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To cite this article: Roman Mendelevitch, Christian Hauenstein & Franziska Holz (2019) The death spiral of coal in the U.S.: will changes in U.S. Policy turn the tide?, *Climate Policy*, 19:10, 1310-1324, DOI: [10.1080/14693062.2019.1641462](https://doi.org/10.1080/14693062.2019.1641462)

To link to this article: <https://doi.org/10.1080/14693062.2019.1641462>



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The death spiral of coal in the U.S.: will changes in U.S. Policy turn the tide?

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ABSTRACT

The administration of U.S. President Donald Trump has promised to stop the ongoing spiralling down of the U.S. coal industry. We discuss the origins of the decline and assess the effects of policy interventions by the Trump administration. We find that, with fierce competition from natural gas and renewables, a further decrease of coal consumption must be expected by the old and inefficient U.S. coal-fired electricity generation fleet. By contrast, we consider the overly optimistic (for coal producers) view of the U.S. Energy Information Agency, and test whether the tide for the U.S. coal industry could turn as a result of three potential support measures: (i) revoking the Clean Power Plan (CPP); (ii) facilitating access to the booming Asian market; and (iii) enhanced support for Carbon Capture, Transport and Storage (CCTS) technology. We investigate the short-term and long-term effects on U.S. coal production using a comprehensive partial equilibrium model of the world steam coal market, COALMOD-World (Holz, Haftendorn, Mendelevitch, & von Hirschhausen, 2016). We find that revoking the CPP could stop the downward trend of steam coal consumption in the U.S., but even allowing for additional exports, will not lead to a return of U.S. coal production to the levels of the 2000s, that is, over 900 Mt per year. When global steam coal use is aligned with the 2°C climate target, U.S. steam coal production drops to around 100 Mt per year by 2030 and below 50 Mt by 2050, even if CCTS is available and exports via the U.S. West Coast is possible.

Key policy insights

- Declining U.S. coal use is primarily caused by competition from natural gas and renewables not by environmental regulation of the coal sector.
- Without substantial policy support, U.S. coal-fired generation capacity will continue to decline rapidly.
- Revoking the Clean Power Plan will lead to about one eighth higher U.S. coal production in the next years.
- Carbon Capture and Storage does not prevent the rapid decline of coal use required under stringent climate policy.
- Even in the most extreme pro-coal scenarios with additional export possibilities, U.S. coal production will not return to its pre-2010 levels.


ARTICLE HISTORY

Received 15 February 2019
Accepted 4 July 2019

KEYWORDS

U.S. coal sector; Trump administration; clean power plan; steam coal; coal ports; CCS

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 Supplemental data for this article can be accessed <https://doi.org/10.1080/14693062.2019.1641462>.

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1. Introduction

The United States (U.S.) under former President Obama (2008–2016) showed great ambitions to take a leading role in climate policy, in particular, through the Climate Action Plan. Things changed dramatically with the inauguration of President Trump in January 2017. He made clear that climate change would no longer be an issue of high priority for the U.S. government (The White House, 2017). Trump's (2017) executive orders revoked and rescinded a number of 'Energy and Climate-Related Presidential and Regulatory Actions' and determine that 'All [Environmental Protection] Agency Actions that Potentially Burden the Safe, Efficient Development of Domestic Energy Resources [like coal]' shall be reviewed. President Trump has indeed aggressively rolled back environmental regulation and commitments, with a complete re-organisation of the environmental administration and, most prominently, by announcing to leave the Paris Agreement and replacing the Clean Power Plan with the Affordable Clean Energy rule (EPA, 2018). One of his declared primary goals during the election campaign, but also in his presidency, is to 'End the War on Coal!' and to revitalize the coal sector (Davenport, 2016). This alludes to the strong role that the U.S. coal sector used to play in the past and its enormous and fast decline in the last decade, amounting to –35% in only ten years between 2008 and 2018.

The Trump administration's efforts to support coal are manifold and extend to a broad range of policy areas. Under the Obama and other previous administrations, energy and environmental policy were used as intermediaries to address climate change, given the lack of consensus at a federal level on climate policy. However, Trump actually uses energy and environmental policy to address his industrial policy targets – which may have strong implications for climate policy. While supporting domestic coal-fired power generation is the most obvious form of support, and was the first to be announced after Trump's election, another focus has been on relieving pressure on mining and, more recently, on expanding access to the international market for U.S. coal. The drastic change in U.S. climate policy under President Trump has sparked research on possible global effects on emission reduction efforts. Jotzo, Depledge, and Winkler (2018) provide a first overview of the emerging literature.

According to Höhne et al. (2017) changes of environmental regulations under the Trump administration, without compensation by other actors, are likely to cause U.S. emissions to flatten instead of continuing to decline, in the short term. However, they argue that, from a 2030 perspective, the policy rollbacks are not likely to have a major impact. Similarly, Urpelainen and Van de Graaf (2018) argue that Trump's policy interventions will not reverse trends in U.S. greenhouse gas emissions. Somewhat in contrast, Erickson and Lazarus (2018) note that ending the Obama administration's moratorium on fossil fuel extraction from U.S. federal land – as done by the Trump administration – may lead to foregoing emission savings of up to 280 Mt tons CO₂ annually by 2030. Undertaking a rough sector-by-sector assessment, Galik, DeCarolis, and Fell (2017) conclude that the effect of Trump's policies will at most be a flattening of U.S. CO₂ emissions at 2015 levels. Depending on the number of his terms, they estimate a total increase in emissions of 12 GtCO_{2e} to 20 GtCO_{2e} until 2050. Taking a global perspective, Selby (2018) emphasises the negative effect on the global energy transition.

While all these studies highlight the decisive role of coal in the energy mix to assess future emission profiles, they lack a detailed analysis of the current and future drivers in the U.S. energy sector. Moreover, they fail to analyse the role of the U.S. as a major coal producer and supplier on the international steam coal market.¹ In sum, it remains unclear from the literature, if the policy rollback or newly introduced policies can slow down the decline of the U.S. coal industry or even turn the tide.

Our paper tries to fill that gap. Thus our research addressed the question of whether Trump's policies can effectively reverse the death spiral (i.e. strong decline of U.S. coal production since 2008) of the U.S. coal industry. For this, we take into account domestic and global coal sector inter-relations. We assess the role of previously tightened environmental regulation compared to cheap alternative electricity generation (gas, renewables) and the age structure of the US coal-fired generation fleet. We then detail current policy measures intended to support the U.S. coal sector. We develop several scenarios around the main policy measures in order to quantify their effects on U.S. coal production and exports using the COALMOD-World model.

