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The death valley of coal – Modelling COVID-19 recovery scenarios for steam coal markets

Paola Yanguas Parra *, Christian Hauenstein, Pao-Yu Oei

Workgroup for Economic and Infrastructure Policy, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Secretariat H33, Germany
Dept. Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin), Mohrenstr. 58, 10115 Berlin, Germany

HIGHLIGHTS

- Pre-COVID-19 negative trends in coal markets are accelerated by pandemic.
- Design of COVID-19 recovery policies have large influence on long-term coal outlook.
- Trade restrictions change dramatically the composition of international coal trade.
- COVID-19 driven coal decline scenarios do not comply with global climate targets.
- Targeted policies to curb coal emissions are needed in pandemic aftermath.

GRAPHICAL ABSTRACT

- Pre-COVID-19 trends in coal markets
  - Higher environmental policies
  - Increased consumption and feedstock.
  - Developmental trends demonstrate financial performance of coal firms.
- Steady growth of coal price pipeline.
- Short-term COVID-19 impact on coal markets
  - Decline in demand due to lock-downs and closures.
  - Imports from international coal price, and derivative coal trade and derivatives.
  - Supply of carbon funds for coal.
  - Decline in demand for coal in Europe.
- Mid and long-term influence of post-COVID-19 recovery measures on coal markets
  - Higher carbon emissions and price trends.
  - Accelerated decommissioning of coal power plants.
  - Increased coal demand.
  - Emergence of new coal markets.
- Plausible post-COVID-15 changes in mid and long-term steam coal production and trade

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ABSTRACT

This paper examines medium and long-term perspectives for global steam coal production and trade, considering the potential impacts of the COVID-19 pandemic and plausible recovery scenarios in its aftermath. We use an interdisciplinary approach to develop a range of stylized global coal demand scenarios until 2040 depicting the influence of the COVID-19 pandemic and resulting recovery stimuli. Additional insights are gained by adjusting trade restrictions of key countries within the coal sector model COALMOD-World to resemble plausible post-COVID-19 policy and market dynamics. Results indicate that the COVID-19 pandemic might cause an “L” or “\" shape instead of the hoped for “V” or “U” shaped recovery of the coal industry. Regional effects vary, as the Atlantic market dries out first, causing shifts in trade patterns in the Pacific market. Moreover, announced trade restrictions could change dramatically the composition of the international steam coal trade. However, even significantly reduced coal consumption levels in low-coal post-COVID-19 scenarios would still be too high to comply with the global climate targets. This emphasizes the importance of concentrated policy efforts in the
pandemic aftermath to manage a coal decline consistent with global climate targets while bringing just transitions efforts substantially forward, in particular in vulnerable coal-dependent countries and regions.

1. Introduction

1.1. Prospects for coal markets during and after COVID-19

Coal accounts for around a third of global primary energy supply and is responsible for 40% of global CO₂ emissions [1]. There is a broad consensus within science that a fast coal phase-out is needed to limit global heating and prevent related catastrophic consequences [2]. Still, uncertainty prevails about the actual pathway that coal countries will take – with scenarios projecting a rapid global coal phase-out within the next 30 years while others announce a renaissance of coal considering that many countries – mostly in the Global South – are still planning to expand coal use in the coming decades [3–7].

Since the signing of the Paris agreement in 2015, however, additional financial, and political pressures on coal businesses can be observed. This includes climate and air pollution regulation, local resistance to projects, climate litigation, trade restrictions, and reduced operational margins of coal companies due to competition with alternative fuels [8]. This resulted in key indicators showing early signs of decline of the global coal industry, such as coal use peaking in 2014 [1], a 75% shrinking of the global coal power plants pipeline [9], accelerated retirement of operating coal fleets in many countries, low international coal prices, and a bleak financial performance for a large share of coal-related businesses in many countries [10–12]. On top of this, the COVID-19 pandemic and the local to global responses to it have led to a sudden drop in economic activity, resulting in drastic reductions of energy demand [13]. With numbers of infections still increasing, no cure or vaccine available yet, the end of the pandemic is still not in sight. While as a consequence Greenhouse Gas (GHG) emissions have declined [14,15], the economic consequences of the pandemic and its further impacts on energy markets are highly uncertain [16]. First assessments of the COVID-19 pandemic indicate that resulting direct and indirect effects will hit the coal industry hard in the short-term [17].

The International Energy Agency (IEA) has published an assessment for the short-term future of global coal demand incorporating the effects of the pandemic [18]. The assessment shows that coal will be severely affected due to the global lockdown measures, and projects global coal demand to fall by an unprecedented 8% by the end of 2020, with coal power generation declining by more than 10% [18]. Similarly, recent 2020 projections for seaborne coal exports have been revised downward considerably to account for the impacts of COVID-19 [19–21]. These absolute declines in trade, combined with decreases in benchmark prices, will have a strong impact in the forecasted earnings from coal exports, as updated national forecasts from coal exporters confirm [21–23].

While the COVID-19 pandemic will likely have a strong negative impact on the short-term outlook for steam coal markets, the longer-term outlook is much more uncertain. For instance, the downward trend in coal investments [24], and growing number of restrictions for coal financing by financial institutions, will likely be accelerated by COVID-19 due to the capital scarcity resulting from the global economic recession. Decreasing capital availability for coal businesses make the prospects for new coal power plants look much worse than before [25–27]. See Fig. 6 in the Appendix mapping various (in-) direct impacts of COVID-19 on the international steam coal market. However, it is important to note that a large part of the coal power plant pipeline relies on public investment [28–30]. This could still be available in the post-COVID-19 period, and could end up being used for “brown-recovery” (favouring fossil-fuels based and carbon-intensive industries) measures as it happened after the 2009 financial crisis, when only 16% of all fiscal measures (~$520 billion) were allocated to “green stimulus” (favouring climate-friendly and low-emissions industries) [31].

In this regard, public investments for projects abroad are of critical importance. China (as largest public investor) has not made any announcements regarding its intentions to continue financing large amounts of new coal power plants abroad in the post-COVID-19 period. Japan and South Korea (second and third largest public investors in new coal power plants [28–30]), on the other hand, have presented steps in the direction of limiting or suspending their lending for new coal projects [32,33], but with loopholes and exceptions that would allow some planned projects to go ahead [34,35].

Therefore, key policy and economic developments in the next years, driven largely by the evolution of the pandemic and governments’ responses to it, nationally and internationally, will be determinant for the medium and long-term future of coal markets and global warming mitigation efforts [17,36]. Pointing towards increasing pressure on coal, “green recovery” issues have taken on a prominent role in the policy, advocacy, diplomatic, and academic discussions around the pandemic and post-pandemic world [14,37–48].

