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The death spiral of coal in the USA: Will new U.S. energy policy change the tide?

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The Death Spiral of Coal in the USA

Will New U.S. Energy Policy Change the Tide?

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Abstract

The Trump administration has promised to stop the spiraling down of the U.S. coal industry that has been going on for several years. We discuss the origins of the decline of the U.S. coal industry and new policy interventions by the Trump administration. We find that a further decrease of coal consumption in the U.S. electricity sector must be expected because of the old and inefficient U.S. coal-fired generation fleet. By contrast, we adapt the EIA's overly optimistic view and analyze three potential support schemes to assess whether under such assumptions they can turn the tide for the U.S. coal industry: i) revoking the Clean Power Plan (CPP); ii) facilitating access to the booming Asian market by developing West Coast coal export terminals; and iii) enhanced support for the Carbon Capture, Transport and Storage (CCTS) technology to provide a long-term perspective for domestic coal use while mitigating climate change. We investigate the short-term and long-term effects for U.S. coal production using a comprehensive partial equilibrium model of the world steam coal market, COALMOD-World (Holz et al. 2016). Revoking the CPP will stop the downward trend of steam coal consumption in the U.S., but will not lead to a return of U.S. coal production to the levels of the 2000s with more than 900 Mtpa. Even when assuming a continuously strong global coal demand and expanding U.S. coal export capacities, U.S. coal production will not return to its previous production highs. When global steam coal use, including U.S. consumption, is aligned with the 2°C climate target, U.S. steam coal production drops to around 100 Mtpa by 2030 and below 50 Mtpa by 2050, respectively, even if CCTS is available and exports via the U.S. West Coast are possible.

Keywords: U.S. coal sector, Trump administration, Clean Power Plan, steam coal, coal ports, CCS

JEL codes: L72, Q34, Q38, F14

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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, the Climate Action Plan gave the U.S. climate policy an important impetus. The situation changed dramatically with the inauguration of President Trump in January 2017. He is aggressively rolling back environmental regulation and commitments, with a complete re-organisation of the environmental administration: most prominently announcing to leave the Paris Agreement¹, and replacing the Clean Power Plan (CPP) with the Affordable Clean Energy (ACE) rule (EPA 2018b). 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.² This alludes to the strong role that the U.S. coal sector used to play in the past and its steady decline in the last decade.

The Trump administration’s efforts to support coal are manifold and extend to a broad range of policy areas. While supporting domestic coal-fired power generation is the most obvious and first announced support after the elections, another focus has been on relieving pressure on mining and, more recently, on expanding the access to the international market for U.S. coal. The drastic change in U.S. energy and climate policy under President Trump has sparked some first research on possible global effects on emission reduction efforts. Jotzo et al. (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. Generally, the range of predicted U.S. emissions in 2025 under different policy scenarios is rather large and scenario trends show some overlap. Fransen and Levin from the World Resource Institute take into account a number of studies and assessments and conclude that considering full implementation of Trump’s policies would lead to U.S. emissions of 5.6 to 6.8 GtCO₂e in 2025 compared to 5.0 to 6.6 GtCO₂e under Obama’s policies (including the Clean Power Plan).³ Similarly, Climate Advisers estimate additional emissions of 0.5 GtCO₂e through a “Trump effect” by 2025.⁴ Undertaking a rough sector-by-sector assessment, Galik

¹ The White House (01.06.2018), *President Trump Announces U.S. Withdrawal From the Paris Climate Accord*. <https://www.whitehouse.gov/articles/president-trump-announces-u-s-withdrawal-paris-climate-accord/>, last accessed August 4, 2018.

² Davenport, Coral (22.09.2016), *Donald Trump, in Pittsburgh, Pledges to Boost Both Coal and Gas*. <https://www.nytimes.com/2016/09/23/us/politics/donald-trump-fracking.html>, last accessed December 18, 2018.

³ Fransen and Levin (06.12.2017), *INSIDER: The Climate Effect of the Trump Administration*. World Resources Institute. <https://www.wri.org/blog/2017/12/insider-climate-effect-trump-administration>, last accessed December 18, 2018.

⁴ Climate Advisers (n.d.), *Trump Back Tracker*. <https://www.climateadvisers.com/trumpbacktracker/>, last accessed December 18, 2018.

et al. (2017) conclude that the effect of Trump's policies will at most be a flattening of U.S. CO₂ emissions on a 2015 level. Depending on the number of his terms, they estimate a total increase of 12 GtCO₂e to 20 GtCO₂e 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 future 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, these studies fail to analyse the role of the U.S. as a major coal producer and supplier on the international steam coal market.⁵ 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 makes a contribution in this direction by providing an assessment of the effects of energy and climate policy measures on the U.S. coal production, taking into account the domestic and global coal sector inter-relations. We first analyse the origins of the decline for coal-fired energy generation and coal production. Surveying the literature and statistics, we disentangle the contributions of macro-economic factors, fundamental changes in the economics of competing energy sources in the form of natural gas and renewables, and effects of environmental and climate policy. Moreover, we detail current policy measures that are intended to support the U.S. coal sector. We develop several scenarios around some of the main policy measures to quantify their effects on the U.S. coal production and exports with the COALMOD-World model. We find that even in the most pro-coal scenario, U.S. production levels will not return to the levels of the late 2000s. However, cancelling the Clean Power Plan will stop the downward trend in U.S. coal production, even more so if combined with the possibility to export via the West Coast. If the world – including the U.S. – were on a 2°C compatible pathway, U.S. coal production would quickly fall and be less than half of current levels by 2025 and less than a quarter by 2030.

2 The Death Spiral: Development of the U.S. coal sector in the last decade

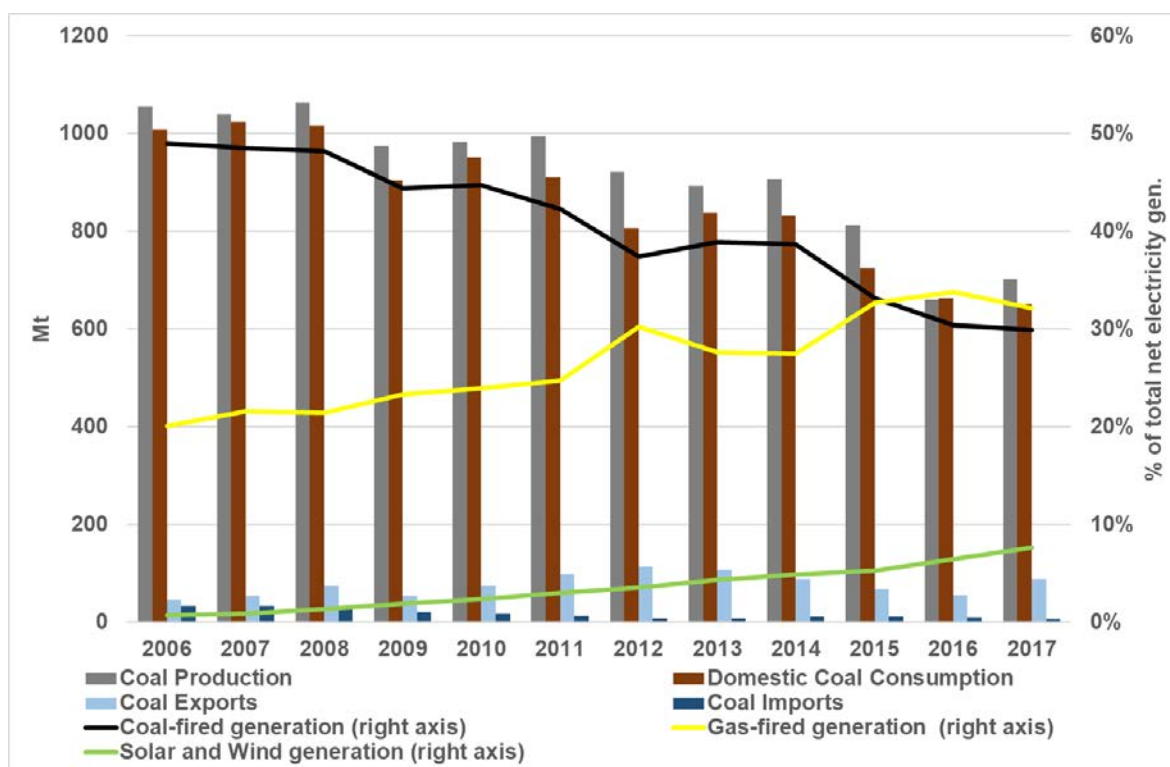
In the past decades, the coal sector has been a central element of U.S. power generation as well as of the U.S. mining sector. In this section, we want to highlight the most recent developments of the sector, both in terms of coal use (consumption) and in terms of coal mining (production).

Figure 1 provides an overview of the development of U.S. coal⁶ production, consumption, exports and imports in the past decade. U.S. domestic coal consumption peaked in 2007 (1.025 billion tons). By 2014, it had declined to 835 million tons, and dropped to 650 million tons (Mtpa) in 2017, the lowest value since 1982.⁷

⁵ The U.S. have 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. are a net exporter of coal, for both steam and metallurgical coal. Due to its relatively high prices, the U.S. are considered a swing supplier for international met and steam coal markets (IEA/OECD 2017b).

⁶ In this section, “coal” refers to all types of coal, i.e. coking and steam coal, including brown and hard coal.

⁷ U.S. Department of Energy Information Administration (EIA) energy data: <https://www.eia.gov/totalenergy/data/browser/?tbl=T06.01#/?f=A&start=2000&end=2017&charted=0-5-8>, last accessed: July 3rd, 2018. Note that the EIA provides data in short tons. We use the EIA conversion factor 0.907184 to convert to metric tons.



Source: U.S. Department of Energy Information Administration (EIA) data on coal:
<https://www.eia.gov/totalenergy/data/browser/?tbl=T06.01#/?f=A&start=2000&end=2017&charted=0-5-8>, last accessed: July 3rd, 2018.