2. Political support for the U.S. coal sector under Trump

In this section, we give an overview of recent developments in coal consumption and production in the U.S. Subsequently, we derive main domestic policy drivers that may influence future U.S. coal production. Finally, we focus on three more concrete policy measures regarding coal, which are in place or proposed by the Trump administration as a basis for our scenarios in the subsequent sections. In our scenario analysis, we aim at quantifying potential effects and interdependencies. Therefore, we deliberately abstract from the underlying policy process and possible entry points to postpone or prevent policy implementation, as this is not in the focus of the paper.

2.1. *The death spiral: development of the U.S. coal sector in the last decade*

In the past decades, the coal sector has been a central element of U.S. power generation as well as of the U.S. mining sector. In this section, we want to highlight the recent developments of the sector, both in terms of coal use (consumption) and in terms of coal mining (production).

U.S. domestic coal consumption and production peaked in 2007/2008 at around 1.0–1.1 billion tons.² Thereafter, a steep decline set in, with consumption dropping to 650 million tons (Mtpa) in 2017, the lowest value since 1982. Production declined to 660 Mtpa in 2016, recovering slightly in 2017 to 700 Mtpa (see Figure S1 in Supplementary Material).³ U.S. coal exports during this period were between 55 and 115 Mtpa, with a relatively stable share of metallurgical coal at around 60%.⁴

Many studies have analysed the decline of the U.S. coal sector (e.g. Coglianesi, Gerarden, & Stock, 2017; Culver & Hong, 2016; Houser, Bordoff, & Marsters, 2017; Kok, 2017; Schlissel, Sanzillo, & Feaster, 2018; Sussams & Grant, 2015; U.S. DoE, 2017). Overall, the explanations can be divided into two categories. The first focuses on domestic demand, especially the demand for steam coal in the electricity sector. The second looks at U.S. coal production, which largely depends on domestic demand, but is also subject to global demand and other factors such as mining regulation.

2.1.1. *Demand side: coal-fired power generation in the U.S.*

Approximately 93% of domestic coal consumption, relatively constant over the last ten years, goes to the U.S. electricity sector, while the remaining 7% is used by industry, mainly as metallurgical coal. Between 2007 and 2017, U.S. electricity generation from coal declined by about 40% (see note 4). Total coal-fired electric generation capacity peaked in 2011 with about 318 GW, and then declined to about 257 GW in 2017.⁵

There is a broad consensus that the drop in U.S. natural gas prices is the main driver behind this decline. The so-called shale gas revolution, which started around 2007, increased U.S. natural gas production by about 45% between 2007 and 2017 and led to a dramatic decrease in the natural gas price.⁶ Thus, natural gas has outcompeted coal as a cheap fuel source for electricity generation in many regions of the U.S.,⁷ with the share of electricity generation from natural gas increasing from 22% in 2007 to 32% in 2017 (see Figure S1).

In the same period, the share of electricity generation from renewables (without hydropower) increased from 2.5% to 10%. Average levelized cost of electricity from (unsubsidized) wind and solar PV declined by 67% and 86%, respectively, between 2009 and 2017 (Lazard, 2017, p. 10). Additionally, federal tax incentives for renewables (the Production Tax Credit) and state renewable portfolio standards supported the expansion of wind and solar power generation in addition to improved efficiencies and capacity factors of wind turbines and solar PV modules (Schlissel et al., 2018). At the same time, U.S. final electricity demand has stayed flat since 2007 (see note 3). Thus, coal-fired electricity generation not only lost relative market share, but also in absolute terms.

Besides competition from cheap natural gas and renewables, environmental regulations for coal-fired power plants were tightened in the past decade (see Table S1 in Supplementary Material for an overview). The Obama administration promulgated nine regulations directly addressing coal-fired power generation. Opinions diverge on the actual effects of the environmental regulations on coal-fired power generation. Out of the nine Obama-era regulations, only four took effect before 2016. Coglianesi et al. (2017, pp. 2–3) and Houser et al. (2017, p. 22) both estimate that environmental regulations (mainly the Cross-State Air Pollution Rule (CSAPR) and the new Mercury and Air Toxic Standards (MATS)) were responsible for approximately 10% of the decline in coal mining output between 2008 and 2016. In contrast, Culver and Hong (2016) argue that the decline of U.S.

coal between 2008 and 2015 had little to do with environmental regulation due to relatively low costs of compliance, but was rather caused by the fierce competition with natural gas noted above.

Another key factor for the decline is the composition of the U.S. coal-fired generation fleet. With its high share of small and very old units, it has been particularly vulnerable to price and cost pressure (U.S. DoE, 2017). As of April 2018, the capacity-weighted average age of operating coal-fired units was 39.7 years and the average capacity of the operating units was only 323 MW.⁸ About 88% of coal-fired capacity was built before 1990 and 52% of currently operating capacity is older than 40 years, with 14% even older than 50 years. Figure 1 shows the average age and size of retired coal units. Until 2017, retired units were on average significantly older and smaller than the units of the remaining fleet. Usually, they were not equipped with significant SO₂ control installations (U.S. DoE, 2017). However, since early 2018 larger and younger, more efficient and largely regulation-compliant units have also been retired.

According to Shearer, Mathew-Shah, Myllyvirta, Yu, and Nace (2018, p. 14) there are no new coal-fired power plants planned or currently under construction in the U.S., while the EIA lists two power plants that are supposed to come online in 2020 and 2022, respectively. The currently applicable ‘new source performance’ emission standard of no more than 1,400 lb (~635 kg) CO₂/MWh would effectively require the use of CCTS at these units.⁹ This also applies for major refurbishments or modifications of existing units that trigger New Source Review (NSR),¹⁰ which are therefore not very likely to happen. Rather, more coal-fired power plants are expected to retire over the next years. Feaster (2018) estimates that (at least) 36.7 GW will be retired between 2018 and 2024. Rhodium Group even expects the retirement of 60–86 GW of net summer coal capacity by 2025 compared to 2018 (John, 2018).

This data clearly shows that the current U.S. coal-fired generation fleet will not sustain electricity production at current levels in the medium-term without substantial refurbishment and investments. Tightened environmental regulation has only exacerbated a competitive situation, which was gloomy before. Therefore, one must expect a further decrease of U.S. coal consumption.