Within this context, this paper examines the medium and long-term perspectives of the global steam coal demand and production considering the potential impacts of the COVID-19 pandemic and its aftermath. A key question in this regard is the speed and geographical distribution of the global decline of coal use and production [49,50]. Main uncertainties hereby prevail with respect to (i) the severity of the short-term demand shock in 2020/21 as well as (ii) to the shape/characteristics of recovery packages – resulting in a range of post-COVID-19 scenarios that shed light on the speed and geographical distribution of coal decline in the next decades. The difficulty of projecting the medium and long-term future of coal can be seen in the failure of most organizations in doing so in the past [51], with mainstream energy projections persistently underestimating the deteriorating outlook for coal demand (and the uptake of renewable energy) in the last years [52–54]. Such overoptimistic projections are used as reference for investment and policy decisions resulting in unnecessary investments in long-term infrastructure that can create or perpetuate a carbon lock-in for many decades, or will become stranded once the carbon bubble bursts [55–58].

To assess energy markets, such as global coal markets, sectoral models using a partial equilibrium approach have been used [59,60]. Equilibrium modelling allows to study energy market development that is subject to individual actor behaviour under constraints, and considering market and investment mechanisms. The partial equilibrium model framework COALMOD was developed to assess the global steam coal market, focusing on steam coal supply and trade [61–63]. The model COALMOD-World is used in a number of studies to investigate the implications of different coal demand and market configuration scenarios for coal producing regions and international coal trade in a pre-COVID-19 world [11,64,65]. In most of the assessed scenarios in these studies, results fall into two different groups. One representing a relatively stable consumption and production around 2015–2020 levels, and the other one, based on 1.5–2 °C pathways, leading to drastic changes for all coal producers.

The above literature review shows that there is an urgent need of...
Our scenario building process of six different scenarios can be divided into three steps, which are summarized in Fig. 1, and explained in more detail in the following sub-sections. First, we determine the plausible range of short-term impacts of the COVID-19 shock (2020–21) on coal demand. Second, we adjust pre-COVID long-term national and/or regional projections (up to 2040) for coal demand based on a plausible range of post-pandemic recovery strategies (‘brown’ vs. ‘green’ recovery). Third, we consider additional (COVID-19 related) coal supply-side policies and add exemplary scenarios taking these coal market influencing measures into account.

For this scenario building process, we derive information from a triangulation of data sources:

(i) Pre-COVID-19 projections based on the IEA World Energy Outlook (WEO) 2019 [72]; and quantitative assessments of the short-term impact of COVID-19 in coal demand based on the 2020 adjusted Energy projections by the IEA [18].

(ii) For the qualitative research on the narratives, we follow a similar approach to Hepburn et al. [42] and base part of our narrative building exercise on surveys of national experts in the coal sector, for the main coal producing and consuming countries. This expert survey (conducted in May and June 2020) provides both qualitative and quantitative assessments of the updated trends for coal demand and supply in key coal consuming and producing countries as well as expert judgement of the long-term implications of the 2020 pandemic on important sectors, we build narratives about possible futures (e.g. brown vs green recovery) based on qualitative research techniques, and build quantitative estimates of the potential range of outcomes, making use of established models in the research field.

2. Methods and scenario building

Within the uncertainty context explained in the previous section, in this article, we conduct a scenario analysis taking pre-COVID-19 trends in the energy and coal sectors into account, to assess the influence of the COVID-19 pandemic and resulting recovery stimuli on the global steam coal market subject to different political decisions. To do so, this paper presents an interdisciplinary approach to develop a range of stylized coal demand scenarios up to 2040 as described in more detail in Section 2. These scenarios’ implications for steam coal international trade and coal producing countries are investigated using the partial equilibrium model COALMOD-World (CMW) [63,66]. Additional insights are gained by assessing effects of coal trade restrictions of key actors in further scenarios. Results of these scenarios for thermal coal production and trade are shown and discussed in Section 3, Section 4 focuses on broader policy and political economy issues of these results. Finally, Section 5 presents our conclusions as well as key issues that require further research.

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Reductions in coal electricity generation in 2020 for selected regions and countries. Reductions indicated with a * are the same as in the IEA Global Energy Review 2020 projection.

| Coal Electricity generation | USA  | Europe | South Africa | Russia | China | India | Japan | South East Asia | Other Asia Pacific |
|----------------------------|------|--------|--------------|--------|-------|-------|-------|----------------|------------------|
| Small shock                | -25%*| -20%*  | -15%         | -10%   | -4%   | -5%   | -5%   | -5%           | -5%              |
| Big shock                  | -50% | -40%   | -30%         | -20%   | -8%   | -10%  | -10%  | -10%          | -10%             |

IEA projections.  

(ii) For general economic trends, non-sector specific information on recovery plans, as well as global climate action narratives related to the storylines behind our scenarios, we examine the scarce academic literature available on the topic, and complement it with non-academic sources (e.g. news articles and press releases,3 policy monitors [73–75], and grey literature [76–80] examining recovery packages) focusing on publications since the outbreak of COVID-19 until September 2020.

Our intention is not to forecast coal demand for individual countries with high accuracy, but rather to map the existing range of uncertainty in the global steam coal market under plausible post-COVID-19 scenarios. This allows us to reflect on strategies major coal-producing countries could adopt to prepare for a highly uncertain future of their coal industries, and how these strategies could be integrated in COVID-19 related policy interventions.

2.1. Demand scenarios – Short term

In our upper bound scenario, we assume a short-term reduction of 8% in global coal-fired power generation (‘small-shock’; for national/ regional reductions see Appendix 6.2). This is based on a combination of the projected decline by the IEA Global Energy Review 2020 [18] (when available), and independent assessments by international experts or review of national energy statistics (when IEA individual forecasts were not available or for divergent reasoned opinions from various regional experts). As a result of this approach our “small-shock” scenario is more conservative compared to the IEA forecast for coal power generation in 2020 (globally at least –10%), with the main difference between this scenario and the IEA projection being lower reductions forecasted by national experts for China (-4% instead of –5%) and India (-5% instead of –6 to –9%). Arguments for these differences were mostly potentially faster uptakes of coal utilization than assumed by the IEA. Still, all experts confirmed high uncertainty about the evolution of the national coal industries, which we try to reflect in our scenario range.

The calculations of the IEA Global Energy Review 2020 (used for the small shock scenario for several regions) are consistent with the reference scenario of the International Monetary Fund (IMF) World Economic Outlook from April 2020, assuming an overall reduction of 3% GDP for 2020 [13]. The IMF, however, has also provided alternative scenarios, covering a range of possible developments regarding the uncertain spread and severity of COVID-19. This includes calculations for a “longer outbreak in 2020” or a “longer outbreak in 2020 with a second wave in 2021”, which would result in global GDP growth estimates of –5.8% for 2020 [13].

Based on an extrapolation of these GDP growth forecasts from the IMF to coal demand forecasts by the IEA, together with alternative forecasts provided by the surveyed experts, we create a second lower bound or “big-shock” scenario resembling a 16% short-term global reduction in coal power generation – twice as steep as the “small-shock” scenario. A summary of reductions in coal demand in 2020 for key countries and regions is presented in Table 1 below. A full overview of the reductions for all regions under the different scenarios is available in the supplementary information (Appendix 6.2).

