaller. Furthermore, a reduction of base load, for instance due to the expansion of renewable energies, reduces the valuation of lignite and therefore possesses the risk of stranded assets.

4.1.4 Contrasting the Results for Lignite and Hard Coal Power Plants

The results for the valuation of lignite and hard coal differ quite significantly not only in the absolute value but also in their structure. The fact that lignite has a generally higher valuation when both industries are comparable in size is to be expected, since lignite has lower variable costs. This leads to a better position in the merit order and therefore to higher earnings. The lower variable costs come at the price of higher investments, which are neglected in this study since only existing power plants are considered.

More interesting is the difference in the structure of the results: Lignite has the highest valuation in the DCAS while hard coals valuation is almost as low as in the EPAS. Due to its low variable costs lignite is able to constantly generate positive cash flows, which decrease over time due to increasing carbon prices. In contrast, hard coal struggles in most years to pay off its fixed costs, since it often sets the market clearing price. When setting the market clearing price, fix costs cannot be covered and therefore hard coal accumulates negative cash flows over a long period of time leading to the lowest NPV.

In summary, the different variable costs of lignite and hard coal are the reason for the large differences of their respective valuation. While for lignite the coal phase-out possesses a risk, it does not for hard coal. In contrast, both technologies EPAS. The main reason is the feed-in from renewable energy sources and moreover high carbon prices, which cut profits and valuation compared to the MCAS for both, hard coal and lignite.

4.2 Economic and Political Implications

4.2.1 Compensation Payments

The decrease in valuation, shown in Section 4.1, depicts severe consequences for the profitability of affected utilities and companies. These potential developments could follow the very similar political events of the nuclear phase-out in Germany resolved after the Fukushima nuclear disaster in 2011. Due to missing revenues, the early nuclear phase-out resulted in losses of billions of euros on behalf of German energy suppliers. In consequence, they sued the government for their claims of damage compensation in the amount of €19.7 billion before the Federal Constitutional Court and the International Centre for Settlement of Investment Disputes (ICSID). The Federal Constitutional Court ruled that the government is responsible for adequately compensating utilities indicating the government's accountability also for the closely linked losses in consequence of the coal phase-out (Bos and Gupta, 2018).

Due to the interdependencies between politics and the energy industry, compensation payments remain highly critical to policymakers (Bos and Gupta, 2019). In this regard, compensation payments for stranded assets could present a practical tool to achieve a reduction in coal capacity. In the past, the German government has indicated its willingness to compensate the energy industry by offering compensation payments to energy suppliers. In return for shutting down 2.7 GW of installed capacity from lignite power plants, energy suppliers received €1.6 billion from, ultimately, German taxpayers (Zhao and Alexandroff, 2019). This equals €0.6 billion per GW of installed capacity. The Coal Commission conforms with this payment in its final report, claiming that potential compensation payments for operating and yet to operate power plants may orientate towards payments for security reserves. These statements imply overall payments of €24.0 billion for the current amount of installed capacities of hard coal and lignite, estimated at 40.3 GW. According to the Coal Commission, overall €1.6 billion are already to be paid to lignite power plants in the security reserve mode (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019). On the other hand, highly exposed energy supplier RWE raises a claim for the compensation of decommissioning coal power plants estimated at a range of €1.2 to €1.5 billion per GW of installed capacity (Steitz and Eckert, 2019). On that basis, payments could amount up to €60.0 billion. In January 2020, the Minister of Finance announced that the government plans to pay €4.35 billion in compensation to operators of lignite power plants over the next years.

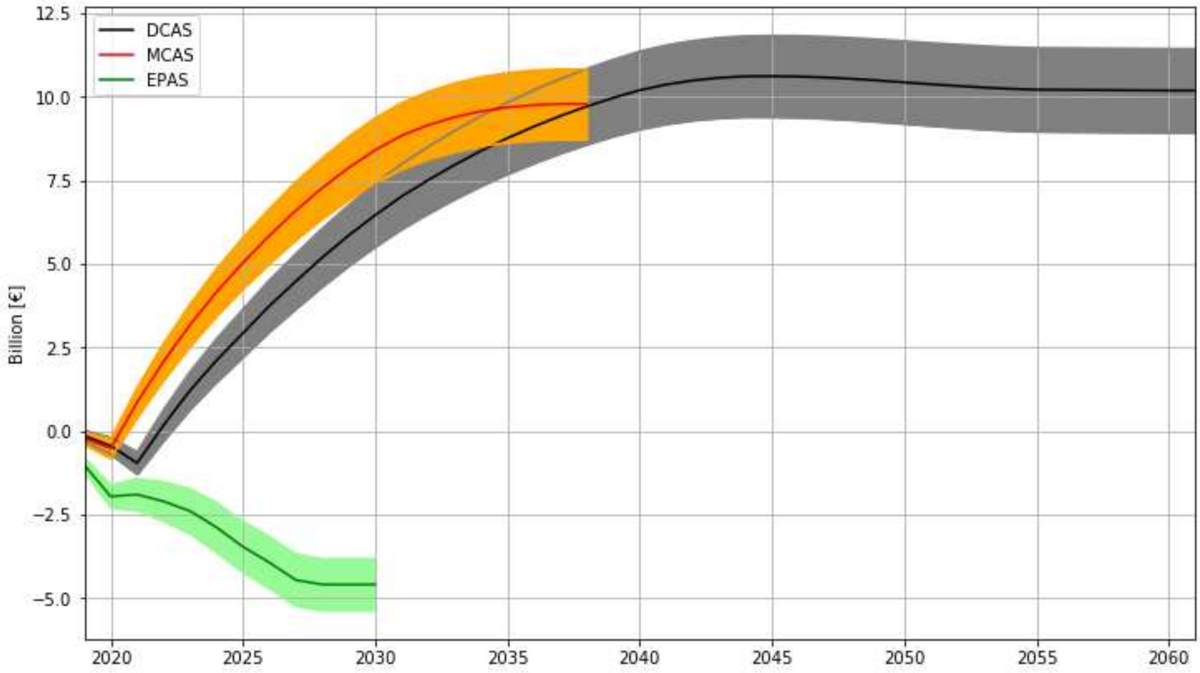


Figure 5: Evolvement of the Net Present Value of the Coal Industry under each Scenario with 80% confidence intervals around the mean values.

