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COVID-19-induced low power demand and market forces starkly reduce CO2 emissions

Christoph Bertram[a,*], Gunnar Luderer[a,b], Felix Creutzig[c,d], Nico Bauer[a], Falko Ueckerdt[a], Aman Malik[a,b], Ottmar Edenhofer[a,c,e]

[a] Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany
[b] Global Energy Systems, Technische Universität Berlin, Berlin, Germany
[c] Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany
[d] Sustainability Economics of Human Settlements, Technische Universität Berlin, Berlin, Germany
[e] Economics of Climate Change, Technische Universität Berlin, Berlin, Germany
[*] corresponding author: bertram@pik-potsdam.de

Abstract

The COVID-19 pandemic continues to strongly affect global energy systems. Global power sector CO_2 emissions show a substantial decline, thanks to a) the COVID-19-induced economic downturn and resulting reduction of electricity demand and b) a decrease of carbon intensity of power generation as coal generation is decreased most strongly. These effects illustrate the opportunity for different policies to support a structural and accelerating decline of power sector emissions.

Main

Even before the COVID-19 pandemic and its impact on the energy system and CO2 emissions[1], the power sector was amidst a dynamic transformation process. While fossil fuels (predominantly coal and gas) generate most power in most countries, renewable energies dominate growth of global power generation (Fig. 1a and b, and Extended Data Fig. 1). The uptake of wind and solar has been concentrated in a few markets with substantial support policies in place in the early 2010s, but has become much more wide-spread in recent years after continued reductions in technology costs and improvement in performance[2].

In this situation, the moderate reduction in electricity demand, stemming both from the direct restrictions in industry, commerce, and other activities and from the overall economic downturn, has had a particularly strong impact on power sector emission. Real-time generation data by fuel up to end of September is available for India[3], USA[4] and Europe[5], which together accounted for 34% of global 2019 CO_2 emissions from power generation[6]. In these three markets, monthly electricity demand has declined by up to 20% compared to 2019, while the monthly CO_2 emissions from the power sector have decreased by up to 50% (Fig. 2). The reason is the so-called merit-order of the capacity mix of different generation technologies. If demand decreases, plants with the highest variable costs are switched-off first. Fossil-based power plants incur costs from burning fuels to generate electricity. Costs of renewable and nuclear power are dominated by the construction of the plants, so these technologies are characterized by low variable costs per kWh and thus operate even with the reduced demand. This merit order mechanism induces an asymmetry against fossil fuels in the electricity generation mix and therefore CO_2 emissions decrease stronger than electricity demand.

Even within fossil generation, reductions in coal power generation are currently higher than reductions in power generation using natural gas (Extended Data Fig. 2), increasing the down-ward trend of coal in OECD countries. This is counter-intuitive, as traditionally natural gas power plants are thought to be less favorably placed on the merit-order, due to higher fuel costs. The overall economic downturn has however reduced demand for oil and natural gas in all sectors, so that spot-market prices for gas have declined, favoring gas-powered generation. Coal prices have also declined, but with a smaller impact on variable costs of coal-based power generation – due to higher shares of extraction and transportation related costs as well as higher maintenance costs. The effect of coal-to-gas switching has additionally been supported in Europe by relatively stable emission prices in the EU Emissions Trading System (EU-ETS), which has contributed further to unfavorable economics for coal-based power generation[7].

With assumptions on 2020 demands based on IMF GDP projections[8] and reduced yearly addition of low-carbon generation (Figure 1b), we estimate yearly CO_2 emissions from the power sector to be 6.8% [4.9-9.0%] lower than in 2019 (Fig. 1c). This is much higher than previously estimated by Le Quéré et al. (1.5% [0.3%-3.1%] power sector emission reduction in their scenario S3, see also Methods), and roughly in line with an updated version of their daily model that we calibrated to the observed emission reductions in Europe, India and the US until end of September (Supplementary Fig. S2), estimating yearly reductions of 7.5% [5.3-10.1%] for the power sector (see SI). The global reduction results from strong reductions of fossil generation in most countries, partly offset by increases in China (Extended Data Fig. 1). As a result, the share of China in global power system CO_2 emissions strongly increases in 2020, from 37 % in 2019 to 39%.