2.1.2. Supply side: U.S. coal production

U.S. coal is extracted primarily from three large regions: the Appalachian region near the Atlantic Coast, the Interior Region, extending from Lake Michigan to Texas, and the Western Region with the Powder River Basin (PRB) and

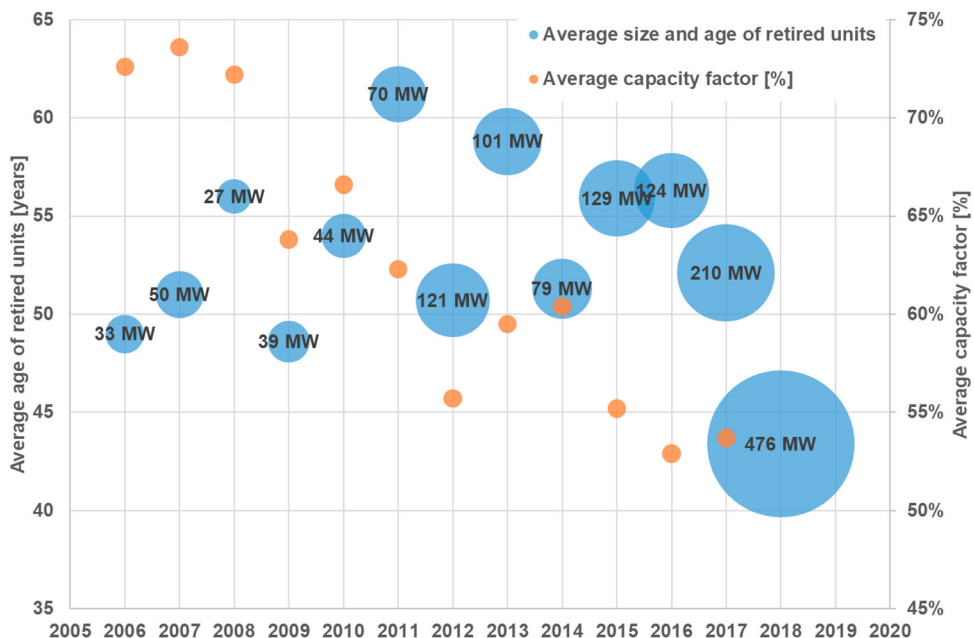


Figure 1 . Average age and size of retired coal-fired power generation units since 2012 (net summer capacity; all sectors; utility scale); and average capacity factor of the U.S. coal-fired power generation fleet 2006–2017 (all sectors, utility scale facilities). Source: own calculations based on EIA data (<https://www.eia.gov/electricity/data/eia860M/> and <https://www.eia.gov/electricity/annual/>, last accessed January 15, 2019).

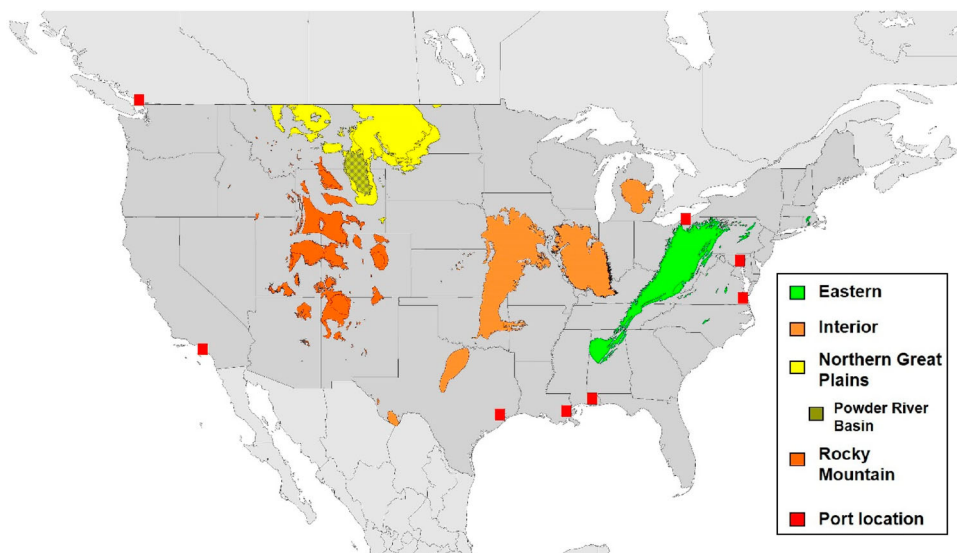


Figure 2. Main U.S. coal extraction regions and port locations. Source: Own depiction based on U.S. Geological Survey data, available at <https://pubs.usgs.gov/of/2012/1205/>, last accessed January 18, 2019.

the Rocky Mountains as main coal basins (Figure 2).¹¹ As coal extracted in the U.S. goes in large part to the domestic power sector, the decrease in domestic coal use has also led to a decline in U.S. coal production.

Some U.S. steam and metallurgical coal is exported. The size of these exports has varied in the past decades, mostly driven by global coal prices and demand. U.S. coal producers generally act as swing suppliers for the international coal market, strongly following the fluctuations in international coal prices with the size of their supplies to the market. Exports were in the range of 4% to 13% of U.S. coal production (54–114 Mt) in the period 2006–2017 (see note 4). About 50% to 70% of U.S. coal exports are metallurgical coal. Due to their geographic location, the coal regions are differently connected to export ports: While coal from the Appalachian region and the Interior Basin can be shipped to the export terminals on the Atlantic Coast as well as the Gulf of Mexico, these terminals are too expensive to be reached by the Western Region and PRB coal. Some PRB coal is exported via the Canadian province of British Columbia and some small quantities via terminals in California.

After 2008, global coal prices were rising and Asian demand was expected to grow continuously. Between 2008 and 2011, U.S. coal companies invested heavily in coal assets domestically and abroad to meet forecasted international coal demand. However, global demand peaked in 2013/2014 and the situation of U.S. coal producers completely turned. The combined market capitalization of the four leading coal companies in the U.S. (Alpha Natural Resources, Arch Coal, Peabody Energy, and Walter Energy) dropped from \$44.6 billion in 2011 to just \$45 million in 2016.¹² These companies had borrowed large sums for the acquisition of assets to meet the expected Asian demand growth. By 2015, debts exceeded their market capitalization by far. These four big – as well as many smaller – U.S. coal producers therefore had to file for bankruptcy around 2015/16. These bankruptcies and the market adjustments in the coal-mining sector of course had a sizeable impact on employment. The total number of coal mine employees in the U.S. dropped from 92,000 in 2011 to 52,000 in 2016.¹³ Jobs in the Appalachian region were especially affected, with about 50% of the 60,000 jobs in 2011 vanishing by 2016. During the same period, coal mine productivity in the Appalachian region increased by on average 13%, yet remaining at about 10% of levels in the PRB.¹⁴

In 2017, after large write-offs of liabilities, Peabody Energy, Arch Coal and Alpha Natural Resources, as well as several smaller-size coal companies, emerged from bankruptcy. However, the situation for the U.S. coal sector remains difficult and expectations for a recovery of the coal sector have been low. Indeed, bankruptcies of U.S. coal companies have continued in recent years, now mostly by companies that serve the domestic market.

2.2. Rescinding the Obama administration's national coal policies

Promising relief, the Trump administration tries to support the U.S. coal sector both on the demand (i.e. in the electricity sector) and supply sides (i.e. coal mining). Here, we briefly discuss the individual measures. For a more detailed overview of the relevant policies and their status under the Obama and the Trump administration and associated references, see Table S1 in the Supplementary Material.