Note: Domestic consumption and exports do not necessarily add up to the sum of coal production. Coal imports (~ 7 – 33 Mtpa) and stock changes (~ -40 – 39 Mtpa) explain minor deviations.

Figure 1: U.S. coal production, consumption, exports and imports as well as U.S. electricity mix 2006-2017

Approximately 93 % of domestic coal consumption, relatively constant over the last ten years, went to the U.S. electricity sector, while the remaining 7 % were used by industry, mainly as coking (metallurgical) coal.⁸ U.S. net electricity generation from coal has declined since its peak in 2007 (2020 TWh) to 1210 TWh in 2017, while total U.S. net electricity generation remained almost constant (2007: 4160 TWh, 2017: 4010 TWh). In other words, the share of coal in net U.S. electricity generation significantly declined from almost 50% in 2007 to just 30% in 2017 (Figure 1). At the same time, the share of natural gas and renewables increased from 22 % to 32 % and 2.5 % to 10 % (without hydropower), respectively.⁹

U.S. coal production peaked around the same time as consumption, namely in 2008, with (1.06 billion tons). In the following years, from 2009 through 2011, yearly production was slightly under 1 billion tons, declining to around 900 million tons during 2012 through 2014, and thereafter dropping to 660 Mtpa in

⁸ EIA coal data browser: <https://www.eia.gov/coal/data/browser/>, last accessed: July 3rd, 2018.

⁹ EIA data on electricity net generation: <https://www.eia.gov/totalenergy/data/browser/?tbl=T07.02A#/?f=A&start=1949&end=2017&charted=1-3-5-8-14-15>, last accessed: July 3rd, 2018.

2016, recovering slightly in 2017 to 700 Mtpa.¹⁰ Coal exports reached their highest levels in 2012 (115 Mtpa; 56 % metallurgical coal) with similar levels than in the 1980s. This dropped to 55 million tons in 2016 (68 % metallurgical coal), recovering in 2017 to 88 Mtpa (57 % metallurgical coal). They range from four percent to 13 % of U.S. coal production (54 Mt – 114 Mt) in the period 2006 to 2017 (EIA 2018a).¹¹

Many studies have analysed the recent decline of the U.S. coal sector (i.a. Coglianese, Gerarden, and Stock 2017; Culver and Hong 2016; Houser, Bordoff, and Marsters 2017; Kok 2017; Schlissel, Sanzillo, and Feaster 2018; Sussams and Grant 2015; U.S. DoE 2017). Overall, the explanations can be divided in two categories. The first type focuses on domestic demand, especially the demand for steam coal in the electricity sector. The second type 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 Declining coal use in the USA

Looking at the demand side and the drastic reduction in U.S. domestic coal use shown in Figure 1, there is a broad consensus that points at the drop of U.S. natural gas prices and the resulting rise of natural gas use in the electricity sector as the main influencing factor. Other factors that adversely affected coal use include i) the increasing share of renewables in U.S. electricity generation; ii) the general electricity demand development in the U.S.; iii) environmental regulations of the electricity sector; and iv) the technological development in the U.S. power plant fleet with many very old coal-fired units and increasingly many modern gas-fired plants. Let us analyse each of these factors in the following, with a focus on steam coal (also called thermal coal).

2.1.1 The (shale) gas boom and the renaissance of gas in U.S. electricity

The significant drop of U.S. gas prices that was caused by the so-called shale gas revolution started around 2007. From 2007 to 2014, shale gas production increased by a factor of 10.4 and total gas production increased by approximately 35 %, thereby leading to significantly lower gas prices (Culver and Hong 2016, 51). The price for delivered natural gas for U.S. power plants dropped from around \$10 per tcf in 2008 to approximately \$3 per tcf in 2016 (a reduction of 70 %), while the average price for delivered coal only decreased by eight percent during this period of time (Houser, Bordoff, and Marsters 2017, 16). Between January 2012 and January 2016, natural gas was outcompeting coal as the cheaper fuel source for electricity generation during the majority of months (Culver and Hong 2016).¹² This trend of cheap natural gas prices for electric power production has continued until today.¹³

When considering the competition between coal and gas as fuel sources for electric power generation, not only variable operation and maintenance (O&M) costs such as fuel costs are of importance.

¹⁰ EIA data on coal:

<https://www.eia.gov/totalenergy/data/browser/?tbl=T06.01#/?f=A&start=2000&end=2017&charted=0-5-8>, last accessed: July 3rd, 2018.

¹¹ EIA coal data browser: <https://www.eia.gov/coal/data/browser/>, last accessed: July 3rd, 2018

¹² Prices of coal and gas for power plants differ by region. Coal from Appalachian sources is the most expensive, followed by coal from the Interior Basin and the Rockies. Coal from Powder River Basin has the lowest price and could compete most of the time between 2012 and January 2016 with gas (Culver and Hong 2016).

¹³ 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.

Moreover, relatively low thermal efficiencies and high fixed O&M costs added to the disadvantages of electricity production of coal compared to gas (Gray and Watson 2017). Also, the heat rate of new gas turbines improved notably over the last years (Culver and Hong 2016), while improvements in international coal power generation technology did not make an entry in the U.S. market (also Section 2.1.5). Additionally, gas generators have shorter ramping times than coal generators and can react more agile to fluctuating generation from renewables, such as solar and wind. This is not only important for grid stability issues, but also affects utilities' revenues. In times of high production from renewables, electricity prices can become very low, and at times negative. Inflexible old generation units, such as the majority of the U.S. coal-fired power plant fleet, rather continue to run and sell electricity at negative prices during these times than shutting down (Gray and Watson 2017).

2.1.2 Increasing share of renewables

Not only flexible generation adjustment to fluctuating load and generation from renewables, but also increased competition from renewables in the power market has affected power production from coal. The share of renewables (excluding hydro) in U.S. electricity generation has increased to 9.6 % (390 TWh) of total electricity production in 2017, compared to 2.5 % in 2007. Wind makes up the largest share, with 6.3 % of total production in 2017 (0.8 % in 2007), followed by solar with 1.3 % (0.0 % in 2007).¹⁴ Unsubsidized, average levelized cost of electricity from wind and solar PV declined between 2009 and 2017 by 67 % and 86 %, respectively (Lazard 2017, 10). Additionally, federal tax incentives for renewables (the Production Tax Credit) and state renewable portfolio standards / goals supported the expansion of wind and solar generation in addition to improved efficiencies and capacity factors of wind turbines and solar PV modules (Schlissel, Sanzillo, and Feaster 2018). In competitive markets, wind and solar power are dispatched first because they have no fuel costs. Thus, coal power is displaced and full load hours of coal power stations are reduced. Moreover, price spikes during peak load hours are reduced in number and size, thereby lowering the revenues of coal fired power generation. Solar power, with highest production levels during the middle of the day, displaces i.a. coal-fired power during the midday peak hours (Gray and Watson 2017; Schlissel, Sanzillo, and Feaster 2018).

2.1.3 Slowing electricity demand

Besides the competition for coal from cheap gas and renewables on the power market, growth of U.S. electricity demand in recent years was lower than predicted. In the reference case of its 2006 Annual Energy Outlook the EIA predicted an annual growth of U.S. electricity demand of on average 1.7 percent between 2004 and 2030 (EIA 2006, 77). However, this growth did not materialize. First the Great Recession (end of 2007 – mid of 2009) led to a general decrease in the U.S. electricity demand.¹⁵ In 2010, it returned to the level of 2007 but has stayed flat since then, while the U.S. economy grew by 15 % (GDP, adjusted for inflation) between 2007 and 2017.¹⁶ According to Schlissel, Sanzillo, and

¹⁴ EIA data on electricity net generation:

<https://www.eia.gov/totalenergy/data/browser/?tbl=T07.02A#/?f=A&start=1949&end=2017&charted=1-3-5-8-14-15>, last accessed: July 3rd, 2018

¹⁵ EIA data on electricity end use: <https://www.eia.gov/totalenergy/data/browser/?tbl=T07.06#/?f=A>, last accessed: July 9th, 2018.

¹⁶ Bureau of Economic Analysis, U.S. Department of Commerce, data on GDP: <https://www.bea.gov/national/>, last accessed: July 9th, 2018

Feaster (2018), factors dampening demand growth have been i) energy efficiency programs and investments; ii) raised awareness for energy saving by consumers and also iii) increased self-generation from households with rooftop solar PV. Thus, the U.S. have experienced a decoupling of economic growth from growth of electricity demand. For the coal-fired generation, this meant a tight market with large renewables and gas-fired capacity additions (Houser, Bordoff, and Marsters 2017, 16).

2.1.4 Tightened environmental regulations

In the past decade, coal-fired power generation had to face new and tightened environmental regulations (Table 5 in the Appendix contains an overview). The Obama administration promulgated nine regulations directly addressing coal-fired power generation (Houser, Bordoff, and Marsters 2017). Opinions on the actual effects of the environmental regulations on coal-fired power generation are diverging. Out of the nine Obama-era regulations, only four took effect before the year 2016. Coglianese, Gerarden, and Stock (2017, 2–3) 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 ten percent of the decline of coal mining output between 2008 and 2016. This is in the same range as estimates of Houser, Bordoff, and Marsters (2017, 22). In contrast to the aforementioned studies, Culver and Hong (2016) argue that the decline of U.S. coal between 2008 and 2015 had little to do with EPA rules due to relatively low costs accruing from compliance measures, but was rather caused by the fierce competition with natural gas (Section 2.1.1).