2.2. Demand scenarios – Medium and long term

Longer-term estimates for global steam coal demand will depend largely on two drivers:

(i) speed of coal phase-out in countries concentrating the majority of the operating coal fleet (China, India, USA and EU); and
(ii) new investment decisions in China, and other few countries (e.g. India, Turkey, Vietnam and Indonesia) which concentrate the large majority (greater than 75%) of planned coal power capacity additions.

Regarding the first aspect, our analysis of relevant literature and our expert survey shows that the coal phase-out will accelerate in most developed economies due to the COVID-19 pandemic, with medium uncertainty level about the extent and speed of the acceleration. On one hand, the pandemic reduces the profitability of the coal industry. On the other, it might also delay retirement decisions in some countries due to factors like delays in capacity replacements, or concerns about employment in a shrinking economy. Considering this uncertainty, our scenarios do not include an explicit assumption on targeted policy interventions on the coal power generation sector.

Even more uncertainty, however, prevails for the second aspect regarding developing and emerging economies and their investments in new coal capacity: Global Final Investment Decisions (FIDs) for coal-fired generation are on a steep downward trend, reaching in 2019 a 40-year historic low at around 17 GW [24]. Nonetheless, around 130 GW of new coal-fired power generation capacity are in the planning phase. Their realization would more than compensate for expected retirements in the next 3 years, resulting in a net growth in the global coal fleet of around 40 GW in this period [24].

Based on conflicting visions about these important drivers, we build two medium-to-long-term post-COVID-19 steam coal demand scenarios, resembling “green” and “brown” recovery scenarios (see Fig. 2). These scenarios are based upon a combination of pre-COVID-19 reference values of the Stated Policy Scenario (STEPS) and Sustainable Development Scenario (SDS) of the IEA [72] WEO. For each post-COVID-19 pathway, we determine a demand spread for each of the WEO regions,

4 At the moment of the analysis, the latest version of the IEA World Energy Outlook (WEO) available was the WEO 2019. All analysis therefore refers to these values. During the process of peer-review and publication of this paper, the WEO 2020 became available. This version is supposed to have been corrected for the COVID-19 shock in their energy sector projections, and reduced both short-term and long-term projections for coal generation. However, compared to our scenarios coal demand in the updated 2020 STEPS scenario is still higher than our highest post-COVID-19 scenario (see Appendix for further information on the differences between the two World Energy Outlooks). Therefore, our criticism of the WEO results not sufficiently representing the upcoming downturn of coal is still valid also for the WEO 2020.
5 This included a qualitative assessment of over 270 documents, including a selection of relevant news articles, public statements, and press releases related to different combinations of the search terms “COVID-19”; “climate”; “recovery”; “policy” – See Table 3 in the Appendix for overview of number of sources considered for individual countries/regions.
6 Our lower bound resembles the “longer outbreak in 2020” scenario of IMF [13] and does not extend the shock beyond 2020. Therefore, it could even underestimate the shock for coal in the case that COVID-19 does not get under control globally by the end of 2020.
which ranges between entirely brown (resembling STEPS growth rates for coal – e.g. in Russia) and entirely green (resembling a SDS trajectory for coal generation – e.g. in Europe).

To determine this range, based on the experts’ survey and our own desk research, we calculate a compound index for each region considering the following variables:

(i) accuracy of STEPS coal capacity projections based on updated information on current retirement schedules and new additions planned in 2019/20 (classified into three categories: unlikely low, likely, unlikely high);

(ii) a qualitative assessment of the overall climate policy environment in the region (classified into three categories: high, medium, and low); and

(iii) degree of discussion on “green recovery” packages for stimuli packages affecting the coal industry (classified into three categories: high, medium, and low) based on mapping media coverage of COVID-19 related measures and policy announcements from March to June 2020.

Results for the individual compound indexes resulting from this method for key countries and regions are presented in Table 2, a full overview of the ranges for each region are available in the supplementary information (Appendix 6.2).

The first criteria (assessment of the STEPS capacity projections) is in particular important for countries where without additional new coal power plants (beyond the ones announced, planned or under development in 2019), the installed capacity assumed by the STEPS scenario would require a significantly increased retirement age for operating coal power plants than what is observed in historical averages or even higher than average technical lifetimes of coal power plants (around 40 years). For these countries, we have lowered the probability of going into a STEPS growth rate post-COVID-19 scenario to account for this mismatch.

A clear example of this is the USA, where despite low overall climate policy environment, and hardly any active attempt from the federal government to design “green recovery” plans, the current investment and closure decisions are far away from the assumptions of the STEPS scenario. While the STEPS scenario assumes coal generation capacity to remain relatively stable throughout the 2030s for the USA, a large number of coal generation units have already announced to retire over the next years, without any new units under construction or planned, and a remaining fleet with an average age higher than 40 years [64].

For the second and third criteria, there is a higher degree of uncertainty on the assessment (reflected on higher spreads in the “brown to green” scale). This results mainly from: (i) the regional aggregation in the IEA [72] WEO, which combines groups of countries with very mixed policy and political environments for climate policy (e.g. Australia and South Korea are grouped under the same region), (ii) the uncertainty about the stability of policy regimes with regards to climate in the medium and long-term in a large number of countries; and (iii) the lack of specific references to the coal sector in most of the “green recovery” announcements or media reports. Therefore, the width of the range of “green” and “brown” post-COVID-19 scenarios increases substantially (and proportionally to this uncertainty) after 2025.

All resulting demand scenarios are depicted in Fig. 2 and the underlying numerical assumptions are available in the supplementary information. For the rest of this article, we will mostly focus on the two extreme cases for post-COVID scenarios, namely small-brown and big-

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### Table 2
Overview parameters green and brown recovery scenarios for selected regions and countries.

|                      | USA | Europe | South Africa | Russia | China | India | Japan | South East Asia | Other Asia Pacific |
|----------------------|-----|--------|--------------|--------|-------|-------|-------|-----------------|-------------------|
| **Compounded green recovery factor** | 1 = STEPS / 0 = SDS | | | | | | | | |
| Min                  | 0.0 | 0.0    | 0.2          | 0.5    | 0.2   | 0.1   | 0.4   | 0.3            | 0.3               |
| Max                  | 0.5 | 0.5    | 0.7          | 1.0    | 0.8   | 0.6   | 0.9   | 0.8            | 0.6               |
| **Accuracy of STEPS coal projections** | unlikely likely high | unlikely likely high | likely likely likely likely likely high | unlikely likely likely likely high | unlikely likely high | unlikely likely high |
| **Overall climate policy environment** | low high medium | low high medium | low high medium | low high medium | low high medium | low high medium |
| **References to Green Recovery** | low high medium | low high medium | low high medium | low high medium | low high medium | low high medium |

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**Fig. 2.** Steam coal global demand projections under selected pre and post-COVID scenarios. Note: STEPS and SDS scenarios from the IEA WEO 2019 are only presented in the figure for reference – but do not incorporate the effects of the COVID-19 pandemic.
green scenarios, since they cover the full uncertainty range of our projections and by reducing the number of combinations, we reduce the complexity of results interpretation. Results for the other scenarios are included in the Appendix.