For the U.S. electricity sector, the Environmental Protection Agency (EPA) was ordered to review the Clean Power Plan (CPP). The CPP was enacted by the Obama Administration in 2015 and was originally scheduled to come into effect in 2022. It set limits on CO₂ emissions from (existing) power plants by defining nationwide emissions performance standards. To replace the CPP, the EPA proposed the so-called Affordable Clean Energy rule (ACE) (EPA, 2018). On 19 June 2019, the final ACE was issued by the EPA and thereby the CPP was finally repealed (EPA, 2019a). In contrast to the CPP, the ACE only addresses coal-fired power plants and leaves it to the states to set their individual standards. Moreover, in the ACE proposal, the EPA proposed an update of the NSR, such that the requirement to apply for approval for major modifications of power plants, and hence the requirement to update emission control technologies, would be softened (EPA, 2018). This reform of the NSR is not part of the issued ACE but is supposed to be implemented with a separate final action (EPA, 2019b, p. 5).

Moreover, conventional power generators continue to lobby for financial support from the Trump administration, which has been very responsive. For example, in 2017, the Department of Energy requested that the profits of new and existing coal-fired (and nuclear) power plants should be guaranteed by the Federal Energy Regulatory Commission (FERC). Moreover, the Trump administration is contemplating using emergency powers to subsidize coal-fired power plants. Grid operators could be ordered to buy electricity from coal and nuclear power plants to prevent these from shutting down. So far, the FERC has denied these requests.

On the supply side, the Trump administration has enacted several law changes to support coal. Most prominently, Trump lifted the moratorium on new coal mine leases on federal land, which his predecessor had introduced in 2016, and reduced the size of two national monuments in Utah. Further, the Valuation Rule (of exported coal) of the former Obama administration was rescinded by the Department of Interior in August 2017. This rule was supposed to close a loophole that allowed coal exports without paying royalties to the federal government. Additionally, the Royalty Policy Committee, an Interior Department advisory panel, proposed to reduce royalties to be paid by companies extracting coal, oil and gas from federal lands and U.S. waters. The Obama-era environmental regulations Stream Protection Rule and Resource Management Planning, both affecting mining activities, were repealed in the first months of 2017.

2.3. CCTS: the Silver Bullet?

Carbon Capture, Transport, and Storage (CCTS; often also Carbon Capture and Storage, CCS) is seen by many as a necessary measure to keep global warming below 2°C (Haszeldine, Flude, Johnson, & Scott, 2018). Many also see it as an opportunity to continue the use of coal for power generation (IEA/OECD, 2017b). However, the expected rate of technological and economic progress of CCTS and the implementation of large-scale CCTS projects has not, so far, been achieved, neither for coal-fired power plants with CCTS, nor for CCTS in other sectors (Hirschhausen, Herold, & Oei, 2012; Mendelevitch, Kemfert, Oei, & von Hirschhausen, 2018; Schlissel & Wamsted, 2018). Costs of new as well as retrofitted CCTS-equipped coal-fired power generation units are currently prohibitively high compared to new gas-fired power plants and renewables, and expectations for cost reductions of CCTS technology are low (EIA, 2018b; Schlissel & Wamsted, 2018). In the U.S., CCTS is currently largely supported by the oil industry, which participates in the CCTS value chain as CO₂ user for Enhanced Oil Recovery (Doukas, Redman, & Kretzmann, 2017).

President Trump is eager to support 'clean coal'.¹⁵ However, he has not distinguished himself as a bold CCTS supporter so far. Still, with the Bipartisan Budget Act of 2018, support for CCTS projects was increased by providing substantial tax credits for such projects (see note 9). This reformed tax incentive could spur further development and application of CCTS, also in the power generation sector. However, the increase of support remains low compared to current cost estimates and it is therefore questionable whether a significant number of new or

retrofitted coal-fired power plants with CCTS will be in place in the near term (Bennett & Stanley, 2018). Moreover, governmental funding for CCTS research and development has been significantly reduced at the same time.

2.4. Exports via the U.S. West Coast

In the context of declining domestic demand and rising world market prices, U.S. coal producers were eager to find new outlets on the international coal market, especially in Asia (Cornot-Gandolphe, 2015; IEA/OECD, 2013, p. 99; Houser et al., 2017). However, export infrastructure is key to this issue. Currently, the only way to export U.S. coal from the West Coast is via small capacities in California (total of 6 Mtpa in three ports) and Canadian ports in British Columbia. Exporting via British Columbia requires long distance rail transport which is used at full capacity (Power & Power, 2013). Thus, in the wake of the strong increase in Asian and world coal demand in the 2000s, plans were made to construct export terminals along the U.S. West Coast, in California, Oregon and Washington. Table S2 in the Supplementary Material details the existing and proposed export terminals along the U.S. American and Canadian West Coast; more recently, alternative options such as exporting via Mexico's Pacific Coast are also being discussed. The Trump administration has started to show some interest in the topic with a request for 'a white paper assessing opportunities to advance U.S. coal exports' by the Secretary of Energy (NCC, 2018, IX).

There have been extensive local concerns about public health, environmental impacts and consequences for global CO₂ emissions associated with new export infrastructure (Western Interstate Energy Board, 2012). With lower global coal prices after 2013, exporting PRB coal via new West Coast ports somewhat lost its attractiveness. By 2017, all proposed terminals except two were shelved and did not proceed further due to denied (environmental) permits or because the proponents themselves abandoned the projects. The two remaining planned terminals are the Millennium Bulk Terminal (40 Mtpa) and the Oakland Bulk and Oversized Terminal (4.5 Mtpa), which are still undergoing court challenges, but are equally unlikely to be realized. Indeed, these terminal projects have not received explicit support by the Trump administration (Volcovici, 2018).

Given the effective opposition to commercial ('civilian') export terminal projects, the Trump administration, in particular the Secretary of the Interior, suggests using military bases for coal exports instead, or at least consider the construction of such terminals on federal lands.¹⁶ However, given modest global coal prices and ample supplies from other world regions, in addition to large (idle) port capacities in other U.S. regions (coal ports at the Atlantic Coast and the Gulf of Mexico were running at average utilization rates of only 24% in 2016 (IEA/OECD, 2017b, p. 129)), it appears unlikely that these ideas will be realized.

3. Modelling U.S. and global coal markets with the COALMOD-World model

We use the COALMOD-World model to assess the implications of the different scenarios (detailed below) on U.S. and international steam coal markets (see Holz et al. (2016) for a detailed description of the model). COALMOD-World is a comprehensive partial equilibrium model of the world steam coal market that features profit-maximizing producers and exporters supplying to a competitive global market. It assesses effects on global steam coal trade, prices, and investments in mines and infrastructure. The model has been used to assess climate policy implications in various contexts (cf. Haftendorn, Kemfert, & Holz, 2012; Holz, Kafemann, Sartor, Scherwath, & Spencer, 2018; Mendelevitch, 2018; Richter, Mendelevitch, & Jotzo, 2018).