Sussams and Grant (2015, 33) point out that the tightened environmental regulations, additionally to their direct effects on coal-fired units, “could have served to increase the risk profile of the U.S. coal industry, and caused action to be taken by utilities, more than the impact of each individual regulation on its own.” In this way also the most prominent Obama-era environmental regulation, the Clean Power Plan (CPP), finalized in October 2015, could have already affected decisions of coal-fired power plant retirements. It was scheduled to come into effect in 2022 and to set limits to carbon dioxide emissions from existing power plants.¹⁷

In the same vein as the CPP that was promoting state carbon caps, some U.S. states or regions already implemented CO₂ pricing schemes (RGGI¹⁸, California¹⁹) or are on the verge of doing so (Oregon, Massachusetts, Virginia).²⁰ The first analyses of their effects on coal-fired power generation are yet inconclusive, given the complexity of the possible reactions to regional carbon pricing. Kim and Kim (2016, 334) provide evidence that coal to gas switching was accelerated by the RGGI implementation and that the RGGI region has a ten percentage points higher gas share in electricity generation than it would have had without RGGI. Somewhat in contrast, Fell and Maniloff (2018, 17) argue that the RGGI

¹⁷ The CPP and the new MATS extend the long-standing New Source Review that regulates pollutant emissions of newly constructed or substantially expanded stationary emission sources such as power plants, to existing power plants. Moreover, MATS supersedes the Clean Air Interstate Rule that has regulated SO₂, NO_x, and mercury emissions in the past decades.

¹⁸ Regional Greenhouse Gas Initiative: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont. RGGI CO₂ prices have been rather low in the last years, between 2.50 US-\$ and 6 US-\$. See yearly market reports on www.rggi.org

¹⁹ CO₂ prices in California were between 11 US-\$ and 16 US-\$ in the last five years, see <http://calcarbondash.org/>

²⁰ International Carbon Action Partnership (ICAP) ETS MAP: <https://icapcarbonaction.com/en/ets-map>, last accessed January 7, 2019.

CO₂ cap induced coal-fired plants in the RGGI region to reduce their capacity utilization by approximately 10 percentage points which was not compensated by an increase in gas-fired generation, but rather by an increase in generation from the areas surrounding RGGI. This “leakage” actually was electricity generation from natural gas-fired power plants.

2.1.5 Cumulative demand-side effects on an old power plant fleet

The combination of the above-mentioned demand-decreasing and cost-increasing factors for coal-fired power generation put high economic strain on existing coal-fired power plants. Regarding “invest or retire” decisions, the age and size of power plants also plays a role and this is where the U.S. fleet of coal-fired plants with many very small and very old units 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 units²¹ was a stumbling 39.7 years and the average (net summer) capacity of the operating units was only 323 MW.²² 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.

Table 1 shows that the oldest and smallest units are now being withdrawn from the system, with the least economic ones being shut down earlier. 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 units have been retired, thereby indicating that the bulk of uneconomic units has left the system by now. While the first phase of this decade’s coal retirement movement removed the most inefficient plants from the market/sector, it is the larger, more efficient and largely regulation-compliant plants that are now losing in the tough competition with natural gas and renewables.

Table 1: Average age and size of retired coal-fired power generation units since 2012 (net summer capacity; all sectors; utility scale)

	2012	2013	2014	2015	2016	2017	2018 (Jan-Sept)
Average age of retired units [years]	50.7	58.8	51.3	55.9	56.3	52.1	43.4
Average size of retired units [MW]	121	101	79	129	124	210	476

Source: <https://www.eia.gov/electricity/data/eia860m/>

Note: Net summer capacity: “The maximum output, commonly expressed in megawatts (MW), that generating equipment can supply to system load, as demonstrated by a multi-hour test, at the time of summer peak demand (period of June 1 through September 30.) This output reflects a reduction in capacity due to electricity use for station service or auxiliaries.” (<https://www.eia.gov/tools/glossary/index.php?id=net%20summer%20capacity>)

Old and small units usually have lower efficiencies than the average operating fleet and are, therefore, dispatched less often. Thus, they ran at lower capacity factors and with higher operating costs (U.S. DoE 2017, 155). Three-year average capacity factors of U.S. coal-fired plants that retired between 2011

²¹ Based on net summer capacity. Includes coal-fired power plants in the sectors electric utilities, independent power producers, commercial and industrial CHP.

²² EIA 2018, *Preliminary Monthly Electric Generator Inventory*. <https://www.eia.gov/electricity/data/eia860m/>, last accessed December 20, 2018.

to 2017 were well below 0.5 in 2014 and 2015 and even below 0.3 in 2017 (U.S. DoE 2017, 155). The average capacity factor of the entire U.S. coal power fleet fell over the last years as shown in Table 2. Table 2 also shows that total coal-fired electric generation capacity was highest in 2011 with about 318 GW and then declined to about 257 GW in 2017. Most of these 61 GW were retired (ca. 45 GW), but some operators also decided to switch from coal to other fuel sources (ca. 16 GW), especially natural gas.²³

Table 2: Total generation, total capacity, and average capacity factor of the U.S. coal-fired power generation fleet 2006-2017 (all sectors, utility scale facilities)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total net generation [TWh]	1,991	2,016	1,986	1,756	1,847	1,733	1,514	1,581	1,582	1,352	1,239	1,206
Total net summer capacity [GW]	313.0	312.7	313.3	314.3	316.8	317.6	309.7	303.3	299.1	279.7	266.6	256.5
Average capacity factor	0.726	0.736	0.722	0.638	0.666	0.623	0.557	0.595	0.604	0.552	0.529	0.537

Source: <https://www.eia.gov/electricity/annual/>; own calculation.

The last coal-fired power plant that was connected to the grid in the U.S. was the Spiritwood Station in North Dakota in 2014.²⁴ According to Shearer et al. (2018, 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 enforced “new source performance” emission standard of no more than 1,400 lb (~635 kg) CO₂/MWh-g would effectively require the use of CCTS at these units.²⁵ According to EIA data, another 16 GW are scheduled to retire until the end of 2025.²⁶ This, however, only includes the already officially announced plans of the utilities. Feaster (2018) also includes corporate documents by utilities and grid operators and other news reports and estimates that (at least) 36.7 GW will be retired between 2018 and 2024. Rhodium Group even expects the retirement of 60 to 86 GW of net summer coal capacity by the year 2025 compared to

²³ Personal communication with U.S. EIA, 23.07.2018; Gossard 18.06.2015, *Coal-To-Gas Plant Conversions in the U.S.* <https://www.power-eng.com/articles/print/volume-119/issue-6/features/coal-to-gas-plant-conversions-in-the-u-s.html>, last accessed July 24th, 2018.

²⁴ Chemnick, 2018: *Trump wants to lead on 'clean coal.' Here's what that means.* <https://www.eenews.net/stories/1060070967>, last accessed July 3rd, 2018

²⁵ “Standards of Performance for Greenhouse Gas Emissions From New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units;,” 80 Fed. Reg. 64661 (October 23, 2015). By end of 2018, there were first attempt of the Trump administration to water down this regulation. See Dennis, Brady, and Steven Mufson. (06.12.2018). “EPA Announces Plan to Ease Carbon Emissions Rule for New Coal Plants.” Washington Post Online. <https://www.washingtonpost.com/energy-environment/2018/12/06/epa-announces-plan-ease-carbon-emissions-rule-new-coal-plants/>, last accessed January 14, 2019.

²⁶ EIA 2018, *Preliminary Monthly Electric Generator Inventory*. <https://www.eia.gov/electricity/data/eia860m/>, last accessed December 20, 2018.

2018.²⁷ Thus between 6 % and 33 % of the current coal-fired generation fleet will retire in the next five years.

Regardless the exact extent, it is clear that the state of the U.S. coal-fired generation fleet does not allow continuing coal-fired electricity production at the current share in the medium-term without substantial refurbishment and investments. Tightened environmental regulation has only exacerbated a situation which was gloomy before. Therefore, one must expect a further decrease of U.S. coal consumption.

2.2 U.S. coal extraction and exports under pressure

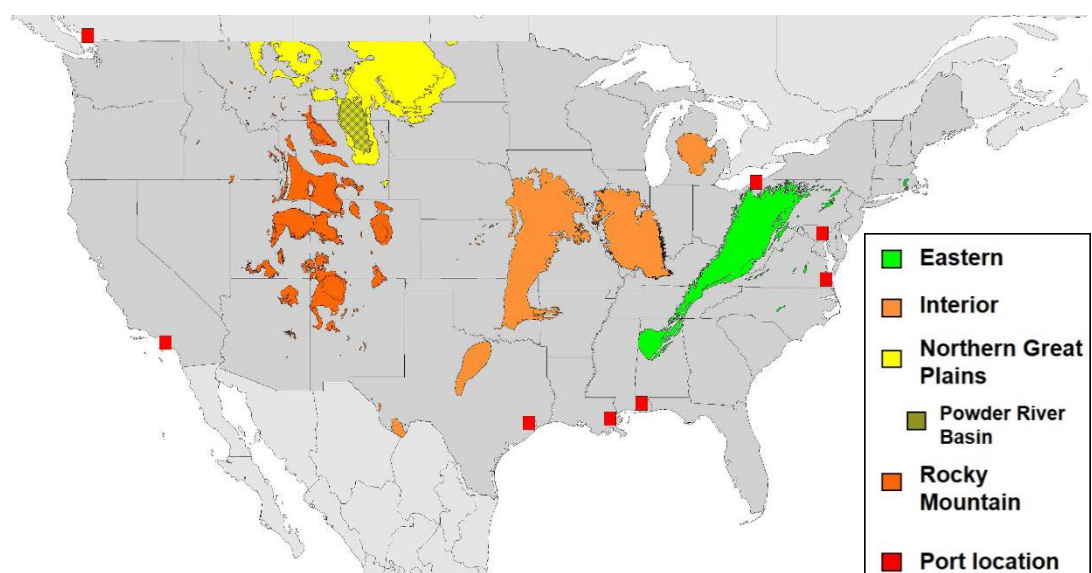
U.S. coal consumption is almost exclusively supplied by domestically extracted (produced) coal. Conversely, coal extracted in the U.S. goes to a large part to the domestic market, mostly power generation (see Figure 1). Thus, the decrease in domestic coal use also led to a decline in U.S. coal extraction. Coal exports have been varying cyclically over time in the past decades, depending on global coal prices and demand. U.S. coal producers generally act as swing suppliers for the international coal market. Exports were in the range of four percent to 13 % of U.S. coal production (54 Mt – 114 Mt) in the period 2006 to 2017 (EIA 2018a).²⁸ About 50 % to 70 % of U.S. coal exports are metallurgical coal.