2.3. Trade restriction scenarios

In 2020, China and India will be collectively responsible for around 70% of global coal consumption and around 60% of global coal production, as well as a large part of global coal imports. China, in addition, has also become a major investor in many international coal projects [28–30]. Our analysis on the supply side therefore focuses on trends in these two countries, as they constitute a dominating force in the international steam coal markets. If for instance, China and India encourage both production and use of coal, then international coal prices could remain stable or even increase. However, if they impose import restrictions, or end up with a national production surplus, then global coal prices could plummet rapidly, with significant impacts in large coal producing countries [81,82]. Preliminary analysis based on announcements by the Chinese government, on the other hand, suggest that China might attempt to use investments into the coal industry (in combination with the steel industry) to restart its economy and while reducing coal imports [85,86]. This would come in addition to already ongoing infrastructure improvements and expansions (e.g. Haoji railway) as part of the domestic coal industry restructuring aimed at boosting production and decreasing dependency on imports [87].

To investigate the implications of different post-COVID-19 coal demand scenarios on coal producing countries, we run a simulation of the demand scenarios presented in the previous sections with the COALMOD-World (CMW) model under two modalities: a “competitive market” scenario, without additional constraints imposed on global coal trade in the model; and a “limited market” scenario, with policy driven import bans in China and India from 2025 onwards, representing the attempt to prop-up their national coal industry as an economic recovery measure. While it is unlikely that all Indian and Chinese coal imports end in 2025, implementing these extreme trade restrictions in the model allows us to observe more clearly the main implications of these countries implementing trade restrictions for coal, in comparison with a “competitive market” scenario.

2.4. Model description

We run a simulation of the above described demand scenarios with a holistic model of the world steam coal market, COALMOD-World (CMW). The model calculates steam coal production, trade, and prices for the world’s regions. It features a detailed representation of domestic and international steam coal supply with a forecasting horizon until 2050 and includes endogenous investment decisions in production, land transport, and export capacity, as well as an endogenous mechanism that updates production costs due to resource depletion [63,66].

Mathematically, COALMOD-World is a perfect foresight complementarity model that collects the profit maximization problems of the major player types in the global steam coal market, producers and exporters, and balances their supply with demand in the coal consumption
regions. The model specification has a focus on the supply side of coal (coal extraction, coal transport) and includes extraction costs and extraction constraints, transport costs and transport constraints, investments in mining and transport. Both the seaborne and the overland international trade as well as the national markets are included, with large countries split in regional nodes.

In our six base scenarios, all input parameters remain unchanged, except the scenario specific, exogenously defined coal demand for the year 2020 and onwards. In the two scenarios with trade restrictions, the option of coal imports is excluded in the model for China and India starting in 2025. This is operationalised in CMW as an arbitrarily high import tax for all Chinese and Indian demand nodes (200 USD per tonne), from 2025 onwards – which, due to model characteristics, is equivalent to an import ban.

In the next section, results of our simulations are presented and discussed regarding its implications for international steam coal trade and for the largest coal exporting countries.

3. Results: A dim mid- and long-term outlook for steam coal markets

3.1. COVID-19 recovery: Avoid false hopes for a “V” or “U” shaped coal demand curve

Our results show that - regardless of the scale of the short-term shock of COVID-19 - medium and long-term global coal demand (Fig. 2) will be far below levels of the outdated reference scenario (STEPS in WE02019) of the IEA. While the IEA has corrected short-term decline in coal demand resulting from the COVID-19 pandemic, it still7 misses to account sufficiently for fundamental pre-COVID trends that affect the long-term coal demand and have been strengthened by the crisis (e.g. scarcity of capital for new coal projects, acceleration in retirements of old coal fleet). Our scenarios show that the developments in China, India, and the USA are hereby the biggest drivers influencing the slope of the overall decline (see Fig. 8 in the Appendix for regional demand developments). Following the decline in demand, global production volumes will observe a contraction of –20 to –60% by 2040 (compared to values of 2015) (see Fig. 3)6.

False hopes for a “V” or “U” shape of the demand curve (assuming a recovery) consequently have to be replaced by an “L” or “W” shape comparison. At best, global demand, and thus production, after the pandemic stays flat at 2020 levels throughout 2025 in case of broad recovery measures supporting coal-fired power production (brown recovery scenarios). However, even in the most optimistic scenarios from a coal perspective, demand starts to decline further after 2025.

3.2. The Atlantic market dries out first, causing shifts in trade patterns

The results of trade patterns show that effects vary across regions – and especially in between the two different markets (see Fig. 4): The Atlantic coal market is being reduced at a much faster pace than the Pacific market (for details see Fig. 10 in the Appendix). This is due to the shrinking demand in the EU and the USA across all scenarios. As a result, especially the USA and Colombia see shrinking volumes of coal exports with the pressure on other export regions economically dependent on their sales. The scenarios also show that South Africa loses its last shares in the Atlantic market and therefore becomes fully dependent on its trade to the Pacific market and especially to India – competing with (relatively cheap) Indonesian exports. This dependency becomes evident in the scenarios that limit coal imports for China and India resembling their aim to protect domestic coal production (see Fig. 5). Introducing trade restrictions in India would lead to an increase of domestic production to meet continuous demand for coal within the country. This would reduce South African exports in 2040 by around 50% compared to scenarios without import restrictions in China and India. Indonesia and Australia, currently the two largest thermal coal exporters in the Pacific market would also be hit by reductions of around 20–40% and 50–80%, respectively, by 2040 (scenario dependent) due to such trade restrictions.

These results illustrate the risk for coal exporting regions such as in Australia, Colombia, Indonesia or South Africa – being dependent on coal policies in India and China. This highlights the importance and urgency of just transition policies in these regions, described in the following section.

4. Discussion

An important insight from our analysis is that the scale of the short-term shock (2010–2021) of COVID-19 on coal demand and the choice of recovery strategy will have considerable repercussions for the long-term coal demand outlook ranging between –20 to –60% (compared to 2015 values).

The importance of the short-term shock effect can be explained by the reaching of tipping points in 2020 for some key players in national and international coal markets, which are not sufficiently considered by mainstream global energy outlooks such as the IEA WEO. Considering the weak economic position of many coal generation operators and mining companies already in 2019, a big-shock could significantly accelerate the retirement or sale (at a depreciated value) of their assets, with considerable long-term implications for national and international coal markets. This is amplified by the difficult economic outlook of finance for the global coal industry, which already was characterised by restricted private finance before COVID-19.