In the COALMOD-World model, we differentiate between different producing and consuming regions and take into account distance-related transportation costs, in addition to region-specific production and investment costs of coal mining. For the U.S., we distinguish the three main geographical mining regions as four separate model nodes (PRB, Rocky Mountains, Appalachia, and Interior Basin). On the consumption side, we differentiate between consumption nodes at the country and regional level depending on their individual levels of coal demand and their paces of coal demand adjustment. We divide the U.S. coal market into five regional nodes: USA-West, USA-North-Central, USA-South-Central, USA-Southeast, and USA-Northeast (Holz et al., 2016).

3.1. Policy scenarios and data

In Section 2 above, we detail a number of current and potential future policy measures supposedly targeted at revitalizing the U.S. coal sector. Focussing on the effects of the CPP, possible West Coast exports, and support for CCTS, we develop six policy scenarios, which we embed in either a *moderate* or an *ambitious climate policy* pathway (see Table 1).

The *moderate climate policy* pathway sees the global community taking some limited action against climate change at the ambition level of the current Nationally Determined Contributions (NDCs). However, this sets the world on course for a rise in global mean temperature by some 3.2°C (2.6–4.0°C) above pre-industrial levels by the end of this century (Fekete et al., 2017, p. 1). Global consumption of steam coal continues at a relatively high level and decreases only little below current consumption levels by 2050. We do not assume any large-scale application of CCTS under the *moderate climate policy* pathway, because the motivation to deploy this costly technology is insufficient if no strong, binding climate targets exist (Budinis, Krevor, Dowell, Brandon, & Hawkes, 2018; Haszeldine et al., 2018).

The *ambitious climate policy* pathway implies a drastic reduction of GHG emissions from fossil fuel consumption to limit global warming to 2°C by 2100. The U.S., possibly under a new administration, returns to an active mitigation strategy. Global steam coal consumption is reduced significantly by 2050. We derive growth rates of steam coal consumption, including in the U.S., from the 450 ppm scenario of IEA's WEO 2016, which is in line with the 2°C target and includes a significant amount of coal-fired power generation capacity equipped with CCTS technology by 2040 (260 GW, see IEA/OECD, 2016, p. 208). We use this data to assess the effect of increased support and availability of CCTS on the coal supply.

The first three scenarios (*Rollback*, *CPP*, *Rollback_ports*) fall under the *moderate climate policy* pathway. For all scenarios in this pathway, we use U.S. coal consumption forecasts from AEO 2018 (EIA, 2018a) which are rather high given the power plant fleet's vintage structure and current energy economic trends (see Section 2). However, they provide a good representation of the views of the Trump administration regarding future U.S. energy sector developments, which are in the focus of our analysis.

The scenario *Rollback* represents U.S. domestic coal consumption induced by new, lax environmental policy under Trump. More concretely, this scenario assumes that the CPP is cancelled, resulting in retrofitting investments and live-time extensions for existing coal power plants and consequently increasing domestic coal demand in the U.S. We contrast this situation to the scenario *CPP*, where the CPP is assumed to remain in place. The scenario *Rollback_ports* assumes that, in addition to measures from the scenario *Rollback*, the Trump administration manages to extend support for the U.S. coal sector by pushing through West Coast coal export ports against massive opposition.

The *ambitious climate policy* pathway includes the scenarios *2°C_CCTS*, *2°C_no-CCTS*, and *2°C_CCTS_ports*. The scenario *2°C_CCTS* assumes that the increased support for CCTS under Trump and possible further support make CCTS available as a mitigation option for coal-fired power stations in the long run. Thus, steam coal consumption

Table 1. Scenario overview.

Pathway (global dimension)	Scenario	Clean Power Plan	West Coast ports	CCTS	2°C target
Moderate climate policy	<i>Rollback*</i>	–	–	–	–
	<i>CPP**</i>	+	–	–	–
	<i>Rollback_ports***</i>	–	+	–	–
Ambitious climate policy	<i>2°C_CCTS****</i>	+	–	+	+
	<i>2°C_no-CCTS*****</i>	+	–	–	+
	<i>2°C_CCTS_ports</i>	+	+	+	+

**Rollback*: assumes growth rate for coal consumption based on IEA WEO 2017 NPS (IEA/OECD, 2017a); for U.S.: reference consumption from AEO 2018 (EIA, 2018a), this reflects the current legal situation as of 2017 without CPP measures.

***CPP*: assumes growth rate for coal consumption based on IEA WEO 2017 NPS (IEA/OECD, 2017a); for U.S.: CPP consumption from AEO 2018 (EIA, 2018a).

****ports*: assumes possibility to expand western port export capacity by 50 Mt each 5 years from 2020 onwards.

*****2°C_CCTS*: assumes growth rate for coal consumption based on IEA WEO 2016 450 ppm scenario (IEA/OECD, 2016)

******2°C_no-CCTS*: assumes growth rate for coal consumption based on IEA WEO 2016 450 ppm without coal consumed by coal-fired power generation capacities equipped with CCTS. (see Box S1 in the Supplementary Material for details).

does not have to be phased out entirely by 2050, while the 2°C climate target is still achieved. The scenario 2° C_{no-CCTS}, in contrast, assumes that CCTS will not be an economically viable option for coal-fired power plants until 2050. Hence, to achieve the 2°C target, coal consumption has to decline even further. The scenario 2° C_{CCTS_ports} extends the 2° C_{CCTS} scenario by allowing additional West Coast exports.

3.2. Results on future coal consumption

Figure 3 shows global and U.S. steam coal consumption, and U.S. steam coal production in all six scenarios. At the global scale, the three scenarios in the *moderate climate policy* pathway differ only slightly (at max. 170 Mtpa or 3% in 2050). As expected, average global steam coal consumption in the *ambitious climate policy* pathway is significantly lower, no matter whether CCTS is available or not. While consumption in all three scenarios of the *moderate climate policy* pathway is around 5,600 to 5,700 Mtpa in 2030 and around 5,300 to 5,500 Mtpa in 2050, it drops to around 2,800 Mtpa (CPP) to 3,100 Mtpa (Rollback & Rollback_ports) in 2030 and 200 Mtpa (2° C_{no_CCTS}) to 800 Mtpa (2° C_{CCTS} & 2° C_{CCTS_ports}) in 2050 in the *ambitious climate policy* pathway, respectively. Even if available, CCTS can only decelerate the global phase-out of coal-fired power generation, but not stop it entirely. Cumulative CO₂ emissions from coal-fired power generation between 2015 and 2050 amount to approximately 470–480 Gt (on average ca. 10 Gt per year) in all three scenarios in the *moderate climate policy* pathway (see Table S3 in Supplementary Material). In the *ambitious climate policy* pathway, less than half the amount of CO₂ is released into the atmosphere from coal-fired power generation (210 Gt total emissions 2015–2050).