U.S. coal is extracted primarily in three large regions: the Appalachian region near the Atlantic Coast, the Interior Region near the Great Lakes, and the Western Region with the Powder River Basin (PRB) and the Rocky Mountains as main coal basins (Figure 2).²⁹ Due to their geographic location, these regions are differently connected to export ports: while coal from the Appalachian region and the Interior Basin can be shipped to the export terminals at 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 British Columbia province. In the wake of the strong increase of Asian and world coal demand in the 2000s, several export terminals on the U.S. West Coast were proposed (see Section 2.2.2).

²⁷ John, Jeff St. (16.08.2018), *Report: Cheap Natural Gas and Renewables Could Close Half of US Coal Fleet by 2030*, <https://www.greentechmedia.com/articles/read/report-nearly-half-of-u-s-coal-plants-could-close-by-2030>, last accessed December 21, 2018.

²⁸ EIA coal data browser: <https://www.eia.gov/coal/data/browser/>, last accessed: July 3rd, 2018

²⁹ In the Northern Great Plains basin (except for PRB), a large share of the coal production is lignite, which is locally consumed ("mine-mouth") and therefore not in the focus of this analysis.



Source: Own depiction based on U.S. Geological Survey data, available at <https://pubs.usgs.gov/of/2012/1205/>, last accessed January 18, 2019.

Figure 2: Main U.S. coal extraction regions and port locations

2.2.1 Financial situation of U.S. coal producing companies

In the period of rising global coal prices, between 2008 and 2011, the U.S. coal production sector was expecting further growth of Asian demand for both metallurgical and steam coal. Thus, U.S. coal companies acquired assets abroad (e.g., in Australia), but also started to plan new export terminals at the U.S. West Coast to open up the way for PRB coal to the Asian market.

However, with the stagnating global and falling domestic coal demand since 2011, the situation of U.S. coal producers completely turned. Houser, Bordoff, and Marsters (2017, 31) estimate that the domestic decline of steam coal demand (Section 2.1) was responsible for about 38 % of the drop in revenues of U.S. coal producers and reduced net steam coal exports for another 6 %. 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 \$45 million in 2016.³⁰ For the acquisitions of (foreign) assets to serve the expected Asian demand growth, these companies had taken on large amounts of debt, which by 2015 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.

Almost 60,000 coal miners and contractors lost their jobs between 2011 and 2016, a 44 % decline in coal mining employment.³¹ Central Appalachia was particularly affected, with half of all job losses occurring in Kentucky and West Virginia alone. Jordan, Lange, and Linn (2018) find that this was mainly caused by the decreasing mine productivity in the Appalachian region. Western coal states have also

³⁰ Statista (2018) *Statista Dossier Coal*. <https://www.statista.com/study/11644/coal-statista-dossier/>, p. 32, last accessed December 20, 2018.

³¹ 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 (Houser, Bordoff, and Marsters, 2017, p. 5).

suffered, though: mining employment fell by 52 % in Colorado, 34 % in New Mexico, and 22 % in Wyoming (Houser, Bordoff, and Marsters, 2017). In most coal producing states, the decline in mining employment since 2011 accounted for less than 0.1 percent of the state-wide workforce. However, in West Virginia, Wyoming, and Kentucky, the decline had a significant impact on state-wide and county-level employment. What is more, the bankruptcies threatened the pension and healthcare security of retired miners and the drop in coal production reduced tax revenues in coal-dependent municipalities (Houser, Bordoff, and Marsters, 2017, p. 7)

In 2017, after large write-offs of liabilities, Peabody Energy, Arch Coal and Alpha Natural Resources, as well as several smaller-size coal companies that had filed for bankruptcy, emerged from bankruptcy. However, the market for coal assets in the U.S. remained oversupplied: a number of coal asset transfers in 2016 and 2017 were cancelled because no investors could be found or assets were transferred with losses for the former owners. According to Schlissel, Sanzillo, and Feaster (2018), this indicates that 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.

2.2.2 Expansion of West Coast coal export capacities

In the context of declining domestic demand and rising world market prices, U.S. coal producers wanted to find new outlets on the international coal market, especially in Asia (Cornot-Gandolphe 2015; IEA/OECD 2013, 99; Houser, Bordoff, and Marsters 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 (6 Mtpa) and Canadian ports in British Columbia. Exporting via British Columbia requires long distance rail transport which is used at full capacity (Power and Power 2013). Thus, plans to construct export terminals along the U.S. West Coast, in California, Oregon and Washington, were made. Table 3 shows 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.

There have been extensive local concerns about public health and environmental impacts and consequences for global CO₂ emissions (Western Interstate Energy Board 2012). With lower global coal prices after 2013, exporting PRB coal via new West Coast ports somewhat lost its attractiveness. Additionally, with Peabody Energy and Arch Coal, some of the port projects' equity investors had gone bankrupt. Moreover, these terminal projects have not received explicit support by the Trump administration.³² By the year 2017, all proposed terminals except two were shelved and not proceeded further due to denied (environmental) permits or because the proponents dropped the projects themselves.³³ The two remaining plans were for the Millenium Bulk Terminal³⁴ and the Oakland Bulk

³² Volcovici, Valerie (30.01.2018), *Coal firms plead to courts, Trump for West Coast export terminals*. <https://www.reuters.com/article/us-usa-coal-exports/coal-firms-plead-to-courts-trump-for-west-Coast-export-terminals-idU.S.KBN1FJ0KB>, last accessed August 3, 2018.

³³ Earthfix (26.09.2017), *Coal Scorecard: Your Guide To Coal In The Northwest*. <https://www.earthfix.info/article/coal-score-card/>, last accessed August 3, 2018.

³⁴ Pearce, Tim (04.05.2018), *The Legal Battle To Save The Largest Coal Export Terminal In The U.S. Is Heating Up*. <https://dailycaller.com/2018/05/04/legal-battle-largest-coal-export-terminal/>, last accessed August 3, 2018.

and Oversized Terminal³⁵, which are still undergoing court challenges³⁶, but are equally unlikely to be realized.

Table 3: Existing and proposed U.S., Canadian, and Mexican West Coast coal export ports

Project	Location	Existing Capacity [Mtpa]	Planned/ Proposed Capacity [Mtpa]	Status 2018
Oxbow Terminal	Long Beach, CA	1.6	-	Operating
Metropolitan Bulk Terminal	Stockton, CA	2.4	-	Operating
Levin-Richmond Terminal	Richmond, CA	2.4	-	Operating
Westshore Terminal	Vancouver, B.C.	29.9	2.7	Operating/ Under construction
Prince Rupert Port (Ridley)	Prince Rupert, B.C.	18.1	-	Operating
Puerto de Guaymas	Guaymas, Sonora, MX	1.8	-	Operating
Port of Ensenada	Ensenada, Baja California, MX	-	?	Proposed
Millenium Bulk Terminal	Longview, WA	-	39.9	Permit denied, decision challenged
Oakland Bulk and Oversized Terminal	Oakland, CA	-	4.5	Ongoing legal case
Gateway Pacific Terminal	Bellingham, WA	-	43.5	Cancelled
Port of Grays Harbor	Hoquiam, WA	-	5	Cancelled
Port Westward	Port of St. Helens, OR	-	27.2	Cancelled
Morrow Pacific	Ports of Morrow and St. Helens, OR	-	8	Cancelled
Project Mainstay	Port of Coos Bay, OR	-	10	Cancelled

Sources: <http://tlsoakland.com/tls-multi-commodity-bulk-terminal/>; <https://www.earthfix.info/article/coal-score-card/>; <http://www.westshore.com/#/main>; <http://www.rti.ca/>; <http://energy.utah.gov/baja-california-utah-offices-sign-agreement-collaborate-energy-export-opportunities/>; NCC (2018).

Given the effective opposition to commercial (“civilian”) export terminal projects, the Trump administration, in particular the Secretary of the Interior, put on the table the suggestion to use military bases for coal exports instead, or at least consider the construction of such terminals on federal lands.³⁷ However, given modest global coal prices and ample supplies from other world regions, in addition to

³⁵ Sierra Club (2018), *Fight for a Coal-free Oakland*. <https://www.sierraclub.org/san-francisco-bay/coalfreeoakland#time>, last accessed August 3, 2018.

³⁶ U.S. Coal Exports (22.05.2018), *California judge ruling opens Oakland port to coal shipping*. <http://uscoalexports.org/2018/05/22/california-judge-opend-oakland-coal-shipping/>, last accessed August 3, 2018.

³⁷ <https://apnews.com/573a19c3d43643e5b2d961b46cd99c67>

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, 129)), it appears unlikely that these ideas will be realized.

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

Despite the death spiral for U.S. coal turning slower since 2016 due to sustained world demand, there is no doubt that it will continue to turn because of the fierce competition by lower priced natural gas and the long-term prospects of climate protection. Since his election campaign in 2016, the current U.S. President Donald Trump has emphasized his wish to support the domestic coal sector. His goal has been, in his words, to “make coal great again”. In this section, we discuss which main policy measures have been and may be chosen by the Trump administration. We derive the main domestic policy drivers to influence future U.S. coal production which we use to structure our scenarios in the subsequent sections.