Regarding the post-pandemic recovery strategies, our results show that their design has long-term implications for the future of coal demand and supply. Thus, when designing these policies, decision makers should consider lessons learned from past economic recovery schemes (e.g. following the last global financial crisis) and previous experiences with coal transitions in coal-dependent regions.

Based on the literature review and our scenario results, we believe there are reasons for optimism regarding the “green” nature of post-COVID-19 recovery packages. A key difference between the 2008 crisis is that in 2020 most countries in the world have ratified the Paris Agreement, and have enacted national GHG emissions reduction targets. This will make it much more difficult for countries to opt for recovery...
Fig. 4. Major steam coal trade flows, and values for production, consumption and exports in 2015 (reference), 2025 and 2040 (model results of the scenario Big Green). Note: Values for 2015 are model results of a 2015 benchmark run (with slight deviations from historical values).
Fig. 5. Steam coal exports by major exporters 2025 and 2040 in scenarios with and without Chinese and Indian import restrictions.

Fig. 6. Summary of impacts of COVID-19 on steam coal markets Source: Own depiction.
Another key difference is that considerably less private capital is available for coal related businesses than in the aftermath of the COVID-19 crisis, and the risk profile of the commodity is much larger. With reduced capital available and interest rates primes compared to other industries, it is unlikely that coal businesses will be able to ensure large amounts of capital for business expansion in the aftermath of the COVID-19 crisis. Moreover, the currently observed currency depreciation and private capital flight in developing countries will make it more difficult for new projects in capital intensive industries (e.g. mining) to take-off unless heavily subsidised by public finance. Therefore, it is much more likely that the capital attracted by coal businesses in the aftermath of the COVID-19 crisis is merely destined to keep current operations on board.

Within this context, investment and policy decision by China, the world largest user and importer of steam coal, could have important international and global consequences, however, large uncertainty remains in this regard. Preliminary analysis based on announcements by the Chinese government suggest that China is willing to relax regulations that limited the expansion of national coal power capacity in the past with over 100 GW of new capacity possibly coming online in the next 10 years [90–92]. Analysis of the provincial post-COVID-19 stimuli plans reveal that coal dependent provinces are planning large sums of investment in rail and coal-to-chemicals projects with the aim of promoting the local coal industry [93]. This stands in stark contrast with the recent announcement of the Chinese government about its intention to peak emissions in 2030 at the latest, and aim for carbon neutrality by 2060. Thus, the central government might turn around provincial strategies centred around carbon intensive industries. This is exemplified by the recent announcements of China and the European Union (among the largest GHG emitters) about increasing the ambition of their GHG reduction targets.

### Table 3
Overview relevant consulted sources per region/country.

| Region/Country       | Number of relevant news articles | Articles with mentions green recovery measures | Articles with mentions brown recovery measures | Articles with mentions neutral/not relevant recovery measures |
|----------------------|----------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------------------|
| United States        | 17                               | 2                                             | 6                                             | 9                                                         |
| America              |                                   |                                               |                                               |                                                           |
| Mexico               | 5                                | 0                                             | 3                                             | 2                                                         |
| Canada               | 7                                | 2                                             | 2                                             | 3                                                         |
| Brazil               | 6                                | 0                                             | 3                                             | 3                                                         |
| Other Central and    | 19                               | 4                                             | 1                                             | 14                                                        |
| South America        |                                   |                                               |                                               |                                                           |
| European Union -     | 15                               | 14                                            | 0                                             | 1                                                         |
| general              |                                   |                                               |                                               |                                                           |
| UK                   | 16                               | 9                                             | 1                                             | 6                                                         |
| EU - Individual      | 67                               | 38                                            | 8                                             | 21                                                        |
| Member States        |                                   |                                               |                                               |                                                           |
| South Africa         | 6                                | 3                                             | 1                                             | 2                                                         |
| Other Africa         | 25                               | 5                                             | 1                                             | 19                                                        |
| Russia               | 5                                | 1                                             | 1                                             | 3                                                         |
| Other Eurasia        | 5                                | 1                                             | 1                                             | 3                                                         |
| China                | 16                               | 5                                             | 4                                             | 7                                                         |
| India                | 13                               | 4                                             | 2                                             | 7                                                         |
| Japan                | 11                               | 2                                             | 0                                             | 9                                                         |
| South East Asia      | 22                               | 5                                             | 7                                             | 10                                                        |
| South Korea          | 7                                | 5                                             | 1                                             | 1                                                         |
| Other Asia Pacific   | 6                                | 2                                             | 0                                             | 4                                                         |
| Australia            | 9                                | 3                                             | 6                                             | 0                                                         |

Note: individual references for reviewed news articles can be provided upon request.
efforts on vulnerable coal-dependent countries and regions to develop. The global steam coal market is characterised by a few producing (and exporting) countries, which have local regional economies that heavily rely on coal in terms of economic activity, fiscal revenue, and employment. The political economy of these regions is strongly linked to coal. Thus, the future of this fuel can have big repercussions on local policy making, which traditionally aims to slow and water-down climate policy efforts. Consequently, false hopes for a “green recovery” that can move the country quickly to its emissions peak and then to a carbon-neutrality pathway.

Moreover, as our results show, special attention needs to be out on coal-export dependent countries, where strong to extreme reductions are expected for coal exports. The global steam coal market is characterised by a few producing (and exporting) countries, which have local regional economies that heavily rely on coal in terms of economic activity, fiscal revenue, and employment. The political economy of these regions is strongly linked to coal. Thus, the future of this fuel can have big repercussions on local policy making, which traditionally aims to slow and water-down climate policy efforts.

Considering the strong social and economic impacts that coal decline has had in heavily coal-dependent regions and countries in the past, already existing negative trends in coal markets have brought renewed interest from policy makers and researchers on the strategies and instruments needed to ensure the existing and upcoming coal transitions are achieved in a just and socially acceptable manner. The extreme reductions on coal exports in some coal exporting countries that our scenarios show, confirm previous findings of the literature on just transitions regarding the importance of focusing recovery and transition efforts on vulnerable coal-dependent countries and regions to develop alternative sustainable development perspectives. In absence of such policies, these countries might become international roadblocks for climate action, while local economies and communities might result highly affected.