U.S. steam coal consumption declines below 2015 levels in all scenarios in the following years. In scenarios with a policy rollback (Rollback and Rollback_ports), consumption declines rather slowly (-10% and -16%, respectively, in 2050 compared to 2015), while in the CPP scenario, consumption declines by around 30%. Cumulative CO₂ emissions from U.S. coal-fired power generation between 2015 and 2050 amount to approximately 43–44

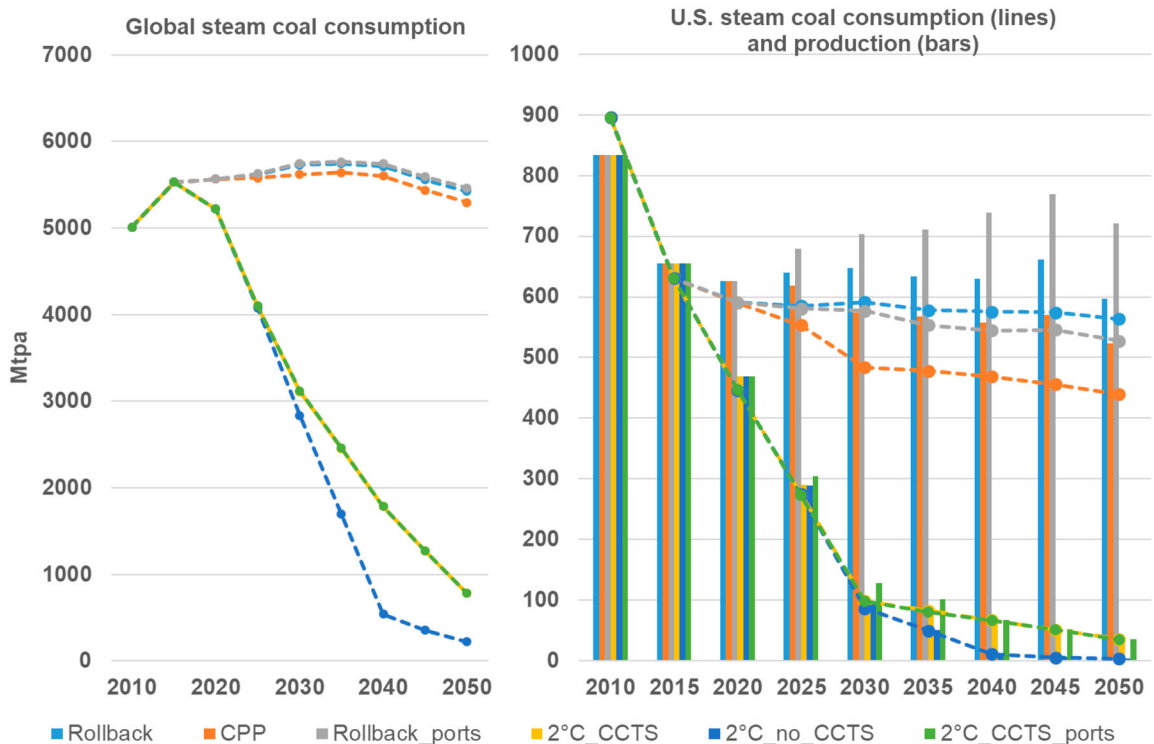


Figure 3. COALMOD-World results for global and U.S. steam coal consumption, and U.S. steam coal production 2010–2050 in all scenarios.

Note: Scenarios 2° C_{CCTS} and 2° C_{CCTS_ports} fully overlap.

Gt (on average ca. 1.2 Gt per year) in the *Rollback* and *Rollback_Ports* scenarios (see Table S3 in Supplementary Material). In the *CPP* scenario, cumulative emissions from U.S. coal-fired power generation are about 13% lower (38 Gt) than in the *Rollback* scenario(s).

In the ambitious climate policy pathway, U.S. coal consumption drops within 15 years by more than 80% to around 100 Mtpa in 2030. Cumulative CO₂ emissions from coal-fired power generation between 2015 and 2050 amount to approximately 13 Gt in all three scenarios of this pathway.¹⁷ Annual emissions drop from ca. 1.3 Gt in 2015 to less than 0.6 Gt in 2025, and ca. 0.2 Gt in 2030.

3.3. Trump's effects on U.S. coal production in a moderate climate policy world

Policy interventions of the Trump administration in favour of coal, represented in the *Rollback* scenario, lead to a stabilization of steam coal production in the U.S. in the long-run at about the production level of 2015 (see Figure 3). However, replacing the CPP with a rather coal friendly rule does not lead to a return to former high, pre-2015 production levels. Revoking the CPP changes U.S. coal production only slightly in the short run because the CPP was scheduled to take effect only in 2022. Only after 2025, are production levels in the *Rollback* scenario around 11% higher than in the *CPP* scenario. Regionally disaggregated, this additional production comes mainly from the PRB. Production in the Appalachia and Interior regions remains at 2015 levels.

The scenario *Rollback_ports* shows the effect of additional export port capacities along the U.S. West Coast. Total U.S. steam coal production rises slowly after 2020. The absolute increase in production induced by these ports (compared to the *Rollback* scenario) amounts to approximately 60 Mtpa by 2030 and 120 Mtpa by 2050. While this leads to slight production increases in all regions compared to the *Rollback* scenario, this additional demand is served mostly by an increase in production in the PRB. However, West Coast export opportunities in combination with the policy rollbacks of the Trump administration still do not lead to a return of U.S. coal production to the peak levels of the 2000s.

Under the *moderate climate policy* pathway, exports increase in all three scenarios compared to 2015 (see Figure 4). Exports in the *Rollback* scenario are lower than in the *CPP* scenario due to the higher domestic demand in the *Rollback* scenario. In the *Rollback_ports* scenario, new West Coast export capacities facilitate additional exports of about 100 Mtpa by 2035, and 150 Mtpa by 2050. In all scenarios, U.S. export destinations shift from Europe and the