3.1 Opposition to climate policy – Support for coal?

As part of its new energy policy, the Trump Administration is taking back measures introduced in the Climate Action Plan under the Obama Administration and trying to introduce measures to provide active support coal-fired electricity generation. With the official announcement in June 2017 to withdraw from the Paris Agreement, the Trump administration made clear that climate change would not be an issue of high priority for the U.S. government anymore.³⁸

In an executive order (Trump 2017), U.S. President Trump ordered an extensive reversal of environmental regulations promulgated under the Obama administration. Amongst others, he ordered to rescind the Climate Action Plan and related regulations. Furthermore, he ordered that rules that encouraged federal regulators to consider climate change in environmental reviews shall be rescinded. At the same time, the Trump administration uses a considerably lower social cost of carbon for future policy assessments than the previous administration did.

3.2 Rescinding the Obama administration’s national coal policies

In addition to the broader anti-climate policies, the Trump administration tries to support the U.S. coal sector both on the demand side (i.e. in the electricity sector) and on the supply side (i.e. coal mining) by rescinding policy measures that were introduced by the previous administration under Obama. Table 5 in the Appendix gives an overview of the relevant policies and their status under the Obama and the Trump administration.

Regarding coal use by the U.S. electricity sector, the Environmental Protection Agency (EPA) was ordered to review the “Clean Power Plan” (CPP) and to suspend, revise, or rescind its contents. The CPP was enacted by the Obama Administration in 2015 and originally scheduled to come into effect in 2022. It sets limits to CO₂ emissions from (existing) power plants. The regulation of existing stationary sources of greenhouse gases is a legal obligation of the EPA via the Clean Air Act. Therefore, the EPA

³⁸ The White House (01.06.2018), *President Trump Announces U.S. Withdrawal From the Paris Climate Accord*. <https://www.whitehouse.gov/articles/president-trump-announces-u-s-withdrawal-paris-climate-accord/>, last accessed August 4, 2018.

could not simply rescind the CPP without replacement. Thus, in August 2018, the Affordable Clean Energy (ACE) rule was proposed by the EPA (EPA 2018b). In contrast to the CPP, the proposed ACE rule only addresses coal-fired power plants and does not set nation-wide minimum performance standards for power plants but states can set their own standards (EPA 2018a). Moreover, with ACE, the EPA proposes an update of the New Source Review such that the requirement to apply for approval for major modifications of power plants, and hence the requirement to install (further) emission control technologies in these modified power plants, is softened.³⁹ As of early 2019, the ACE rule is a proposal so far and has not been passed yet.

Conventional power generators continue to lobby for financial support with 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).⁴⁰ Moreover, the Trump administration contemplates using emergency powers to subsidize coal-fired power plants.⁴¹ 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.⁴²

On the supply side of the U.S. coal sector, the Trump administration 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 2016.⁴³ He reduced the size of two national monuments in the Western Coal Region, both in Utah (Bears Ears National Monument by 85 % and Grand Staircase-Escalante National Monument by 46 %).⁴⁴ Further, the “Valuation Rule” (of exported coal) of the former Obama administration was rescinded by the Department of Interior in August 2017.⁴⁵ This rule was supposed to close a loophole allowing coal exports without paying royalties to the federal government. Additionally, the Royalty Policy Committee, an Interior Department advisory panel, proposed to reduce

³⁹ Hankins, Meredith (21.08.2018), *The Clean Power Plan Replacement Comes With a Major Change to NSR (Part 1)*, <http://legal-planet.org/2018/08/21/the-clean-power-plan-replacement-comes-with-a-major-change-to-nsr-part-1/>, last accessed September 3, 2018.

⁴⁰ Wara, Michael (05.10.2017), *The Trump Administration Moves to Guarantee Profits for Coal-fired and Nuclear Power Plants*, <http://legal-planet.org/2017/10/05/guest-blogger-michael-wara-the-trump-administration-moves-to-guarantee-profits-for-coal-fired-and-nuclear-power-plants/>, last accessed May 21, 2018.

⁴¹ Farber, Dan (14.05.2018), *Emergency Powers: A Two-Edged Sword*, <http://legal-planet.org/2018/05/14/emergency-powers-a-two-edged-sword/>, last accessed: 05/21/2018.

⁴² John, Jeff St. (12.06.2018), *FERC Commissioners Agree: No Grid Emergency Exists to Justify Coal, Nuclear Bailout*, <https://www.greentechmedia.com/articles/read/ferc-commissioners-agree-no-grid-emergency-exists>, last accessed August 3, 2018.

⁴³ Lipton, Eric and Meier, Barry (06.08.2017), *Under Trump, Coal Mining Gets New Life on U.S. Lands*, <https://www.nytimes.com/2017/08/06/us/politics/under-trump-coal-mining-gets-new-life-on-us-lands.html>, last accessed: 05/21/2018.

⁴⁴ Korte, Gregory (05.12.2017), *Trump shrinks Bears Ears, Grand Staircase-Escalante monuments in historic proclamations*, <https://www.usatoday.com/story/news/politics/2017/12/04/trump-travels-utah-historic-rollback-national-monuments/919209001/>, last accessed: 05/21/2018; Nordhaus, Hannah (02.02.2018), *What Trump's Shrinking of National Monuments Actually Means*, <https://news.nationalgeographic.com/2017/12/trump-shrinks-bears-ears-grand-staircase-escalante-national-monuments/>, last accessed: 05/21/2018.

⁴⁵ U.S. Department of the Interior (07.08.2017), *Interior Repeals Defective Federal Mineral Valuation Rule*, <https://www.doi.gov/pressreleases/interior-repeals-defective-federal-mineral-valuation-rule>, last accessed: 05/29/2018.

royalties to be paid by companies extracting coal, oil and gas from federal lands and U.S. waters.⁴⁶ The Obama-era environmental regulations “Stream Protection Rule”⁴⁷ and “Resource Management Planning”⁴⁸, both affecting mining activities, were repealed in the first months of 2017.⁴⁹

3.3 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 et al. 2018). Many also see it as an opportunity to keep on burning coal (IEA/OECD 2017b). However, the expected rate of technologic and economic progress of CCTS and the implementation of large-scale CCTS projects so far has not been achieved, neither for coal-fired power plants with CCTS, nor for CCTS in other sectors (Hirschhausen, Herold, and Oei 2012; Mendelevitch et al. 2018; Schlissel and 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 RES and expectations for cost reductions of CCTS technology are low (Schlissel and Wamsted 2018; EIA 2018c). In the U.S., CCTS currently is largely supported by the oil industry, which participates in the CCTS value chain as CO₂ user in Enhanced Oil Recovery.⁵⁰

President Trump is eager to support “clean coal”. However, he has not outed himself as a bold CCTS supporter so far.⁵¹ Still, with the Bipartisan Budget Act of 2018, passed in February 2018, support for CCTS projects was increased⁵² and some observers suggest that “the carbon-capture era may finally be starting”.⁵³ This reformed tax incentive could spur further development and application of CCTS, also in the power generation sector. However, the increase of support compared to the previous policy

⁴⁶ Hegyi, Nate (28.02.2018), *Industry May Pay Less For Coal Dug Up On Federal Lands*, <http://kuer.org/post/industry-may-pay-less-coal-dug-federal-lands#stream/0>, last accessed: 05/21/2018.

⁴⁷ The Stream Protection Rule was designed to “better protect water supplies, surface water and groundwater quality, streams, fish, wildlife, and related environmental values from the adverse impacts of surface coal mining operations and provide mine operators with a regulatory framework to avoid water pollution and the long-term costs associated with water treatment.” (Office of Surface Mining Reclamation and Enforcement (OSM) (20.12.2016), *Stream Protection Rule*, <https://www.regulations.gov/document?D=OSM-2010-0018-10631>, last accessed: 05/21/2018).

⁴⁸ The Resource Management Planning rule affirmed “the important role of other Federal agencies, State and local governments, Indian tribes, and the public during the planning process and (...) [enhanced] opportunities for public involvement and transparency during the preparation of resource management plans. (...) [It emphasized] the importance of evaluating the resource, environmental, ecological, social, and economic conditions at the onset of planning” (Bureau of Land Management (12.12.2016), *Resource Management Planning*, <https://www.regulations.gov/document?D=BLM-2016-0002-0415>, last accessed: 05/21/2018).

⁴⁹ Ballotpedia (n.d.), *Federal agency rules repealed under the Congressional Review Act*. https://ballotpedia.org/Federal_agency_rules_repealed_under_the_Congressional_Review_Act?gclid=EAlaIqobChhMltejB8M6e2QIVCIN-Ch1XSADXEAMYASAAEqIFPFD_BwE, last accessed: 05/21/2018.

⁵⁰ Alex Doukas, Janet Redman, and Steve Kretzmann (2017): Expanding Subsidies for CO₂-Enhanced Oil Recovery. <http://priceofoil.org/2017/10/24/expanding-subsidies-for-co2-enhanced-oil-recovery-analysis/>, last accessed January 4, 2019.

⁵¹ 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.

⁵² 26 U.S. Code § 45Q - Credit for carbon dioxide sequestration.

⁵³ Temple, James (20.02.2018), *The carbon-capture era may finally be starting*. <https://www.technologyreview.com/s/610296/the-carbon-capture-era-may-finally-be-starting/>, last accessed August 17, 2018.

remains minor and it is therefore questionable whether there will be a significant number of new or retrofitted coal-fired power plants with CCTS.⁵⁴ What is even more, governmental funding for CCTS research and development was significantly reduced at the same time.⁵⁵

3.4 Exports via the U.S. West Coast

As noted in Section 2.2.2, the Trump administration has taken little action so far in favour of coal terminals on the U.S. West Coast. However, as also discussed in Section 2.2.2, the issue is on its agenda as the proposal for export facilities on military land and the request for “a white paper assessing opportunities to advance U.S. coal exports” by the Secretary of Energy show (NCC 2018, IX). Meanwhile, lobbying continues for the Millenium Longview (WA) and Oakland (CA) terminal projects, including by Republican Party officials.⁵⁶ However, the jurisdictions in charge are mostly regional (local or state level) and not directly influenced by the federal U.S. administration.