5. Conclusion

This paper has analysed the influence of the COVID-19 pandemic and resulting recovery stimuli on the mid and long-term outlook for the global steam coal market. Results show that the short-term impact of COVID-19 on coal power demand will be significant and unprecedented. The pandemic mostly reinforces already existing trends and market effects negatively affecting the coal sector. Consequently, false hopes for a “V” or “U” shape of the coal demand curve (assuming a recovery) will have to be replaced by an “L” or “\" shape demand outlook. Our results for mid- and long-term coal demand and production trends are significantly lower than in the IEA reference scenario STEPS, independently of possible pro-coal COVID-19 recovery attempts. This is in-line with recent analyses of the coal sector and its future development. The fact that future coal demand in the IEA STEPS lays far above plausible volumes in any post-COVID scenario is an important finding considering that investment decisions (in particular on the supply side), as well as some policy decisions, rely on mainstream reference scenarios for coal demand, which are still depicting outdated trends. These predictions were already too high before COVID-19, but now after the pandemic have become even more unrealistic. This increases the risk of misleading short-term decision making in many coal regions and highlights the need for further independent research. However, our research shows that there are reasons for optimism regarding the post-COVID-19 recovery packages when it comes to the impacts of the “green recovery” packages in the energy sector and its alignment with climate targets.

The economic crisis following the COVID-19 pandemic will most likely result in a dying coal industry, unless substantial support through national subsidies and public financing is provided to this sector. In this regard, China’s potential support for new coal power generation units, both domestically and internationally, is a critical factor regarding the future coal demand trajectory. The question arises if this support for coal can be aligned with agreed on climate targets, calling for additional research.

Depending on the extent of the pandemic, we find that it could also open the door for the world to get into a trajectory of decline in coal power generation that is more in line with scenarios limiting global heating to tolerable levels. Post-COVID-19 economic recovery packages should therefore be designed in a way that promotes clean energy, moves away from new investments on coal infrastructure, stays away...
from subsidies that prolong artificially the life of coal assets, and delivers a just transition to the most affected.

Nonetheless, neither the SDS of the IEA, nor our (slightly higher) lowest post-COVID-19 coal demand scenario are in line with the Paris Agreement [8]. Existing market trends triggered by the pandemic, together with “green recovery” plans for a big number of coal consuming countries therefore will not be enough to achieve the reductions needed in the coal sector under low warming scenarios. Additional targeted climate policy interventions aimed at the coal sector are therefore needed in addition to “green recovery” policies. These include the acceleration of already existing coal retirement schedules, much stricter air pollution and emissions standards, the early retirement of coal power plants that have been built in the last 20 years, and the shelving of the large majority of new coal power plants currently in construction or planning stage.

Our results and approach highlight the importance of further interdisciplinary work that provides the foundations for evidence-based policy making on these important issues [108]. Limitations of our methodology, which can be addressed by further research, include developing scenarios with more detailed projections and information for individual non-OECD countries with ongoing discussion about the future of coal. These are under-represented in our literature research and scenario sampling (e.g. Indonesia, Pakistan, Bangladesh, Turkey, etc.). Furthermore, to close the quantitative bias towards the global energy demand projections from the IEA, a larger sample of scenarios could be added as soon as other relevant global energy outlooks start providing COVID-19-adjusted projections. To improve coverage of regional specifics and details, modelling and analysis of the consequences of global demand scenarios should be carried on with a higher resolution and deeper level of analysis for individual coal exporters (e.g. impact for specific coal basins, regions, or companies; impacts on fiscal revenues and national accounts; coal supply assets at risk of stranding; etc.). Our analysis does not consider additional targeted climate policies and therefore only covers parts of the scenario cone. Scenarios taking into account additional policies aimed at reducing the use of fossil fuels could significantly worsen the outlook for coal producers and should be assessed in further studies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

5.1. Mapping the impact of COVID-19 on the steam coal market

The following figure maps various (in-)direct impacts of COVID-19 on the international steam coal market which are the basis for the developed scenarios.

5.2. Disaggregation of sources for scenario building and possible shortcomings

The shortcomings of this methodology include potential biases towards OECD countries; considering the level of detail and amount of information available is bigger than for non-OECD countries; potential omission of important information in local languages given that the team only reviewed materials in English, Spanish, Portuguese, and German; the lack of academic literature on the topic available at the moment of information collection; and a quantitative bias towards the International Energy Agency demand outlooks given that at the moment of the study, no other relevant global energy outlook had provided COVID-19-adjusted projections. We have tried to mitigate these shortcomings by 1) including the largest number of possible sources with relevant information (e.g. news articles and grey literature); 2) actively searching for opposing narratives on the future developments of individual countries (e.g. environmental groups vs coal industry); 3) contrasting the underlying assumptions of the IEA projections at the country level with i) the judgment of the national expert consulted, and ii) bottom-up estimates of current and planned coal power generation capacity, based on global database of coal power plant fleet (see Tables 3 and 4).

5.3. Comparison of WEO 2019 and WEO 2020

At the moment of the analysis, the latest version of the IEA World Energy Outlook (WEO) available was the WEO 2019. During the process of peer-review and publication of this paper, the WEO 2020 became available. This version is supposed to have corrected for the COVID-19 shock in their energy sector projections, and reduced both short-term and long-term projections for coal generation. Table 5 shows a comparison of total coal power generation, as well as cumulative coal generation capacity net additions between the two STEPS scenarios.

The WEO 2020 has – as in all previous years – reduced its coal projection in its annual outlook, showcasing the need for more accurate forecasts. As a general trend, the IEA projects a lower coal pipeline in its updated 2020 STEPS scenario showing for the first time a net global reduction in coal generation capacity until 2040 (more retirements than additions). However, detailed explanations on the assumptions changes that explain the differences between cumulative power generation capacity retirements and additions in the individual regions/countries are missing, leaving important questions unanswered.

This lack of detail makes it difficult to compare the updated STEPS scenario with our post-COVID scenarios in detail. However, in general terms, we can observe that the STEPS scenario of the WEO 2020 represents only a modest change in the pre-COVID trends for the coal power generation sector. This is illustrated by the fact that projected long-term coal demand is still higher than even the highest of our post-COVID scenarios, as illustrated in Fig. 7. Moreover, the slopes of the two scenarios for coal demand have a very similar long-term slope, showing that structural changes in coal markets that could follow the COVID-crisis (e.g. strong green recovery policies) have not been taken into account in the revised long-term projections, and the short-term shock is just seen as temporary, which strands in strong contrast with the scenarios we have developed in this paper.

Therefore, our criticism of the WEO results not sufficiently representing the upcoming downturn of coal is still valid also for the WEO 2020.
5.4. More detailed results of the scenario runs

See Figs. 8–11.

Fig. 8. Steam coal consumption in major consumption countries and regions in all scenarios, 2020–2040.

Fig. 9. Steam coal production by major steam coal producing countries 2015–2040 in additional scenarios.
Fig. 10. Steam coal imports by major steam coal import regions (x-axis) in 2015, 2025, and 2040 from major steam coal exporters (y-axis).