Based on our results, we calculate a total stranded asset value of €0.4 billion for a phase-out by 2038 instead which is also depicted in the difference between the respective end points of DCAS and MCAS in Figure 5. Even if only lignite power plants are taken into consideration, the total amount would only sum up to €3.07 billion. Thus, our estimates are considerably lower than the demanded compensation.

Since energy utilities argue with their current running capacity, it might also be of interest to know which amount of power generation is actually to be compensated. Our calculations show that in the DCAS only 9.07 GW are still running by the end of 2038. Multiplied with the previously paid €0.6 billion per GW results in €5.44 billion, which is still significantly lower than the amount demanded by the energy suppliers.

On another note, an even earlier phase-out would be more costly, but still below the raised claims. Rinscheid and Wüstenhagen (2019) show that German voters would accept additional costs of €8.5 billion for a phase-out by 2025 or €3.2 billion by 2030 compared to the scheduled 2038 phase-out. Our calculations for a phase-out in 2030 instead of 2038 lead to an additional stranded asset value of about €14.32 billion (€11.38 billion) for both technologies (lignite only). The large difference between the phase-out dates is depicted in Figure 5. Thus, the total strand asset value for a phase-out in accordance with the Paris Agreement would sum up to €14.72 billion (€14.45 billion lignite only).

In addition to the far lower decrease in valuation for an early phase-out, our study evidences that the phase-out of coal-fired electricity generation by 2030 does not require an accelerated decommissioning. Instead, the introduction of carbon prices on adequate levels present economic conditions where hard coal and lignite power plants cannot remain competitive. More specifically, high carbon prices can disrupt the merit order to an extent that leads to the phase-out of lignite and hard coal simply based upon economic conditions. This outcome confirms Michaels (1994) who argues that stranded investment compensation solely designate lost revenues of companies that were not to be reclaimed in a competitive market. However, this requires prices of at least 35 €/t by 2020 quickly increasing to 180 €/t, as they were provided by the Forum Ökologisch-Soziale Marktwirtschaft (2019) on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. However, as of January 2020 the settlement price for CO2 emission allowances futures is about 25€/t.

4.2.2 Carbon Dioxide Emissions

The yearly and overall CO_2 emissions have been calculated for the baseline scenario, as well, to give a brief overview on Germany's political ambitions on mitigating climate change impacts. Figure 6 depicts the cumulated CO_2 emissions based on the mean values of the distribution. This reduction in CO_2 emissions is in line with Jewell et al. (2019), who estimate the avoided emissions at a range of 0.6 and 1.6 Gt depending on the actual phase-out date. If the phase-out for Germany remains in 2038, 1.32 Gt of CO_2 emissions are avoided compared to a phase-out in 2061. The early phase-out by 2030 scenario (EPAS) even has the potential to save up to 2.15 Gt of emissions. In comparison to the current phase-out by 2038, the accelerated phase-out of hard coal and lignite is able to cut CO_2 emitted by 48%. The comparison to the hypothetical emissions approximates the extent of emissions that results only from coal-fired power generation.

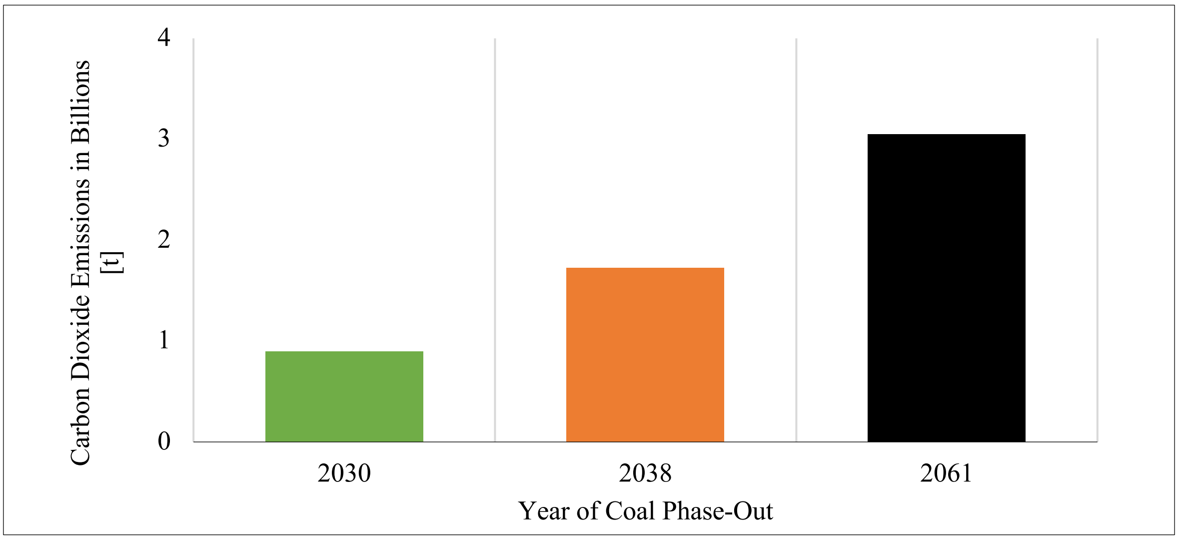


Figure 6: Required carbon budget depending on the timeframe of hard coal and lignite decommissioning.