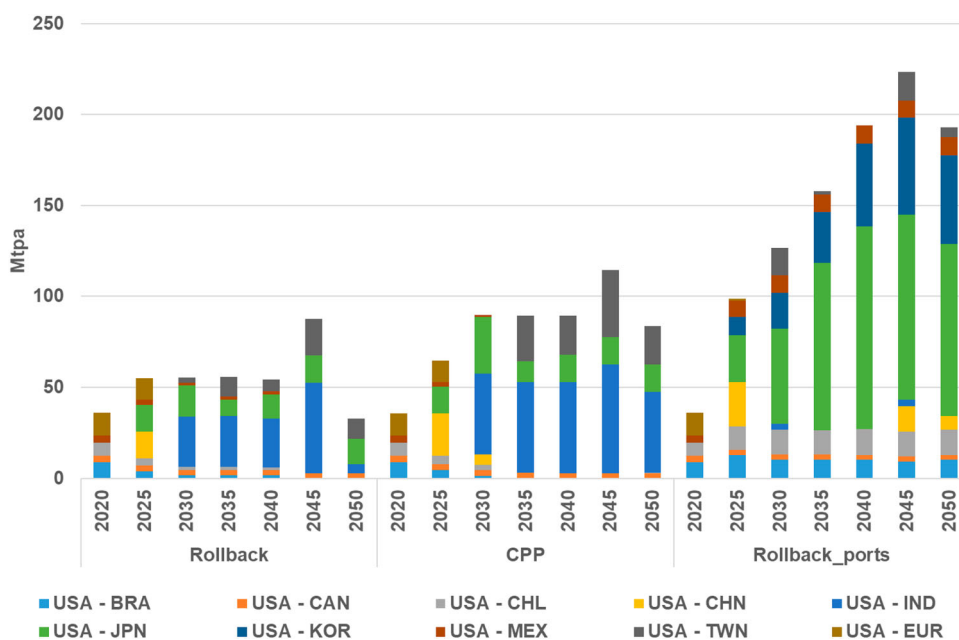


Figure 4. COALMOD-World results for U.S. steam coal exports 2020–2050 in moderate climate scenarios.

Americas towards Asian countries. While in the scenarios *Rollback* and *CPP*, without new West Coast export facilities, U.S. exports from 2030 onwards go mostly to India, Japan and South Korea are the two main destinations under the scenario *Rollback_ports*.¹⁸ Here, they replace mainly Colombia and Russia as coal suppliers.

Between 2020 and 2050, cumulative investments in the range of four billion US\$ (in 2010 US\$) in new U.S. transport and export infrastructure would be necessary to realize the additional exports in the scenario *Rollback_Ports*. Furthermore, cumulative investments in mining capacities between 2020 and 2050 would have to increase by about 80% in the *Rollback_Ports* scenario compared to the *Rollback* scenario, albeit at a relatively low level of 10.7 billion US\$.¹⁹ For comparison, in 2012 alone, capital expenditure in the sector was around 9 billion US\$.²⁰ In the *CPP* scenario, cumulative investments in coal production capacities are halved compared to the *Rollback* scenario.

While many qualitative studies assess the possible effects of policy changes under the Trump administration on U.S. coal supply and consumption, quantitative assessment is very limited. Assuming a full regulatory rollback and arguing for coal exports to remain at current levels, Houser et al. (2017, p. 38) find that total U.S. coal production, including metallurgical coal and lignite, could rise to 820 Mt in 2030 compared to 610 Mt in 2030 under Obama administration policies. They stress, however, that depending on the development of primary energy prices, U.S. coal consumption by 2022 could either further decline to 550 Mt or rise to 800 Mt (720 Mt in reference case). Similarly, the EIA projects in its reference case that U.S. coal production will remain relatively flat at around 680 Mt until 2050 (EIA, 2018a, p. 92). With the CPP being implemented, coal production would decrease to 570 Mt by 2030 and ca. 540 Mt by 2050 (EIA, 2018a, pp. 91–92).

3.4. U.S. coal production in an ambitious climate policy world

If the political frame to get on track for reaching the 2°C target is reset, prospects for U.S. coal production look significantly different (see Figure 3). U.S. steam coal production drops under all three scenarios in the ambitious climate policy pathway by around 85% between 2015 and 2030. Coal production vanishes in all regions between 2020 and 2030 except in the PRB.

CCTS cannot prevent this drastic decline even under optimistic assumptions regarding the availability of CCTS technology (2°C_CCTS). The largest part of the decline in U.S. steam coal production takes place before CCTS for coal-fired power plants is widely available. The availability of CCTS only changes prospects for U.S. steam coal production starting in 2030. Without CCTS (2°C_No_CCTS), U.S. steam coal production declines from around 90 Mt in 2030 to only 10 Mt in 2040. A sensitivity model run with a 1.5°C target shows an even more drastic decline, with a coal phase-out in the U.S. by 2030. With CCTS available, coal production declines more slowly after 2030 and reaches ca. 40 Mtpa in 2050. This is around 6% of 2015 production levels.

The possibility of exporting steam coal via the West Coast does not change prospects for U.S. steam coal production significantly in this pathway. Exports stay below 35 Mtpa in all three scenarios and by 2040 no more steam coal is exported from the U.S. (see Figure S2 in Supplementary Material). The U.S. retains its role as a swing supplier. In the Asian market, U.S. coal competes on the margin with, e.g. low cost Indonesian coal. U.S. coal loses its market shares rapidly towards 2035–2040 (depending on the scenario), while other exporting countries continue to serve the Asian market. In the Atlantic markets, U.S. coal has already disappeared by 2020. In other words, U.S. coal exports are very vulnerable to climate policy in these markets.

No investments in coal supply infrastructure are made from 2020 onwards, except in scenario 2°C_CCTS_Ports, where some investments into additional export facilities are made (ca. 300 million US\$).

4. Conclusions

At the latest by the time of the second presidential term of Barack Obama, prospects for the U.S. coal sector were already fading fast. Many have blamed Obama's Climate Action Plan and other climate policy measures that targeted emission reduction from coal-fired generation as a primary driver of this decline. Indeed, U.S. coal-fired power generation is the primary destination of U.S. coal production. However, in the U.S. electricity sector, coal suffers less from climate and other environmental regulation and more from lower competitiveness compared to recently built gas-fired power plants and renewables. Our literature survey shows that current and

recent US environmental policies have had relatively little effect on U.S. coal production and consumption. From this perspective, revoking environmental policies will not change the fundamental economics in the energy market. Unless new regulation disproportionately favours coal-fired generation over other energy technologies, lax rules will not turn the tide for coal. Notably, market support for renewables and natural gas production is not under question by the current administration. Obama's climate policies worked to reinforce market forces and helped natural gas and renewables to outcompete coal, while Trump's policies and policy rollbacks try to pull in the opposite direction. Using a comprehensive model of the international steam coal market, we assess the effects of this policy change on U.S. steam coal production, exports, and investments.

We use rather high assumptions on U.S. coal consumption in the pro-coal scenarios provided by the EIA which neglect current structural and economic trends. Moreover, we assume prompt policy implementation, despite many potential entry points to postpone or prevent policy implementation. Nevertheless, our results with the COALMOD-World model show that in no case does coal production return to the all-time high levels of the 2000s (about 20% higher than 2015 levels). Compared to a case with environmental regulation (CPP), U.S. coal production would increase by one-eighth in the next years but still stay far from the levels of 2010 or before. Accordingly, the policy rollback would increase CO₂ emissions from the U.S. coal sector by 13%, stabilizing U.S. coal consumption at approximately 2015 levels. However, if the Trump administration takes its promise of reviving coal seriously, it will need to take much bolder action. In this paper, we therefore look at two additional scenarios, which potentially bring about a change to the current trend in the coal sector: a hypothesised break of opposition against West Coast coal export ports or a widespread application of CCTS technology.