Previous research expects up to 380 Mtpa of exports via the West Coast if investments in export terminals were freely to be made, even if taking into account the extra costs of investing and using the terminals (e.g., Holz et al. 2015). Indeed, PRB coal could then be exported (i.e. shipped overseas) in large quantities at quite low costs, avoiding the long rail transportation to the British Columbia export terminals (see Table 3), the bottlenecks in the export value chain and also shortening the shipping distances to the Asian market. Given PRB coal’s comparably low production costs, it could then compete at relatively low costs on the Asian markets.

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

4.1 Policy scenarios, data and method

In Section 3 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 (see Table 4). We embed the scenarios in either a *moderate* or an *ambitious climate policy* pathway.

The *moderate climate policy* pathway sees the global community taking some limited action against climate change at the ambition level of the currently active Nationally Determined Contributions (NDCs) that were pledged immediately after the Paris Agreement. However, this is not sufficient to limit global warming to below 2°C by the year 2100 but rather sets the world on course for a rise of the global mean temperature by some 3.2°C (2.6 – 4.0°C) above pre-industrial levels by the end of this century (Fekete

⁵⁴ Bennett, Simon and Tristan Stanley (12.03.2018), *Commentary: U.S. budget bill may help carbon capture get back on track*. <https://www.iea.org/newsroom/news/2018/march/commentary-us-budget-bill-may-help-carbon-capture-get-back-on-track.html>, last accessed August 17, 2018; Temple, James (20.02.2018), *The carbon-capture era may finally be starting*. <https://www.technologyreview.com/s/610296/the-carbon-capture-era-may-finally-be-starting/>, last accessed August 17, 2018.

⁵⁵ Chemnick, Jean (16.01.2018), *Trump wants to lead on 'clean coal.' Here's what that means*. <https://www.eenews.net/stories/1060070967>, last accessed August 17, 2018.

⁵⁶ See, for example, Boerger, Emily (14.08.2018), *US Senators sponsor bill to “clear the way” for Millennium Bulk Terminal*, <https://washingtonstatewire.com/us-senators-sponsor-bill-to-clear-the-way-for-millennium-bulk-terminal/>, last accessed December 2, 2018.

et al. 2017, 1). Global consumption of steam coal continues at a relatively high level and decreases only little below current consumption levels by 2050. To implement this pathway, we derive growth rates of steam coal consumption for all countries, except for the U.S., from the New Policies Scenario (NPS) of IEA's WEO 2017 (IEA/OECD 2017a). Data on future domestic steam coal consumption for the U.S. is based on EIA's Annual Energy Outlook (2018b). 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 et al. 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. Around the world, countries adopt effective climate policies and take action to reach the long-term targets of the Paris Agreement. The U.S., possibly under a new administration after President Trump's term has ended, return 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 450ppm 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. We use this data to assess the effect of an 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 2018b) which are rather high given the power plant fleet's vintage structure and the current energy economic trends (see Section 2). However, they give a good idea of the views of the Trump administration on the future U.S. energy sector developments which are in the focus of our analysis.

Table 4: Scenario overview

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

*Rollback: assumes growth rate for coal consumption based on IEA WEO 2017 NPS; for U.S.: reference consumption from AEO 2018

** CPP: assumes growth rate for coal consumption based on IEA WEO 2017 NPS; for U.S.: CPP consumption from AEO 2018

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

**** 2°C_CCTS: assumes growth rate for coal consumption based on IEA WEO 2016 450ppm

***** 2°C_no-CCTS: assumes growth rate for coal consumption based on IEA WEO 2016 450ppm without coal consumed by coal-fired power generation capacities equipped with CCTS

The scenario *Rollback* represents U.S. domestic coal consumption induced by new, lax environmental policy under U.S. President 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 mimic this situation by setting future U.S.

coal consumption equal to the values of the reference case in the AEO 2018 (EIA 2018b), which is based on the legal situation in the U.S. as of the end of the year 2017, not including the CPP. We contrast this situation to the scenario *CPP*, where the CPP is assumed to be in place. We use data for U.S. coal consumption from AEO 2018's reference case with CPP (EIA 2018b). 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. We implement this by allowing investments in Western ports to increase their export capacity by up to 50 Mt every 5 years from 2020 onwards.

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 President 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 does not have to be phased out entirely by the year 2050, while still reaching the 2°C climate target. In this scenario, the growth rates for steam coal demand are taken from the 450ppm scenario of the WEO 2016, which assumes around 260 GW of global coal-fired power generation capacity equipped with CCTS by the year 2040 (IEA/OECD 2016, 208). 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. Therefore, we take coal demand in the *2°C_CCTS* scenario and subtract calculated demand from CCTS equipped coal-fired units.⁵⁷ The scenario *2°C_CCTS_ports* assumes that, additional to measures from the scenario *2°C_CCTS*, the capacity of West Coast coal export ports can be expanded like in the scenario *Rollback_ports*.

To assess the implications of the different scenarios on U.S. and international steam coal markets, we employ a comprehensive model of the world steam coal market, COALMOD-World (see Holz et al. (2016) for a detailed description of the model). It assesses effects on global steam coal trade, prices, and investments as well as CO₂ emissions from coal consumption. The model was used in various contexts before: Haftendorn, Kemfert, and Holz (2012) use COALMOD-World to examine interactions between climate policies and the global steam coal market until 2030. With an extended modeling approach, Richter, Mendelevitch, and Jotzo (2018) explore the rationale for export taxes on coal and implications for climate change mitigation. Mendelevitch (2018) assess the distributional implications of different supply side policies. Holz et al. (2018) investigate the risk of asset stranding for major coal exporters and for various global climate ambition scenarios.

⁵⁷ We derive the amount of CCTS-equipped coal-fired power generation capacities from IEA's (2016) 450ppm scenario. By the year 2040, it assumes around 258 GW coal-fired power generation equipped with CCTS globally (total power generation capacities with CCTS: 430 GW; 60 % of them coal-fired) (IEA/OECD 2016, 208). First significant amounts of annual power generation capacity additions equipped with CCTS (not limited to coal) occur around the year 2025 (ca. 5 GW), increasing with annual additions of ca. 30 GW by 2030, then staying at this level throughout 2040 (IEA/OECD 2016, 253). We therefore assume the following global CCTS equipped coal-fired power generation capacities: year 2025 – 5 GW; 2030 – 58 GW; 2035 – 158 GW; 2040 – 258 GW. According to IEA/OECD (2016, 208), 75 % of coal-fired power plants equipped with CCTS will be located in China (193.5 GW in 2040) and about 12.5 % in the U.S. and India. For the remaining 12.5 % no information is given. We assume equal amounts of CCTS-equipped capacities in the U.S. and India (each 16 GW in 2040), 2.5 % (6.5 GW) in OECD Asia Oceania, and 10 % (26 GW in 2040) in Non-OECD Asia. Furthermore, we assume a load factor of 85 % for CCTS-equipped coal-fired power plants and 35 % efficiency of these units (only coal-fired units, not CCTS).

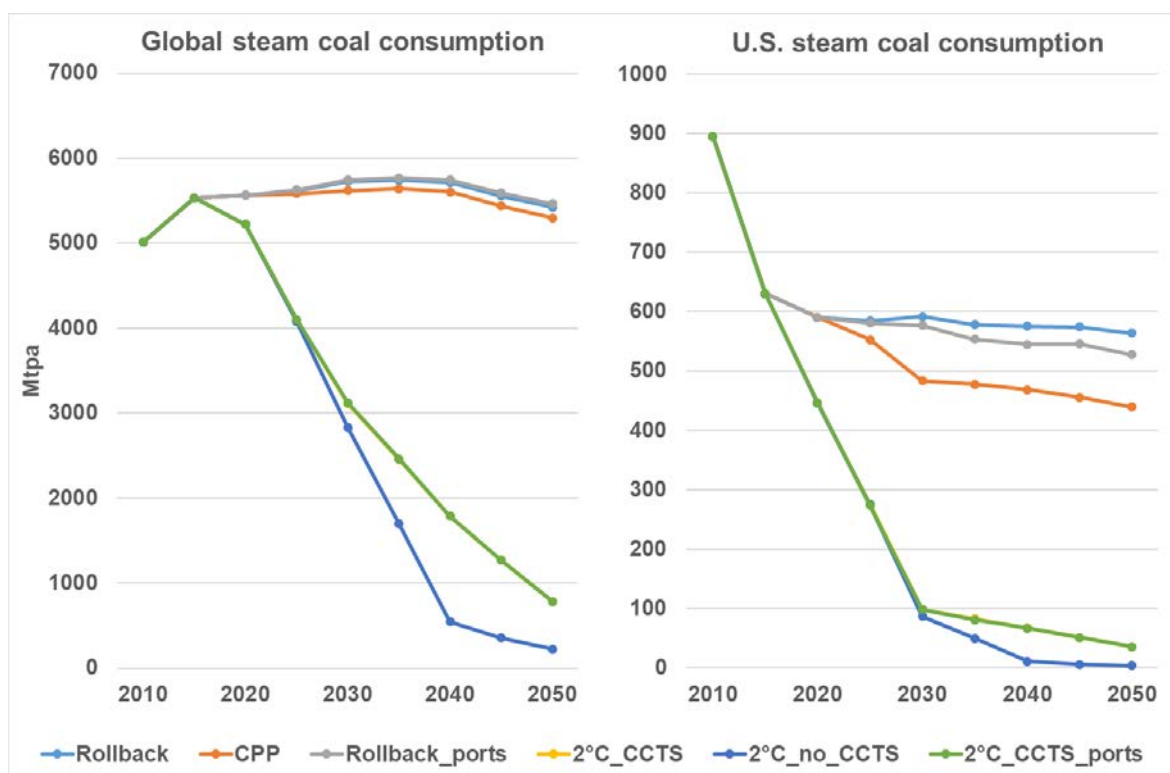
In the COALMOD-World model, we differentiate different producing and consuming regions and take into account distance-related transportation costs, in addition to region-specific production and investment costs of coal mining. For the U.S., we distinguish the four main mining regions as separate model nodes (PRB, Appalachia, Interior Basin, and Rocky Mountains). On the consumption side, we differentiate consumption nodes on the country and region level with 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.⁵⁸

4.2 Overview of future coal consumption scenario results

Figure 3 shows global and U.S. steam coal consumption 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 Mtpa to 5,700 Mtpa in 2030 and around 5,300 Mtpa 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 6 in the Appendix). 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 to 44 Gt (on average ca. 1.2 Gt per year) in the *Rollback* and *Rollback_Ports* scenarios (see Table 6 in Appendix). 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 this scenario, annual emissions decline continuously while in the *Rollback* scenarios they stay relatively stable.