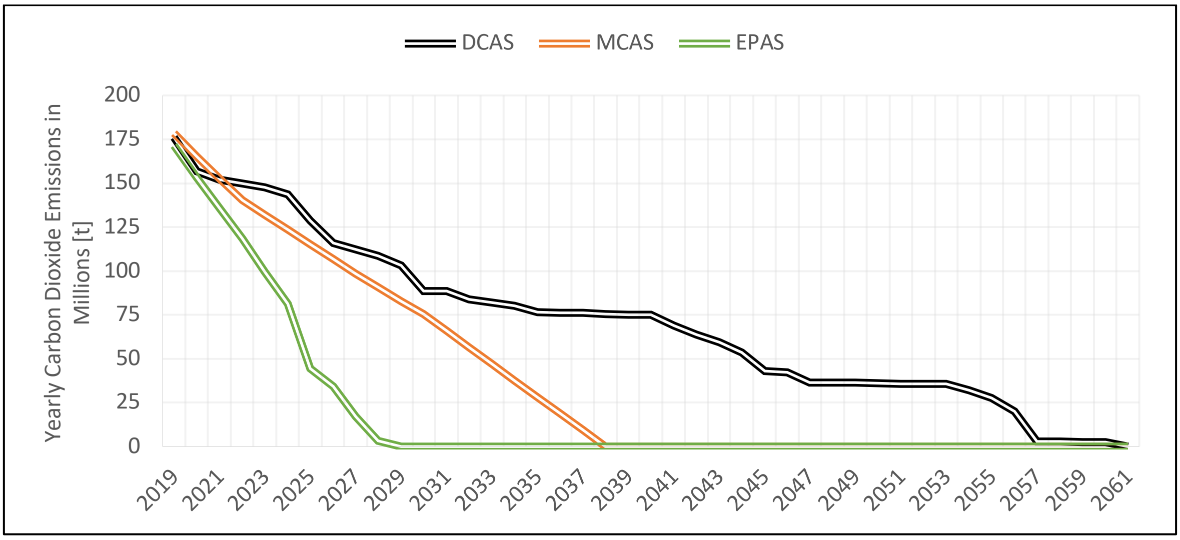


Figure 7: Development of CO_2 emissions for each scenario.

Figure 7 illustrates the mean of the yearly emissions from coal-fired power generation resulting from the three scenarios. Without additional policy measures, emissions decrease slowly due to the ageing of the coal fleet without retro fits and new power plants starting operation. However, accelerating the phase-out of hard coal and lignite up to 2030 presents the only possibility to keep up with the already moderate 2030 goals of reducing greenhouse gas emissions set in the 2015 Paris Agreement. A study by Climate Analytics (2018) demonstrates that only a continuous reduction in coal-related CO_2 emissions down to zero by 2030 ensures the compliance with the defined goals. Thus, Germany is not able to meet its reduction goals set in the Paris Agreement in 2015 given the timeframe of 2038 as proposed by the Coal Commission. In the meanwhile, this data does not address the substitution of coal by natural gas and therewith related emissions.

4.2.3 Financial Market Implications

Our Monte Carlo analysis depicts the extent of assets stranding in the coal power generation industry. The lignite and hard coal industry both suffer losses in valuation between a scenario with current energy and climate policy objectives (MCAS) and a scenario with ambitious objectives to reduce greenhouse gas emissions (EPAS). The valuation impacts of the power generation industry in Germany affect shareholder valuation, if no compensation payments are made. For instance, Sen and von Schickfus (2018) show that current climate policy is already reflected in the share prices of German power utilities. However, the authors also show that while investors care about stranded asset risk, they also expect compensation.

For further assessment, the MCAS displays the valuation of the hard coal and lignite power generation industry that are considered in the current share prices of utility and power generation companies. Using the results from our baseline Monte Carlo analysis, the changes in mean NPVs between the three scenarios are presented in Table 4.

Parameter	DCAS Hard Coal	Lignite	MCAS Hard Coal	Lignite	EPAS Hard Coal	Lignite
Mean NPV	-3.79	13.97	-1.12	10.90	-4.11	-0.48
Absolute Change	-2.67	3.07	-	-	-2.99	-11.38
Relative Change	-239%	28%	-	-	-267%	-104%

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). Numbers with the exception of the percentage change are in billion €.

Table 4: Value impacts of the hard coal and lignite power generation between the scenarios.

Since the coal phase-out by 2030 is in the focus of current debates, Table 4, again, underlines the decrease of valuation between the MCAS and EPAS. In order to estimate the potential adverse impacts that shares of exposed companies may experience in the case of the EPAS, this decrease must be transferred onto the shareholder value. We approach the individual stock devaluation by decomposing each company's stock price to the fraction concerned with the coal fired power generation.

In this study, the absolute decrease between the two scenarios is broken down to the affected hard coal and lignite fleets. Neglecting municipal utilities, the companies EnBW, LEAG, RWE, and Uniper account for 96% of the lignite installed capacity in 2019. For hard coal, 74% of installed capacity belongs to EnBW, ENGIE, LEAG, RWE, STEAG, Uniper, and Vattenfall. Table 10 in the appendix visualizes the proportions of the hard coal and lignite capacities, respectively. It is shown that EnBW, RWE, Uniper, and Vattenfall equally account for the largest capacities of hard coal power plants. Lignite power plants are, in contrast, predominantly owned by LEAG and RWE. However, only the shares of ENGIE, RWE, and Uniper are publicly traded and the reduction in valuation is assessed within the shareholder value. In doing so, the percentage of capacity is used to calculate the absolute loss between the MCAS and EPAS. The absolute loss, thus the stranded asset value, for lignite amounts to €11.38 billion and for hard coal to €2.99 billion. Next, this absolute loss is divided by the shares issued by the company. Table 5 presents the shareholder value outcome for each company.

Company	**Absolute Loss [billion €]**	**Loss per Share [€/share]**	
		Equity Ratio = 1.0	**Equity Ratio = 0.4**
Lignite			
RWE AG	5.58	9.07	3.63
LEAG AG	4.29	-	-
Uniper AG	0.54	1.48	0.59
EnBW AG	0.53	-	-
Others	0.45	-	-
Hard Coal			
EnBW AG	0.43	-	-
Uniper AG	0.41	1.11	0.44
RWE AG	0.40	0.66	0.26
Vattenfall GmbH	0.40	-	-
STEAG GmbH	0.27	-	-
ENGIE AG	0.22	0.09	0.04
LEAG AG	0.10	-	-
Others	0.76	-	-

Table 5: Absolute loss and loss per share of listed companies.

Table 5 displays different extents of vulnerability of the investigated shares. Presupposing that equity capital also covers for losses of debt, the cumulated losses for RWE's stock amount to 9.73 €/share indicating that RWE with its large coal fleet is greatly affected by the coal-phase out prior to 2038. It is followed by Uniper's share that suffers losses of 2.59 €/share. ENGIE has a lower exposure to hard coal power plants and accounts for losses of 0.09 €/share. Given an autonomous financing, losses for equity only occur for the share of equity in a power plant. Assuming a 60% debt-to-capital ratio (Fraunhofer Institute for Solar Energy Systems, 2018), the loss per share for RWE is 3.89 €/share. Uniper and ENGIE each account for losses of 1.03 €/share and 0.04 €/share, respectively. Given this range of financing structure, the financial analysis highlights the potential, yet immediate impact of regulatory changes to coal assets. The—currently unanticipated—phase-out of coal by 2030 not only has visible valuation impacts but directly impairs shareholder values of affected companies, especially RWE and Uniper.