Fig. 11. Steam coal exports by major steam coal exporters (x-axis) in 2015, 2025, and 2040 to major steam coal import regions (y-axis).
References

[1] IEA. Data & Statistics. IEA 2020. https://www.iea.org/data-and-statistics (accessed April 10, 2020).
[2] IPCC. Summary for Policymakers. In: V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Con年由, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E., Lonnoy, T. Marelli, O. West atter, T. Waterfield, Eds. 1.5°C. IPCC Spec. Rep. Impacts Glob. Warn. 1.5°C Pre-Ind. Levels Relat. Glob. Greenh. Gas Emiss. Pathw. Context Strength. Glob. Response Threat Clim. Change Sustain. Dev. Efforts Eradicate Poverty, Geneva, Switzerland: World Meteorological Organization; 2018, p. 35pp.
[3] Audoly R, Vogt-Schilb A, Guivarch C, Pfeiffer A. Pathways toward zero-carbon electricity required for climate stabilization. Appl Energy 2018;225:884–901. https://doi.org/10.1016/j.apenergy.2018.05.026.
[4] Burandt T, Xiong B, L Briceno Gómez, E., & Davidon, C. M. Effective integration of coal-fired power plant financing. Inst Energy Econ Financ Anal 2020. https://ieefa.org/japan-plant-financing/ (accessed July 6, 2020).
[5] Chen H. The Questionable Future of Overseas Coal Investments. NRDC 2018. https://www.nrdc.org/experts/han-chens/questionable-future-overseas-coal-investments (accessed October 6, 2020).
[6] ILO. GREEN STIMULUS MEASURES 2011. https://www.ilo.org/wcmsp5/groups/public/--/dgreports/--/inst/documents/publication/wcms_194185.pdf (accessed April 8, 2020).
[7] BNP Paribas CIB. Asia sees green recovery from Covid-19 2020. https://cib.bnpparibas.com/sustain/asia-sees-green-recovery-from-covid-19-a-3-3484.html (accessed July 7, 2020).
[8] IEFFA. Japan Bank for International Cooperation takes first steps away from coal-plant financing. Int Energy Econ Financ Anal 2020. https://ieefa.org/japan-bank-for-international-cooperation-takes-first-steps-away-from-coal-plant-financing/ (accessed July 8, 2020).
[9] Bloomberg, Blackrock Warns Korea Utility on Overseas Coal Plant Push. BloombergQuint 2020. https://www.bloombergquint.com/business/blackrock-warns-korea-s-power-giant-on-overseas-coal-plant-push (accessed July 10, 2020).
[10] Renewable Energy Institute of Japan. Four Reasons Japan Needs to Cease Coal-Fired Power Exports and Shift to Supporting Renewable Energy 2020. https://www.renewable-ei.org/en/activities/reports/2018082601.html (accessed July 10, 2020).
[11] Hainckis, Krause, H., and K. Oet P-V. Decarbonizing China’s economy – modeling the transformation of the electricity, transportation, heat, and industrial sectors. Appl Energy 2019;255:113820. https://doi.org/10.1016/j.apenergy.2019.113820.
[12] ILO. 4 Ways to Eradicate the Corporate Disease that Is Worsening the Covid-19 Pandemic. Int Econ The 2020. https://www.ieconomics.org/blog/4-ways-to-eradicate-the-corporate-disease-that-is-worsening-the-covid-19-pandemic (accessed April 6, 2020).
[13] Mukanjari S, Sterner T. Charting a Green recovery policies for the COVID-19 crisis: modelling the impact on the economy and greenhouse gas emissions. Environ Resour Econ 2020;76:731–50. https://doi.org/10.1007/s10640-020-00454-9.
[14] Rosenbloom D, Markard J. A COVID-19 recovery for climate. Science 2020;368:477. https://doi.org/10.1126/science.abc4887.
[15] Callaghan B, Stern N, Stiglitz J, Zenghelis D. Building back better: Green COVID-19 recovery packages will boost economic growth and stop climate change. https://www.ox.ac.uk/news/2020-05-05-building-back-better-green-covid-19-recovery-packages-will-boost-economic-growth-and (accessed July 10, 2020).
[16] Heinrichs, S. - Coal outlook stays negative intensifying ESG concerns 2020. https://www.moodys.com/research/Moodys-Coal-outlook-stays-negative-amid-declining-earnings-investors-intensifying–PBC_1211465?showPdf (accessed April 2, 2020).
[17] Oei P-Y, Yanguas-Parra P, Hauenstein C. COVID-19 - Final Straw or Deathblow for the Coal Industry? Appl Energy 2020;288:116564. https://doi.org/10.1016/j.apenergy.2020.116564.
[18] Chen H. The Questionable Future of Overseas Coal Investments. NRDC 2018. https://www.nrdc.org/experts/han-chens/questionable-future-overseas-coal-investments (accessed October 6, 2020).
[19] BNP Paribas CIB. Asia sees green recovery from Covid-19 2020. https://cib.bnpparibas.com/sustain/asia-sees-green-recovery-from-covid-19-a-3-3484.html (accessed July 7, 2020).
[20] IEFFA. Japan Bank for International Cooperation takes first steps away from coal-plant financing. Int Energy Econ Financ Anal 2020. https://ieefa.org/japan-bank-for-international-cooperation-takes-first-steps-away-from-coal-plant-financing/ (accessed July 8, 2020).
[21] Renewable Energy Institute of Japan. Four Reasons Japan Needs to Cease Coal-Fired Power Exports and Shift to Supporting Renewable Energy 2020. https://www.renewable-ei.org/en/activities/reports/2018082601.html (accessed July 10, 2020).
[22] Hainckis, Krause, H., and K. Oet P-V. Decarbonizing China’s economy – modeling the transformation of the electricity, transportation, heat, and industrial sectors. Appl Energy 2019;255:113820. https://doi.org/10.1016/j.apenergy.2019.113820.
Loeffler K, Burandt T, Hainisch K, Oei P-Y. Modeling the low-carbon transition of the European energy system—A quantitative assessment of the stranded assets problem. Energy Strategy Rev 2019;25. https://doi.org/10.1016/j.esr.2019.100422.

Pfeiffer A, Millar R, Hepburn C, Beinhocker E. The ’2°C capital stock’ for electricity generation: Committed cumulative carbon emissions from the electricity generation sector and the transition to a green economy. Appl Energy 2016;179:1395–408. https://doi.org/10.1016/j.apenergy.2016.02.093.

Gabriel SA, Conejo AJ, Fuller JD, Hobbs BF, Ruiz C. Complementarity Modeling in Energy Markets 2012; ed. New York, USA: Springer, 2012.

Träby J, Paulus M. Market structure scenarios in international steam coal trade. Energy J 2012;33:91–123. https://doi.org/10.5547/01956574.33.3.4.

Hafendorf C, Holz F. Modeling and analysis of the international steam coal trade. Energy J 2010;31:205–30.

Hafendorf C, Holz F, Hirschhausen C von. The End of Cheap Coal?: A Techno-Economic Analysis until 2030 Using the COALMOD-World Model. 102 2012 305-325 2012;102S. 305-325.