⁵⁸ The U.S. states are mapped to the five coal consumption regions in the following way: USA-West (AK, AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, WY), USA-North-Central (IL, IN, IA, KS, MI, MN, NE, MO, ND, OH, SD, WI), USA-South-Central (AR, LA, OK, TX), USA-Southeast (AL, DE, DC, FL, GA, KY, MD, MS, NC, SC, TN, VA, WV), and USA-Northeast (CT, ME, MA, NH, NJ, NY, PA, RI, VT).



Note: Scenarios 2°C_CCTS and 2°C_CCTS_Ports lay on top of each other.

Figure 3: COALMOD-World results for global and U.S. steam coal consumption 2015 – 2050 in all scenarios

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.⁵⁹ 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.

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

U.S. steam coal production in the three scenarios of the moderate climate policy pathway is shown in Figure 4. 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 longrun at about the production level of 2015. However, replacing the Clean Power Plan with a rather coal friendly rule does not lead to a return to former high 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, production levels in the *Rollback* scenario are around eleven percent higher than in the scenario with the CPP.

⁵⁹ 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.

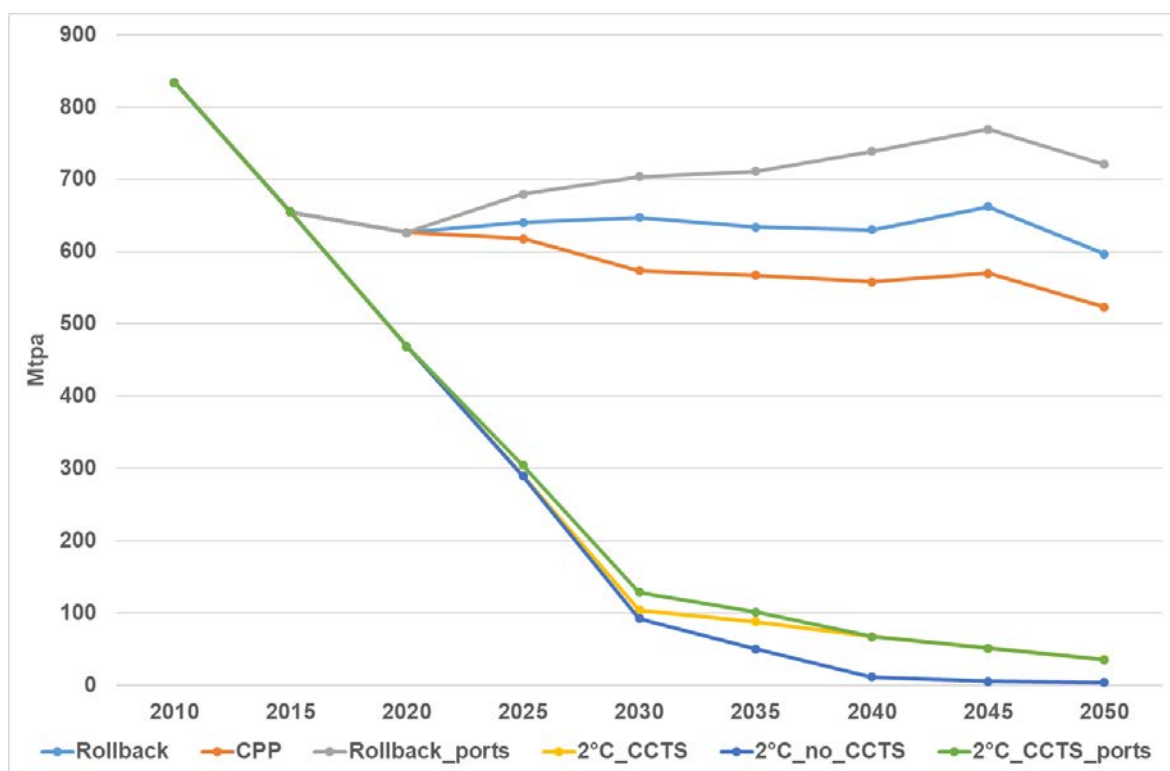


Figure 4: COALMOD-World results for U.S. steam coal production 2010 – 2050 in all scenarios

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 the year 2020. The absolute increase in production induced by these ports (compared to the *Rollback* scenario) amounts to approximately 60 Mtpa by the year 2030 and 120 Mtpa by the year 2050. 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.

Figure 5 shows the amount and destination of steam coal exports from the U.S. in the scenarios of the moderate climate policy pathway. Exports increase in all three scenarios. 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 the year 2035, and 150 Mtpa by the year 2050. In all scenarios, U.S. export destinations shift from Europe and the South America towards Asian countries. While in the scenarios *Rollback* and *CPP*, without new West Coast export facilities, U.S. exports from the year 2030 onwards go mostly to India, the two main destinations of U.S. steam coal in the scenario *Rollback_Ports* are Japan and South Korea.⁶⁰ Here, they replace mainly Colombia and Russia as coal suppliers.

⁶⁰ 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.

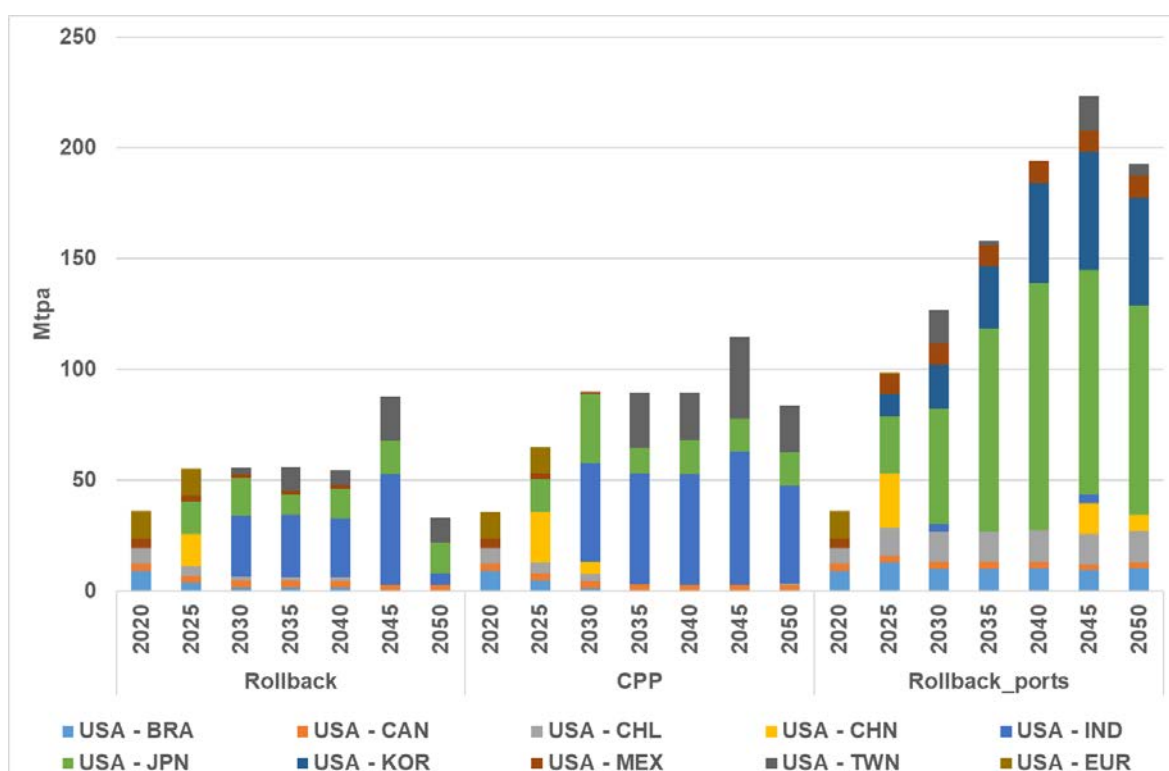


Figure 5: COALMOD-World results for U.S. steam coal exports 2020 – 2050 in moderate climate scenarios

Between 2020 and 2050, cumulative investments in the range of four to five 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.⁶¹ 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 the 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, Bordoff, and Marsters (2017, 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

⁶¹ COALMOD-World includes a mine mortality mechanism by which the oldest mines are physically depreciated over time. 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.

around 680 Mt until 2050 (EIA 2018b, 92). With the CPP being implemented, coal production would decrease to 570 Mt by 2030 and ca. 540 Mt by 2050 (EIA 2018b, 91–92).

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

If the political environment changes and the political and economic frame to get on track for reaching the 2°C target is set, prospects for U.S. coal production look significantly different (see Figure 3). U.S. steam coal production drops in all three scenarios in the ambitious climate policy pathway by around 85 % between 2015 and 2030 (Figure 4Fehler! Verweisquelle konnte nicht gefunden werden.).