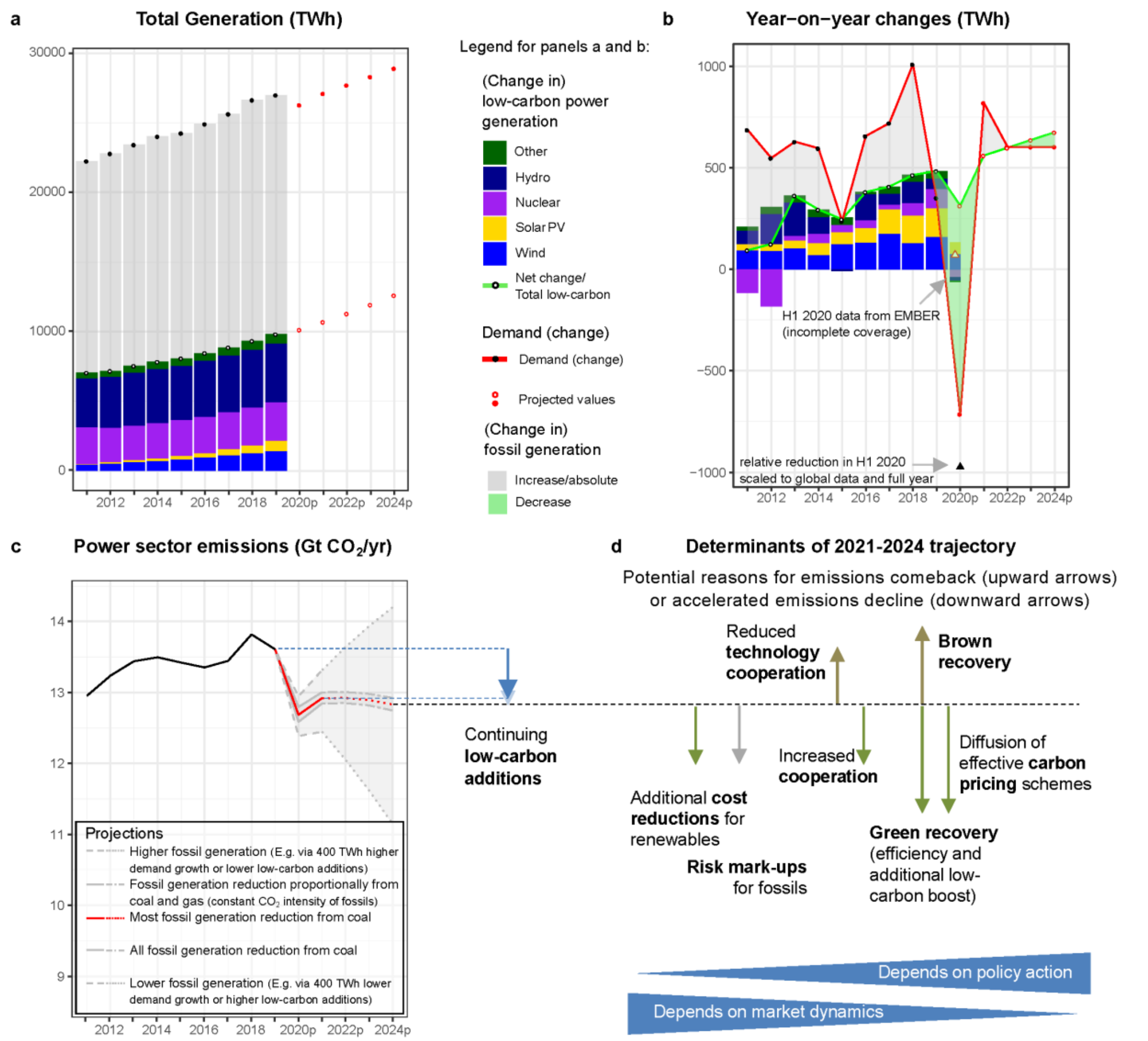

__Figure 1: Historical evolution of global power generation and CO_2 emissions, and projections until 2024.__ a) Absolute values for each year, with low-carbon technologies shown separately (colored bars) and aggregated (circles). b) Year-on-year changes of power generation by individual low-carbon technologies (colored bars), their total net change (white dots and green line), and total power generation as proxy for demand (black dots and red line). The shaded areas indicate increases of residual fossil generation (grey) and decreases (green). c) Power sector emissions from 2011-2019, and projections for 2020-2024 based on the power system evolution in panels a) and b) (please note that the y-axis scale does

not start at zero). d) Qualitative analysis of key factors determining the near-term evolution of global power sector CO_2 emissions. For details on data sources and projections, see Methods.