In summary, this study puts stranded assets in direct relationship to equity prices, exemplary conducted for the stranded asset risk of coal-fired power generation in Germany. It therefore comprehensively addresses not only the operators' exposure but also the financial asset risk of coal assets stranding. This finding corroborates theoretical studies aiming at the potential impairment of bonds and equity in the financial sector, as discussed in Section 2. Furthermore, the coal phase-out impact on financial assets depicts a material risk in the near-term future in contrary to perception of the long-term nature of stranded carbon assets (Griffin et al., 2015). On that note, financing decisions typically of short-term time horizons should factor in the stranded asset risk linked to the coal phase-out in Germany (World Resources Institute and UNEP Finance Initiative, 2016). Nonetheless, this approach is limited, as it does not provide the distribution of losses with a temporal adjustment. The reduction in cash flows is not equally allocated across the years just like the installed capacities. However, this assessment presents an approximation to the extent of adverse impacts on stock prices.

5 Conclusion and Policy Implications

This research addresses the highly topical issue of a coal phase-out driven by the current discussion on the transition to a low-carbon economy in Germany. Employing a Monte Carlo based scenario analysis, we estimate a stranded asset value of the German coal-fired power plants in consequence of the approaching phase-out of coal. The underlying scenarios present three pathways including different phase-out schedules as well as regulatory and economic measures. A two-stage model is constructed that first replicates the merit order and thus determines the peak and base market clearing prices. Second, the model determines the annual cash flows for the NPV estimation. Within this framework, the prospective cash flows for hard coal and lignite power plants are estimated until the final decommissioning to assess the NPV. Additionally, input parameters are assigned distributions in order to display the uncertainty of policy and economic developments. Methodologically, this study further attempts to bridge the gap between the stranding physical and financial assets.

The results from our scenario analysis proves a decrease in valuation for lignite, if the installed capacities phase out until 2038 and moderate carbon and fuel prices are assumed. Unlike lignite, the NPV of hard coal increases by assuming the phase-out by 2038. This difference is mainly due to the substantially lower marginal costs of lignite ensuring a profitable position in the merit order. Looking at the phase-out scenario by 2030, we find evidence of a huge decrease in the valuation of lignite and a moderate decrease in the valuation of hard coal, compared to the phase-out scenario by 2038.

Taken together, the timeframe of coal-phase out by 2038 as proposed by the Coal Commission would help German hard coal and lignite industries to save €14.32 billion, but Germany will not be able to meet its reduction goals set in the Paris Climate Agreement in 2015. Apart from this, the scenario analysis demonstrates that the feed-in from renewable energy sources (and thus a decline in the residual base load) and higher carbon prices would lower the hard coal and lignite industry valuations.

Our study also shows two important implications of stranded assets: Firstly, physical assets become stranded through losses in revenues, as outlined within the exemplary study on the coal phase-out in Germany. This contributes to a broader understanding of stranded assets that is shifted from unanticipated write-downs to rather cash-effective valuation impacts. Secondly, we highlight the interconnection between physical assets and financial assets, which are adversely affected by carbon-intensive sectors. The decrease in valuation of the examined shares poses a significant financial risk to companies, financial institutions, and investors. Given the political uncertainty of the pathways and in progressive policy measures, our findings ultimately call for the incorporation of these climate-related risks into the investment decision-making process.

Concerning the state of research, this study draws further attention to the risks of climate change as well as the understanding of stranding physical assets and implications for the financial sector. Research has yet to proceed on the quantitative assessment of stranded assets related to climate change in order to grasp the complexity of this issue. Additional research is needed to determine the relationship between the stranding of physical and financial assets. For example, our study only investigates the limited case of a coal phase-out in Germany, while other country- or technology-specific cases might also be of interest for academics and policy makers. Hitherto, most studies are using DCF models to assess the value of stranded assets due to climate-related risk. However, Balint et al. (2017) and Monasterolo et al. (2019) call for more sophisticated models considering the complexity of our economic and financial eco-system.

References

Ansar, A., Caldecott, B., Tilbury, J., 2013. Stranded Assets and the Fossil Fuel Divestment Campaign: What Does Divestment Mean for the Valuation of Fossil Fuel Assets? University of Oxford's Smith School Stranded Assets Programme.

Atanasova, C., Schwartz, E.S., 2019. Stranded Fossil Fuel Reserves and Firm Value (Working Paper No. 26497). National Bureau of Economic Research. https://doi.org/10.3386/w26497

Balint, T., Lamperti, F., Mandel, A., Napoletano, M., Roventini, A., Sapio, A., 2017. Complexity and the Economics of Climate Change: A Survey and a Look Forward. Ecological Economics 138, 252–265.

Barnett, M., Brock, W.A., Hansen, L.P., 2019. Pricing Uncertainty Induced by Climate Change. SSRN Journal 46. https://doi.org/10.2139/ssrn.3440301

Bloomberg, 2019. Stock Quotes Database [WWW Document]. Bloomberg.com. URL https://www.bloomberg.com/markets/stocks (accessed 9.30.19).

Bloomberg New Energy Finance, 2013. Carbon Risk Valuation Tool. White Paper.

Bos, K., Gupta, J., 2019. Stranded Assets and Stranded Resources: Implications for Climate Change Mitigation and Global Sustainable Development. Energy Research & Social Science 56, 101–215. https://doi.org/10.1016/j.erss.2019.05.025

Bos, K., Gupta, J., 2018. Climate Change: The Risks of Stranded Fossil Fuel Assets and Resources to the Developing World. Third World Quarterly 39, 436–453. https://doi.org/10.1080/01436597.2017.1387477

Breitenstein, M., Nguyen, D.K., Walther, T., 2019. Environmental Hazards and Risk Management in the Financial Sector: A Systematic Literature Review (SSRN Scholarly Paper No. ID 3428953).

Brunner, C., Deac, G., Braun, S., Zöphel, C., 2019. The future need for flexibility and the impact of fluctuating renewable power generation. Renewable Energy. https://doi.org/10.1016/j.renene.2019.10.128

Bundesnetzagentur, 2019. Power Plant List for Germany [WWW Document]. URL https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/kraftwerksliste-node.html (accessed 7.10.19).