CCTS cannot prevent this drastic decline even under optimistic assumptions regarding the availability of CCTS technology (scenario 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 the year 2030. Without CCTS (scenario 2°C_No_CCTS), U.S. steam coal production declines from around 90 Mt in 2030 to only 10 Mt in 2040. With CCTS available, coal production declines more slowly after the year 2030 and reaches ca. 40 Mtpa in 2050. This is around six percent of 2015's production.

The possibility to export 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 the year 2040 no more steam coal is exported from the U.S. (see Figure 6 in Appendix). The U.S. retain their role of 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 to 2040 (depending on the scenario), while other exporting countries continue to serve the Asian market. In the Atlantic markets, already in 2020 no more U.S. coal is present. In other words, U.S. coal exports are very vulnerable to climate policy in these markets.

In all three scenarios, no investments in coal supply infrastructure are made from the year 2020 onwards, except in scenario 2°C_CCTS_Ports, some investments into additional export facilities are made (ca. 300 million US\$).

5 Policy conclusions

At the latest with the second presidential term of Barack Obama, the U.S. coal sector has been heavily feeling the fading perspective for coal. 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 prime factor for the U.S. coal sector development. However, in the U.S. electricity sector, coal suffers from lower competitiveness compared to recently built natural 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 environmental regulation will disproportionately favor coal-fired generation over other energy technologies, lax rules will not change the tide for coal.

The new U.S. administration, however, has promised to stop the spiralling down of the U.S. coal sector. To this end, President Trump is aggressively rolling back environmental regulation and commitments, with a complete re-organisation of the environmental administration: most prominently announcing to

leave the Paris Agreement and replacing the Clean Power Plan (CPP) with the Affordable Clean Energy (ACE) rule. 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. Nevertheless, our results with the COALMOD-World model show that in no case coal production to the all-time high levels of the 2000s (that were 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 of 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 promise of the Trump administration is to be taken seriously, it needs to take actions at another scale. 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 Carbon Capture, Transport and Storage (CCTS) technology.

For coal exports via the U.S. West Coast, overcoming the regulatory hurdles to expand West Coast terminals is necessary. Moreover, investments to expand coal transport infrastructure in the range of four billion US\$ (in 2010 US\$) would become necessary in the period 2020 to 2040, in particular to allow exports from the low-cost Powder River Basin in the Western United States. In addition, investments into coal mining infrastructure would need to fourfold compared to the *CPP* scenario during the same period, albeit at a relatively low level of 10.7 billion US\$. For comparison, in 2012 alone, capital expenditure in the sector were around 9 billion US\$.⁶² Moreover, these investments would be at high risk of stranding, given that U.S. coal exports vanish under an *ambitious climate policy* pathway and production drops to six percent of 2015 levels, or less. While West Coast exports support Powder River Basin 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.

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 Mtpa 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, 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

⁶² See U.S. Census Bureau, 2012 Economic Census. Capital expenditures (except land and mineral rights) <http://www2.census.gov/econ2012/EC/sector21/EC1221SG1.zip>.

scenarios is driven by exports, even without West Coast ports being available. Traditionally a supplier to Europe and South America, 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 asset stranding from sudden climate policy shifts in other world regions. We already see a risk of this type looming with the recent announcement to shut down a large share of South Korean's coal-fired power plants until the mid 2020s.⁶³ So, neither export markets nor the domestic U.S. market will be able to change the tide for U.S. coal production in the long-term.

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⁶³ <https://www.climatechangenews.com/2018/10/03/south-korean-province-joins-international-coal-phaseout-club/>

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Appendix

Table 5: U.S. environmental policy relevant for the coal sector in the governments of President Obama (2009-2017) and President Trump (since 2017)

Affected sector	Environmental policy under Obama	Environmental policy under Trump
General	<ul style="list-style-type: none"> - <i>Paris Agreement</i> - <i>Climate Action Plan</i> 	<ul style="list-style-type: none"> - Withdrawal from <i>Paris Agreement</i> (effective earliest in 2020) - <i>Climate Action Plan</i> rescinded - DOE Grid Study highlighting the will to facilitate licensing of new coal power plants⁶⁴
Coal-fired power generation	<ul style="list-style-type: none"> - Clean Power Plan - Carbon Pollution Standards for New, Modified and Reconstructed Power Plants - New Source Review under the Clean Air Act (since 1977) - Cross-State Air Pollution Regulation (CSAPR) - Mercury and Air Toxics Standards (MATS) - National Ambient Air Quality Standards (NAAQS) for particulate matter (PM) - EPA regulation of coal combustion residuals (i.e., ash) disposal - NAAQS for ozone - Visibility and Regional Haze Rule - EPA regulation of cooling water intake under the Clean Water Act in the framework of the National Pollutant Discharge Elimination System (NPDES) - Effluent guidelines for wastewater discharge 	<ul style="list-style-type: none"> - Rescinding Clean Power Plan - Proposal for aid to coal and nuclear power plants - Financial incentive for CCTS - Social cost of carbon reduced for future assessments of energy policy - All other regulations are still in place at this time, but where regular review is mandated there will be no further tightening of standards and rules (e.g., NAAQS for PM and ozone). - Reconsidering some more rules has been announced (e.g. Visibility and Regional Haze Rule)

⁶⁴ Staff Report to the Secretary on Electricity Markets and Reliability (<https://www.energy.gov/staff-report-secretary-electricity-markets-and-reliability>, accessed on October 8, 2018).

Coal production (extraction)	<ul style="list-style-type: none"> - Stream Protection Rule - Waters of the United States Rule - Moratorium on new coal mine leases (on federal land) - Bureau of Land Management's Resource Management Planning Rule (BLM 2.0) for federal land - Closed a loophole in the Valuation Rule (for royalty payments from extraction on federal lands) 	<ul style="list-style-type: none"> - Stream Protection Rule disapproved before implementation - Repeal of Waters of the US Rule under way - Moratorium on new coal mine leases cancelled - Resource Management Planning rule repealed - Valuation Rule rescinded - Reduction of two national monuments' size - Proposal to reduce royalties
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Sources: Adapted from (Houser, Bordoff, and Marsters 2017; U.S. DoE 2017)

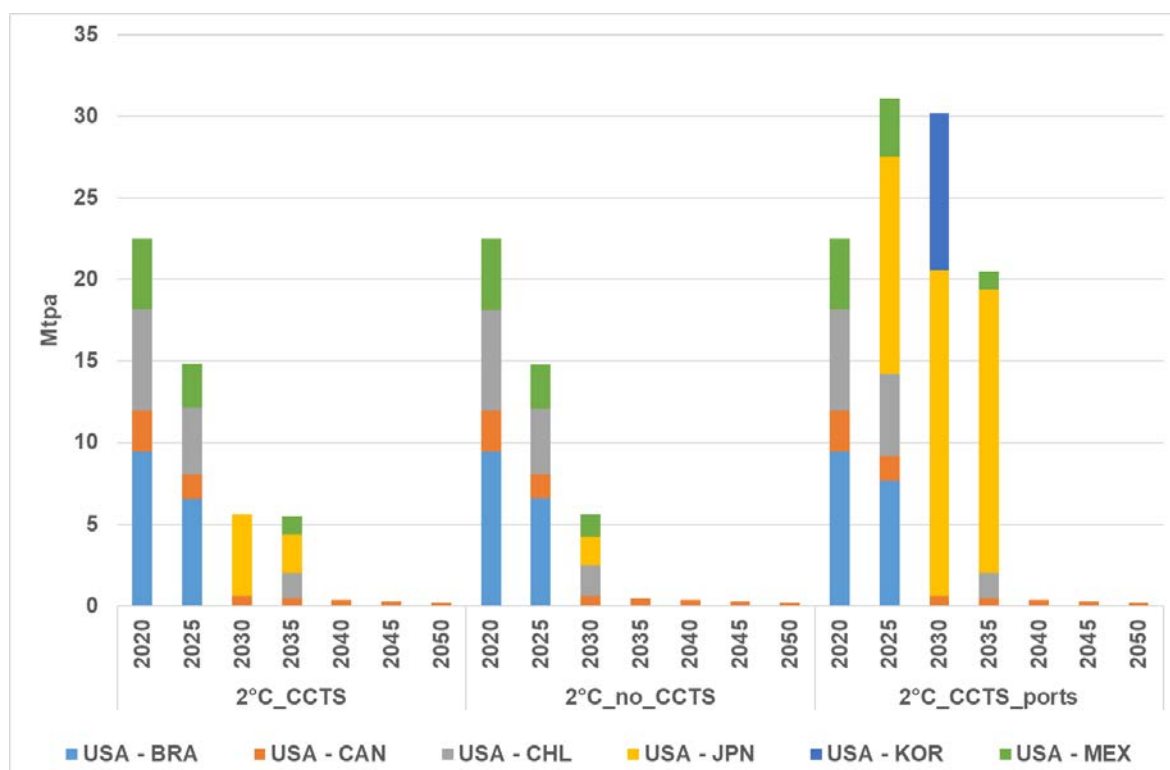


Figure 6: U.S. steam coal exports 2015 – 2050 in the ambitious climate policy pathway (all scenarios)

Table 6: World and U.S. CO₂ emissions from coal in the different scenarios, cumulative and by model year in Gt

Scenario	World cum 2015-2050	USA cum 2015-2050	USA annual average (2015- 2050)	USA 2015	USA 2025	USA 2030	USA 2050
Rollback	480	43.9	1.2	1.3	1.3	1.3	1.2
CPP	473	37.7	1	1.3	1.2	1	0.9
Rollback_P orts	480	43.2	1.2	1.3	1.2	1.3	1.2
2°C_CCTS	214	12.5	0.3	1.3	0.6	0.2	0
2°C_No_C CTS	214	12.5	0.3	1.3	0.6	0.2	0
2°C_CCTS _Ports	214	12.5	0.3	1.3	0.6	0.2	0