Holz F, Hafendorf C, Mendelevitch R, Hirschhausen C von. The COALMOD-World Model: Coal Markets until 2030. In: Morke RK, Thürber MC, editors. Glob. Coal Market. - Supplying Major Fuel Emerg. Econ., Cambridge, UK: Cambridge University Press, 2015; p. 411–72.

Haeusserlein C, Holz F. The US Coal Sector between Shale Gas and Renewables: Last Resort Coal Exports? Berlin: DIW Berlin, 2020.

Holz F, Kafemann I-V, Sartor O, Scherwath T, Spencer T. What Does “Peak Coal” Mean for International Coal Exporters? A Global Modeling Analysis on the Future of the International Steam Coal Market. Berlin: IDIIR and Climate Strategies, 2018.

Holz F, Hafendorf C, Mendelevitch R, von Hirschhausen C A. Model of the International Steam Coal Market (COALMOD-World), Berlin, Germany: DIW Berlin, German Institute for Economic Research; 2016.

Amari D, Holz F, al-Kuhlami H. Energy outlooks compared: Different methods, different futures. Econ Energy Environ Policy 2020;9.

Schömaker P.H. Scenario Planning: A Tool for Strategic Thinking. MIT Sloan Manag Rev n.d. https://oslnrev.mit.edu/article/scenario-planning-a-tool-for-strategic-thinking/ (accessed September 24, 2020).

van Notten P. Writing on the Wall; Scenario Development in Times of Discontinuity. 2005.

Mietzner D, Reger G. Advantages and Disadvantages of Scenario Approaches for Strategic Foresight. Rochester, NY: Social Science Research Network; 2005.

Amer M, Daim TU, Jetter A. A review of scenario planning. Futures 2013;46: 23–40. https://doi.org/10.1016/j.futures.2012.10.003.

IEA. World Energy Outlook 2019. International Energy Agency; 2019.

Vivid Economics. Greenness of Stimulus Index. Vivid Econ n.d. https://www.vivideconomics.com/casestudy/greenness-for-stimulus-index/ (accessed September 24, 2020).

Carbon Brief. Coronavirus: Tracking how the world’s ‘green recovery’ plans aim to cut emissions. Carbon Brief 2020. https://www.carbonbrief.org/coronavirus-tracking-how-the-worlds-green-recovery-plans-aim-to-cut-emissions (accessed September 24, 2020).

OECD. Support for fossil fuel production rising again 2020). https://www.oecd.org/coronavirus/policy-responses/post-covid-economy/post_covid_economy.pdf.

IEA/OECD. Medium-Term Coal Market Report 2016. Paris, France: International Energy Agency, OECD Publishing; 2016.

Geels FW. The impact of the financial-economic crisis on sustainability transitions: Financial investment, governance and public discourse. Environ Innov Soc Transit 2013;6:67–95. https://doi.org/10.1016/j.eist.2012.11.004.

GEM, CREA. A New Coal Boom in China. Global Energy Monitor (GEM) / Centre for Research on Energy and Clean Air (CREA); 2020.

Myllyvirta L, Zhang S, Shen X. Analysis: Will China build hundreds of new coal plants in the 2020s? Carbon Brief 2020. https://www.carbonbrief.org/analysis-will-china-build-hundreds-of-new-coal-plants-in-the-2020s (accessed June 12, 2020).

Meidan M. COVID-19 and the electrification of the Chinese economy 2020;2:7. https://doi.org/10.1016/j.apenergy.2020.114778.

Carbon Brief. Analysis: China’s Covid stimulus plans for fossil fuels three times larger than low-carbon. Carbon Brief 2020. https://www.carbonbrief.org/analysis-chinas-covid-stimulus-plans-for-fossil-fuels-three-times-larger-than-low-carbon (accessed September 25, 2020).

Myllyvirta L. China’s 2060 climate pledge: long-awaited breakthrough or sugar-coating another decade of rising emissions? Cent Res Energy Clean Air 2020. https://energyanddecarbon.org/china-2060-carbon-neutrality/ (accessed September 25, 2020).

Pai S, Zerriffi H, Jewell J, Pathak J. Solar has greater techno-economic resource suitability than wind for replacing coal mining jobs. Environ Res Lett 2020;15: 034065. https://doi.org/10.1088/1748-9326/abb6cd.

Sartor O. Implementing coal transitions: insights from case studies of major coal-consuming economies. IDIIR and Climate Strategies 2018.

Cardoso A, Turhan E. Examining new geographies of coal: dissecting energyscapes in Colombia and Turkey. Appl Energy 2018;224:398–408. https://doi.org/10.1016/j.apenergy.2018.04.096.

Ehdenhofer O, Steckel JC, Jakob M, Bertram C. Reports of coal’s terminal decline may be exaggerated. Environ Res Lett 2018;13:024019. https://doi.org/10.1088/1748-9326/aaaa24.

Iooaho K, Markard J. The Politics of Technology Discourse: Discursive Struggles over Coal Phase-Out in the UK. Rev Policy Res 2020;ropr.12370. https://doi.org/10.1111/ropr.12370.

Svobodová K, Owen JR, Harris J, Wordsen C. Complexities and contradictions in the global energy transition: a re-evaluation of country-level factors and dependencies. Appl Energy 2020;265:114778. https://doi.org/10.1016/j.apenergy.2020.114778.

Bräuer H, Herpich P, Von Hirschhausen C, Jürgens I, Neuhoff K, Oei P-Y, et al. Coal transition in Germany Learning from Past transitions to build phase-out pathways 2018.

Coldubec B, Sartor O, Spencer T. Lessons from previous “Coal Transitions” High-level Summary for Decision-makers. IDIIR and Climate Strategies; 2017.

Campbell S, Coenen L. Transitioning beyond coal: Lessons from the structural renewal of Europe’s old industrial regions. Melbourne, Australia: Australian National University; 2017.

Herpich P, Brauer H, Oei P-Y. An historical case study on previous coal transitions in Germany. Berlin, Germany: IDIIR and Climate Strategies; 2018.

Ocelik P, Svobodová K, Hendrychová M, Lehotýský L, Everingham J-A, Ali S, et al. A contested transition toward a coal-free future: advocacy coalitions and coal policy in the Czech Republic. Energy Res Soc Sci 2019;58:101283. https://doi.org/10.1016/j.erss.2019.101283.

Recková D, Recká L, Šamý M. Coal Transition in the Czech Republic. IDIIR and Climate Strategies; 2017.

Wehnert T, Andreva T, Fekete H, Lütkehöner K, Luna L, Vievog M. Challenges of coal transitions: a comparative study on the status quo and future prospects of coal mining and coal use in Indonesia. Colombia and Viet Nam 2019.

McCarthy D, Ramsay V, Heffron RJ, Sovacool BK, Mebratu D, Mundaca L. Energy justice in the transition to low carbon energy systems: exploring key themes in interdisciplinary research. Appl Energy 2019;233:234–916. https://doi.org/10.1016/j.apenergy.2018.10.005.