If the annual net addition of low-carbon generation (from wind, solar, nuclear, and hydro power generation) surpasses the increase in power demand, total fossil generation decrease. During most of the last decade, annual demand growth slightly surpassed additional generation of low-carbon power, except for 2015 and 2019 (see Fig. 1b). The central estimate of the latest World Economic Outlook by the IMF[8] projects 2021 GDP levels to be equal to the 2019 level, after a strong dip in 2020. Based on the strong coupling between economic growth and power demand (Supplementary Fig. S3), electricity demand is likely to remain at or below 2019 levels at least until the end of 2021. On the other hand, the build-up of low-carbon power capacity is expected to continue in the near and longer term future, with only a slight deceleration in 2020, mostly caused by reduction of nuclear generation in Europe[9]. This leads to continuing decrease of emissions intensity per kWh of power generation, with a steep drop in 2020 (Extended Data Fig. 3). To the extent that the growth in low-carbon power generation exceeds future demand increases, power supply emissions may have reached their all-time peak in 2018 (central estimate in Fig. 1c). Power sector emissions in 2021 will likely increase compared to 2020, but remain below 2019 values, given continuing additions of low-carbon generation (Fig. 1c, blue arrow).

If the rate of low-carbon additions increases through 2022 and beyond, and assuming that demand growth rates in 2022-2024 are back to average levels over past years (which are similar to near-term yearly increases expected by IEA[10]), a cross-over point would be reached. Passing this point would mean a structural transition from growing to decreasing fossil power generation. CO_2 emissions would thus decline from 2018 onwards based on underlying drivers, accelerated by the COVID-19 pandemic. If demand increases faster, or low-carbon growth slows considerably, fossil fuel generation and emissions could continue to increase through 2024, but would reach the 2018 peak level only with very high demand increases or very low additions of low-carbon generation.

Fig. 1c contrasts the central estimate, assuming the demand and low-carbon additions as in panels a and b, and assuming constant emission intensity of fossil power generation, with alternative projections. These vary the carbon intensity of fossil generation, and the overall amount of fossil generation (which given the merit order structure is determined by both absolute power demand and low-carbon generation). Emissions could revert back to levels of the 2018 peak by 2024 if demand increases are 400 TWh per year higher (or annual low carbon additions 400 TWh lower, or any combination leading to a 400 TWh/yr net difference for fossil generation), while very fast emissions decline is possible if demand increases are 400 TWh lower per year (or low carbon addition 400 TWh higher).

Various market factors affects the projections (Fig. 1d). A disruption in supply chains, reduced availability of capital investments and reduced international technology cooperation would hurt low carbon power addition and deployment of energy efficiency technologies, especially in emerging economies[11]. Existing plans to expand the fleet of coal-based power plants[12] face very immediate risks of resulting in stranded assets, both due to fast technological change and climate change considerations[13,14]. The current situation illustrates the weakening market position of coal-power generation- suffering simultaneously from reductions in power prices and from an unfavorable position on the merit order compared to low-carbon alternatives, resulting in strongly reduced market shares. This demonstration of low resilience of coal will make it more difficult for future projects to access financing, in turn increasing the attractiveness of low-carbon projects. Lastly, any delay of investment decisions for power generation expansion makes renewable energy projects more attractive, as costs of wind, solar, and storage[15] continue to decrease.