Byrd, J., Cooperman, E.S., 2018. Investors and Stranded Asset Risk: Evidence from Shareholder Responses to Carbon Capture and Sequestration (CCS) Events. Journal of Sustainable Finance & Investment 8, 185–202. https://doi.org/10.1080/20430795.2017.1418063

Cai, Y., Judd, K.L., Lontzek, T.S., 2017. The Social Cost of Carbon with Economic and Climate Risk. Hoover Institution Economics Working Paper.

Caldecott, B., 2017. Introduction to Special Issue: Stranded Assets and the Environment. Journal of Sustainable Finance & Investment 7, 1–13. https://doi.org/10.1080/20430795.2016.1266748

Caldecott, B., Dericks, G., Tulloch, D.J., Liao, X., Kruitwagen, L., Bouveret, G., Mitchell, J., 2017. Stranded Assets and Thermal Coal in China: An Analysis of Environment-Related Risk Exposure. University of Oxford's Smith School Stranded Assets Programme.

Caldecott, B., Howarth, N., McSharry, P., 2013. Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks. University of Oxford's Smith School Stranded Assets Programme.

Carbon Tracker Initiative, 2011. Unburnable Carbon - Are the World's Financial Markets Carrying a Carbon Bubble?

Carney, M., 2015. Breaking the Tragedy of the Horizon - Climate Change and Financial Stability. Speech by Mr. Mark Carney, Governor of the Bank of England and Chairman of the Financial Stability Board, at Lloyd's of London on 29 September 2015.

Client Earth, 2019. Kein Geld für alte Braunkohlekraftwerke.

Climate Analytics, 2018. Science Based Coal Phase-Out Pathway for Germany in Line With the Paris Agreement 1.5°C Warming Limit.

Dietz, S., Bowen, A., Dixon, C., Gradwell, P., 2016. 'Climate Value at Risk' of Global Financial Assets. Nature Clim Change 6, 676–679. https://doi.org/10.1038/nclimate2972

Ernst & Young, 2016. Climate change: The Investment Perspective.

European Commission, 2018. A Clean Planet for All: A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate-Neutral Economy.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019. Kommission Wachstum, Strukturwandel und Beschäftigung: Abschlussbericht. Berlin.

Forum Ökologisch-Soziale Marktwirtschaft, 2019. Lenkungs- und Verteilungswirkungen einer klimaschutzorientierten Reform der Energiesteuern, on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Fraunhofer Institute for Solar Energy Systems, 2018. Stromgestehungskosten Erneuerbare Energien.

German Bundestag, 2018. Ausarbeitung: Stilllegung von Kohlekraftwerken.

German Government, 2020. Bundesregierung | Aktuelles | Bund und Länder einigen sich auf Stilllegungspfad zum Kohleausstieg [WWW Document]. URL https://www.bundesregierung.de/breg-de/aktuelles/einigung-zum-kohleausstieg-1712888 (accessed 1.27.20).

Griffin, P.A., Jaffe, A.M., Lont, D.H., Dominguez-Faus, R., 2015. Science and the Stock Market: Investors' Recognition of Unburnable Carbon. Energy Economics 52, 1–12. https://doi.org/10.1016/j.eneco.2015.08.028

Heinrichs, H.U., Schumann, D., Vögele, S., Biß, K.H., Shamon, H., Markewitz, P., Többen, J., Gillessen, B., Gotzens, F., Ernst, A., 2017. Integrated Assessment of a Phase-Out of Coal-Fired Power Plants in Germany. Energy 126, 285–305. https://doi.org/10.1016/j.energy.2017.03.017

HSBC Global Research, 2013. Oil & Carbon Revisited: Value at Risk from 'Unburnable' Reserves.

HSBC Global Research, 2012. Coal and Carbon-Stranded Assets: Assessing the Risk.

Institut für Protest- und Bewegungsforschung, 2019. Fridays for Future: Profil, Entstehung und Perspektiven der Protestbewegung in Deutschland.

Institute for Climate Protection, Energy and Mobility, 2018. Stellungnahme zum Gutachten der Kanzlei „Redeker Sellner Dahs" für den Deutschen BraunkohlenIndustrieverein (Debriv).

Institutional Investors Group on Climate Change, 2015. Open Letter to Finance Ministers in the Group of Seven (G7).

International Energy Agency, 2018. World Energy Outlook 2018. Paris.

International Renewable Energy Agency, 2017. Stranded Assets and Renewables - How the Energy Transition Affects the Value of Energy Reserves, Buildings and Capital Stock.

IPCC, 2018. Special Report: Global Warming of 1.5°.

Jewell, J., Vinichenko, V., Nacke, L., Cherp, A., 2019. Prospects for Powering Past Coal. Nat. Clim. Chang. 9, 592–597. https://doi.org/10.1038/s41558-019-0509-6

Kepler Cheuvreux, 2014. Stranded Assets, Fossilised Revenues.

Krause, F., Bach, W., Koomey, J., 1989. Energy Policy in the Greenhouse. International Project for Sustainable Energy Paths.

Leipprand, A., Flachsland, C., 2018. Regime Destabilization in Energy Transitions: The German Debate on the Future of Coal. Energy Research & Social Science 40, 190–204. https://doi.org/10.1016/j.erss.2018.02.004

Markard, J., 2018. The Next Phase of the Energy Transition and its Implications for Research and Policy. Nat Energy 3, 628–633. https://doi.org/10.1038/s41560-018-0171-7

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J., Allen, M.R., 2009. Greenhouse Gas Emission Targets for Limiting Global Warming to 2°C. Nature 458, 1158–1162. https://doi.org/10.1038/nature08017

Mercer Investment Consulting, 2015. Investing in a Time of Climate Change.