Establishing coal exports via the U.S. West Coast requires overcoming the regulatory hurdles to expand terminal capacity. Moreover, investments to expand coal transport infrastructure would become necessary, in particular to allow exports from the low-cost PRB in the Western United States. These investments would be at high risk of becoming stranded, given that U.S. coal exports vanish under an *ambitious climate policy* pathway and production drops precipitously. While West Coast exports support PRB coal, there is no scenario which allows the Eastern coal basins (Appalachia and Interior) – which Trump had in mind when claiming to 'make coal great again' – to return to their pre-2015 production levels. Assuming current labour productivity levels, which differ by an order of magnitude between the PRB and Appalachian basins, a shift in production towards the PRB implies a further reduction in jobs in the coal sector.

CCTS cannot save the U.S. coal sector either. The strong financial and policy support that is required to realize private investments into this costly technology can only be justified if climate change mitigation is accepted as the ultimate underlying objective. However, this also means embarking on an ambitious climate policy pathway that leaves little space for coal-fired power generation, even with CCTS in place. The availability of the technology makes the difference between 100 and 50 Mtpa of steam coal production by 2035, thus it only mildly decelerates the rapid coal phase-out that is required to meet the 2°C target.

In summary, new U.S. policies are not likely to turn the tide for U.S. coal. To the contrary, the coal sector is under ever-increasing risk of asset stranding, because it is uncertain which climate policy trajectory will be taken, both domestically and internationally. Coal mining assets are particularly at the risk of stranding (while domestic coal-fired power plants continue to be so, too). This is even more true from a global climate policy perspective, as much of the difference between scenarios is driven by exports, even without West Coast ports being available. Traditionally a supplier to Europe and the Americas, the U.S. will take the role of a swing supplier between the Atlantic and the Pacific coal markets. Due to its higher supply costs to the import markets compared to other exporters (e.g. Indonesia, South Africa), it can only be the marginal supplier to Asian markets such as India, Japan, and South Korea. In other words, while exports can potentially contribute to the survival of U.S. coal production for a few more years, they make the U.S. coal sector even more vulnerable to sudden climate policy shifts in other world regions.

Notes

1. The U.S. has been the second largest coal producer worldwide for a long time, accounting for approximately 10 % of global coal production (IEA/OECD, 2018). India surpassed U.S. coal production for the first time in 2016. The U.S. is a net exporter of coal, for both steam and metallurgical coal. Due to its relatively high prices, the U.S. is considered a swing supplier for international met and steam coal markets (IEA/OECD, 2017b).

2. Figures in coal tonnage are given in metric tons. Short tons are converted using the EIA conversion factor 0.907184.
3. EIA energy data browser: <https://www.eia.gov/totalenergy/data/browser/>, last accessed January 26, 2019.
4. EIA coal data browser: <https://www.eia.gov/coal/data/browser/>, last accessed: July 3rd, 2018.
5. EIA electricity data: <https://www.eia.gov/electricity/>, last accessed January 31, 2019.
6. EIA natural gas data: <https://www.eia.gov/naturalgas/data.php>, last accessed: January 26, 2019.
7. EIA monthly data on U.S. natural gas electric power price: <https://www.eia.gov/dnav/ng/hist/n3045us3M.htm>, last accessed July 5th, 2018. Prices of coal and gas for power plants differ by region. Coal from Appalachian mines is the most expensive, followed by coal from the Interior Basin and the Rockies. Coal from Powder River Basin has the lowest price and was competitive with natural gas most of the time between 2012 and January 2016 with gas (Culver & Hong, 2016).
8. Based on net summer capacity. Includes coal-fired power plants in the sectors electric utilities, independent power producers, commercial and industrial CHP. Source: EIA 2018, *Preliminary Monthly Electric Generator Inventory*. <https://www.eia.gov/electricity/data/eia860m/>, last accessed December 20, 2018.
9. See Supplementary Material for more details on this and other regulations.
10. The New Source Review (NSR) is a permitting process under the Clean Air Act. It is triggered if new polluting facilities are built or existing ones are modified in such a way that emissions increase. These facilities have to fulfill state-of-the-art emission standards, even if the pre-modification facility was exempt from those standards. See also EPA *Permitting Under the Clean Air Act*: <https://www.epa.gov/caa-permitting>, last accessed July 2, 2019.
11. A large share of the coal production in the Northern Great Plains basin, is lignite (except for PRB), which is locally consumed ("mine-mouth") and therefore not in the focus of this analysis.
12. Statista, 2018: *Statista Dossier Coal*. <https://www.statista.com/study/11644/coal-statista-dossier/>, p. 32, last accessed December 20, 2018.
13. EIA Coal Data Browser: <https://www.eia.gov/coal/data/browser/>, last accessed January 31, 2019.
Coal mining employment has been on the decline for decades: from a peak of more than 800,000 in the 1920s to 130,000 in 2011 (including contractors; Houser et al., 2017, p. 5).
14. EIA Coal Data Browser – Aggregate coal mine productivity: <https://www.eia.gov/coal/data/browser/#/topic/37>, last accessed 04/26/2019.
15. Bade, Gavin (31.01.2018), *Trump touts end of 'war on beautiful, clean coal' in State of the Union*. <https://www.utilitydive.com/news/trump-touts-end-of-war-on-beautiful-clean-coal-in-state-of-the-union/516000/>, last accessed August 17, 2018.
16. <https://apnews.com/573a19c3d43643e5b2d961b46cd99c67>, last accessed August 3, 2018.
17. For simplicity, the coal demand from CCTS-equipped coal-fired power stations is assumed not to cause CO₂ emissions. Given capture rates between 85% and 95%, the difference in total CO₂ emissions is small.
18. The underlying model does not consider specific coal quality requirements of different power plants. Oei and Mendelevitch (2018) highlight this issue which hampers substitutability between different suppliers. This could possibly constrain demand for low-energy content PRB coal.
19. COALMOD-World includes a mine mortality mechanism by which production capacity depreciates over time according to extraction. Investments are necessary to replace the depreciated capacities. However, the new mines are assumed to have higher costs because typically easiest-to-access deposits are mined first. Average mine maturity differs between regions.
20. See U.S. Census Bureau, 2012 Economic Census. Capital expenditures (except land and mineral rights) <http://www2.census.gov/econ2012/EC/sector21/EC1221SG1.zip>.

Acknowledgements

Comments to presentations at IAEE International Conference 2018 and Trans-Atlantic Infraday 2018, BELEC 2018 and DIW Sustainability Brown Bag Seminar January 2019 are gratefully acknowledged. We would also like to thank three anonymous reviewers who provided helpful feedback and comments.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the German Ministry for Education and Research (Bundesministerium für Bildung und Forschung – BMBF) under grant numbers 01LN1704A ('CoalExit' project) and 01LA1811 ('FoReSee' project).

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