Mercure, J.-F., Pollitt, H., Viñuales, J.E., Edwards, N.R., Holden, P.B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A., Knobloch, F., 2018. Macroeconomic Impact of Stranded Fossil Fuel Assets. Nature Climate Change 8, 588. https://doi.org/10.1038/s41558-018-0182-1

Michaels, R.J., 1994. Unused and Useless: The Strange Economics of Stranded Investment. The Electricity Journal 7, 12–22. https://doi.org/10.1016/1040-6190(94)90054-X

Monasterolo, I., Roventini, A., Foxon, T.J., 2019. Uncertainty of Climate Policies and Implications for Economics and Finance: An Evolutionary Economics Approach. Ecological Economics 163, 177–182. https://doi.org/10.1016/j.ecolecon.2019.05.012

Pahle, M., 2010. Germany's Dash for Coal: Exploring Drivers and Factors. Energy Policy 38, 3431–3442. https://doi.org/10.1016/j.enpol.2010.02.017

Rentier, G., Lelieveldt, H., Kramer, G.J., 2019. Varieties of Coal-Fired Power Phase-Out Across Europe. Energy Policy 132, 620–632. https://doi.org/10.1016/j.enpol.2019.05.042

Rinscheid, A., Wüstenhagen, R., 2019. Germany's Decision to Phase-out Coal by 2038 Lags Behind Citizens' Timing Preferences. Nature Energy 4, 1–8. https://doi.org/10.1038/s41560-019-0460-9

Sen, S., von Schickfus, M.-T., 2018. Climate Policy, Stranded Assets, and Investors' Expectations. Journal of Environmental Economics and Management 102–277. https://doi.org/10.1016/j.jeem.2019.102277

Silver, N., 2017. Blindness to Risk: Why Institutional Investors Ignore the Risk of Stranded Assets. Journal of Sustainable Finance & Investment 7, 99–113. https://doi.org/10.1080/20430795.2016.1207996

Steitz, C., Eckert, V., 2019. Coal Compensation Talks With Government Driven by Facts: RWE CEO [WWW Document]. Reuters. URL https://www.reuters.com/article/us-rwe-results-coal-idUSKCN1V40TT (accessed 9.30.19).

The Economist Intelligence Unit, 2015. The Cost of Inaction: Recognising the Value at Risk from Climate Change.

UBS, 2016. Stranded Assets: What Lies Beneath?

Umweltbundesamt, 2019. Energiebedingte Emissionen [WWW Document]. URL https://www.umweltbundesamt.de/daten/energie/energiebedingte-emissionen (accessed 10.16.19).

UNFCCC, 2015. Summary of the Paris Agreement [WWW Document]. URL https://unfccc.int/resource/bigpicture/ (accessed 6.13.19).

van der Ploeg, F., Rezai, A., 2019. The Risk of Policy Tipping and Stranded Carbon Assets. Journal of Environmental Economics and Management 102–258. https://doi.org/10.1016/j.jeem.2019.102258

World Resources Institute, UNEP Finance Initiative, 2016. Carbon Asset Risk Discussion Framework.

Zhao, S., Alexandroff, A., 2019. Current and Future Struggles to Eliminate Coal. Energy Policy 129, 511–520. https://doi.org/10.1016/j.enpol.2019.02.031

A Appendix

A.1.1 Sensitivity Analysis of the Base Load

Parameter	DCAS Hard Coal	Lignite	MCAS Hard Coal	Lignite	EPAS Hard Coal	Lignite
Minimum	-5.76	8.79	-2.64	2.39	-4.29	-3.32
Maximum	-4.60	13.18	-1.43	5.52	-2.80	-1.28
Mean	-5.18	11.00	-2.03	4.00	-3.64	-2.33
Range	1.16	4.39	1.20	3.13	1.49	2.04
VaR (α=0.05)	-5.41	9.73	-2.25	3.08	-3.88	-2.82
VaR (α=0.01)	-5.50	9.37	-2.35	2.81	-3.99	-2.99
STDEV	0.14	0.76	0.14	0.53	0.15	0.30
Rel. STDEV	0.0263	0.0693	0.0679	0.1320	0.0414	0.1291

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). We denote VaR as the Value-at-Risk and STDEV as standard deviation. Numbers are in billion €.

Table 6: Summary statistics of hard coal and lignite using the mean base load assumption.

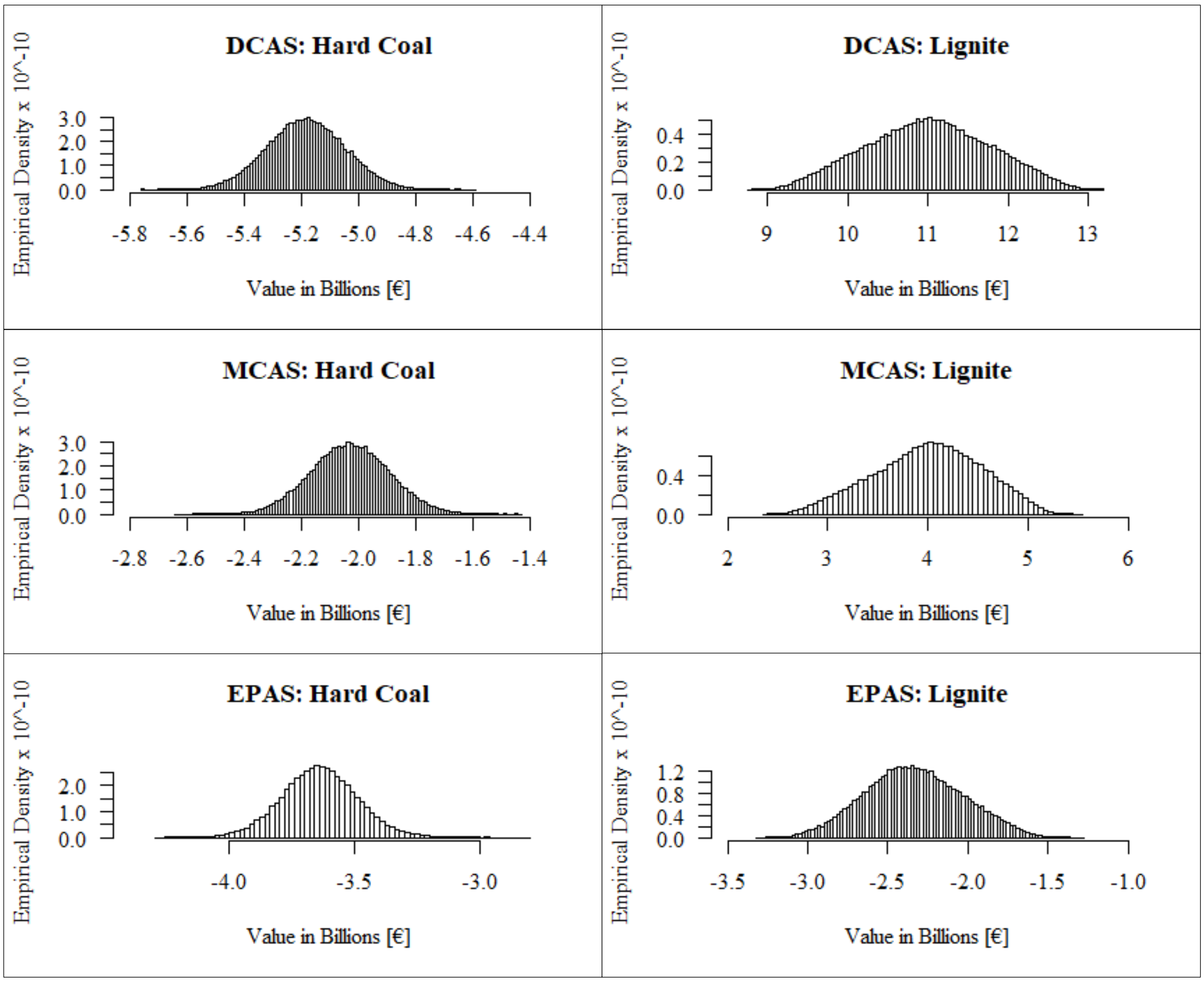


Figure 8: Distributions for each technology in each scenario using the mean base load assumption.

Parameter	DCAS Hard Coal	Lignite	MCAS Hard Coal	Lignite	EPAS Hard Coal	Lignite
Minimum	-5.23	4.76	-1.27	1.11	-4.16	-2.55
Maximum	-3.88	8.50	0.17	3.87	-2.31	-0.05
Mean	-4.59	6.66	-0.59	2.52	-3.31	-1.28
Range	1.35	3.73	1.43	2.76	1.85	2.50
VaR (α=0.05)	-4.85	5.59	-0.86	1.77	-3.59	-1.80
VaR (α=0.01)	-4.96	5.29	-0.97	1.54	-3.71	-1.98
STDEV	0.16	0.64	0.17	0.45	0.17	0.32
Rel. STDEV	0.0354	0.0961	0.2817	0.1794	0.0522	0.2472

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). We denote VaR as the Value-at-Risk and STDEV as standard deviation. Numbers are in billion €.

Table 7: Summary statistics of hard coal and lignite using the lower limit base load assumption.

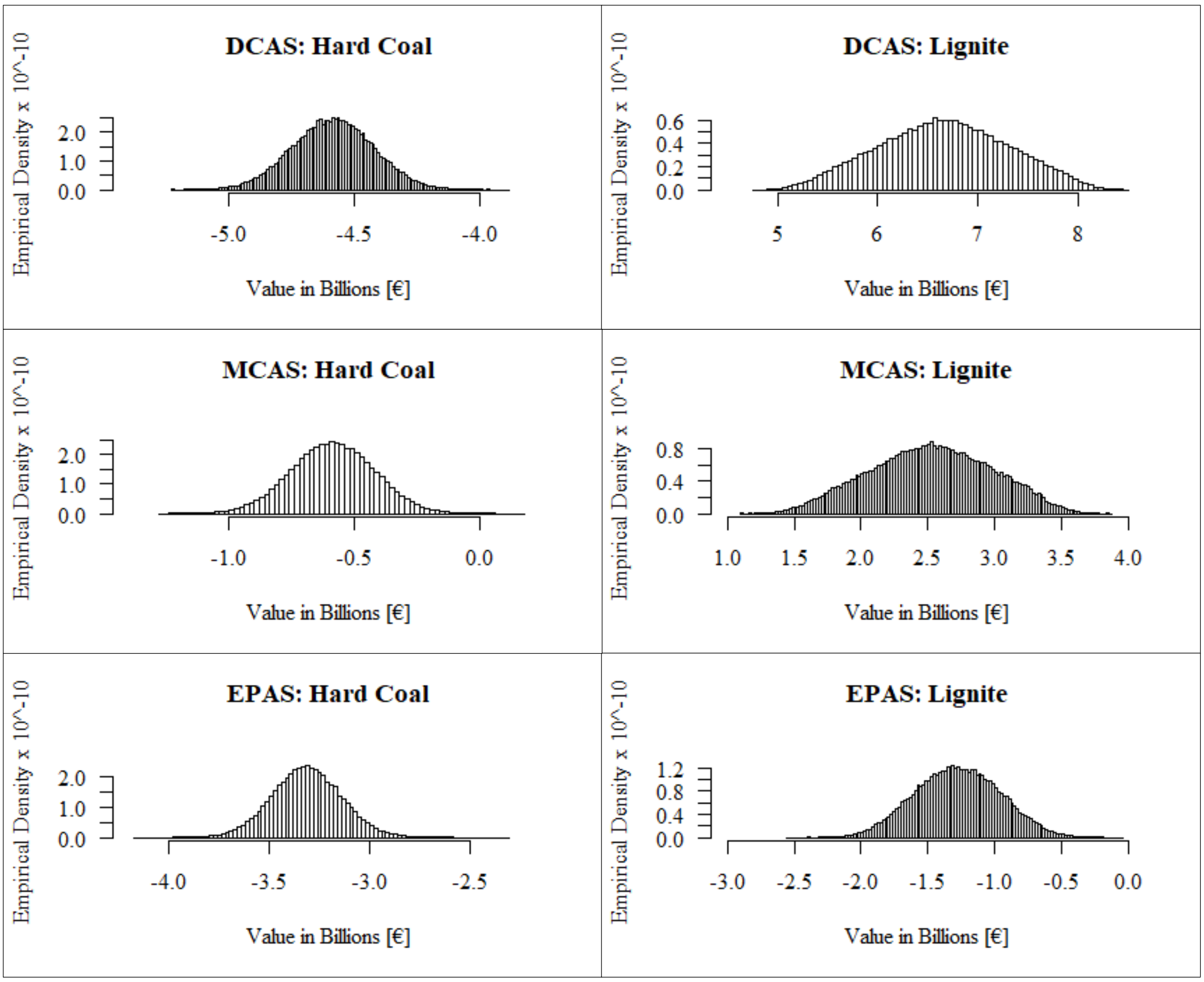


Figure 9: Distributions for each technology in each scenario using the lower limit base load assumption.

Parameter	**DCAS** **Hard Coal**	**Lignite**	**MCAS** **Hard Coal**	**Lignite**	**EPAS** **Hard Coal**	**Lignite**
Minimum	-5.86	5.21	-2.66	1.23	-4.79	-3.86
Maximum	-2.87	16.30	0.10	12.24	-2.45	0.88
Mean	-4.74	11.27	-1.67	5.92	-3.62	-1.68
Range	2.99	11.09	2.76	11.01	2.34	4.74
VaR (α=0.05)	-5.35	8.50	-2.17	2.85	-4.10	-2.91
VaR (α=0.01)	-5.52	7.20	-2.31	2.30	-4.31	-3.23
STDEV	0.45	1.46	0.36	2.53	0.27	0.79
Rel. STDEV	0.0956	0.1291	0.2163	0.4266	0.0754	0.4741

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS). We denote VaR as the Value-at-Risk and STDEV as standard deviation. Numbers are in billion €.

Table 8: Summary statistics of hard coal and lignite using the stochastic base load assumption.

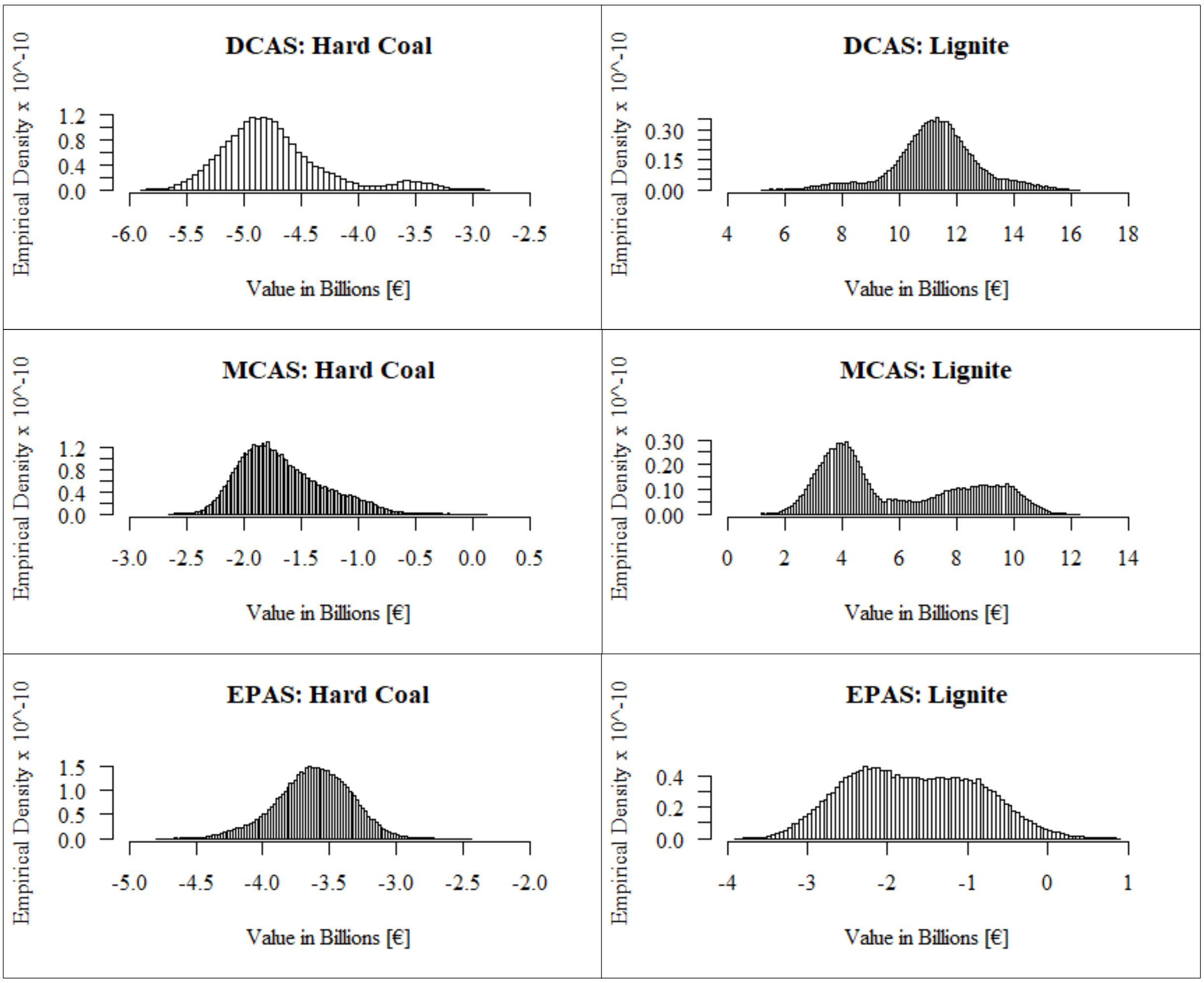


Figure 10: Distributions for each technology in each scenario using the stochastic base load assumption.

Baseload	DCAS	MCAS	EPAS
Stochastic	0.4272	0.4965	0.2196
Lower Limit	0.1046	0.2367	0.4930
Mean	0.1451	0.1182	0.1258
Upper Limit	0.2474	0.2838	0.3219

We refer to the different scenarios by Delaying Climate Action Scenario (DCAS), Maintaining Climate Action Scenario (MCAS), and Enforcing Paris Agreement Scenario (EPAS).

Table 9: Correlation of hard coal and lignite across the used baseload analyses.

A.1.2 Financial Market Implications

Company	Power Plants	Capacity [MW]	Share of Capacity [%]	Shares Outstanding [Mio.]
Lignite				
RWE AG	19	9273.00	49.02	614.75
LEAG AG	12	7127.00	37.67	-
Uniper AG	2	900.00	4.76	365.96
EnBW AG	1	875.00	4.63	-
Others	20	742.52	3.93	-
Hard Coal				
EnBW AG	8	3091.60	14.48	-
Uniper AG	6	2902.00	13.59	365.96
RWE AG	4	2888.70	13.53	614.75
Vattenfall AB	9	2831.00	13.26	-
STEAG GmbH	5	1934.00	9.06	-
ENGIE SA	3	1553.00	7.27	2435.28
LEAG AG	1	690.00	3.23	-
Others	37	5458.89	25.57	-

Capacity values and power plant ownership based on the power plant list as of March 2019.

Source: Own presentation based on Bloomberg (2019) and Bundesnetzagentur (2019).

Table 10: Percentages of hard coal or lignite capacity share.