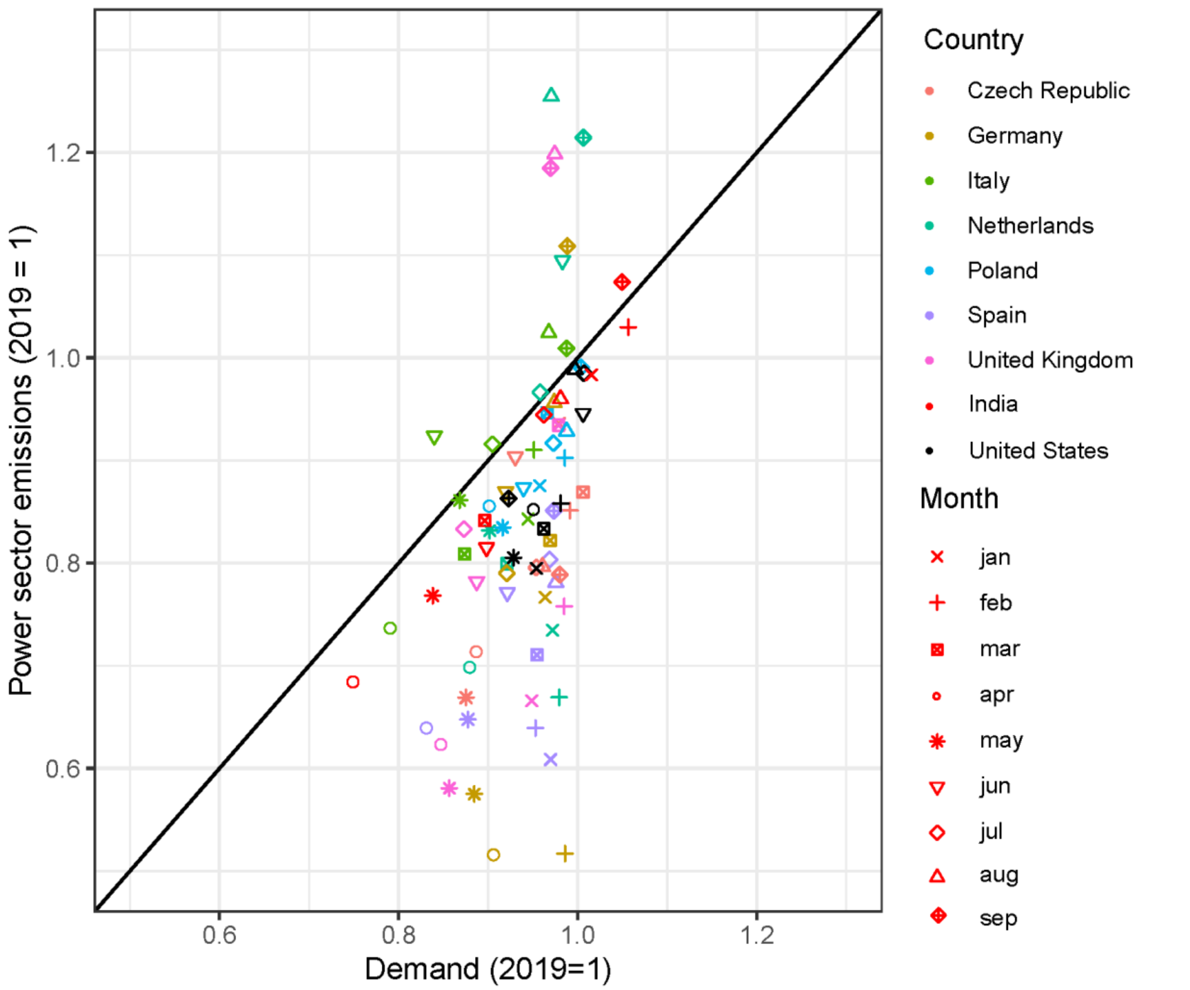

Figure 2: 2020 values of monthly power demand (x-axis) and emissions (y-axis), relative to 2019. *Emissions calculated from fossil generation data by fuel for European countries with highest power sector emissions from ENTSO-E. Indian data from carbontracker.in. US data from EIA, calculated from fossil generation data by fuel. February data is adjusted to account for the leap year 2020.*

It is clear that the post-crisis developments will be strongly impacted by near-term policy choices. There is a distinct risk that brown recovery packages will give support to construction of additional fossil-fueled power plants. These are, however, very risky investments, as the rate of utilization of coal power plants has been decreasing in nearly all markets over the past years and has plummeted amid the pandemic in 2020[9] (see above). Only with very strong rebound of demand, supported by indiscriminate support also for inefficient industries, will fossil generation be able to expand back to 2018 levels, but would be the first to lose market shares in repeated suppression of demand, both due to crises or increased efficiency.

Inversely, the current situation offers a unique opportunity for policy-makers to make the decreasing trend in power sector emissions irreversible, while total electricity generation continues to grow. The most effective means for accelerating the transformation of the power system is to strengthen carbon pricing around the world and eliminating subsidies for fossil fuels. The current situation of very low fossil fuel prices offers a good opportunity for these measures, especially if revenue recycling is used to support other societal goals[16]. Experience from the UK minimum price and recent auction price increases in the EU-ETS show that moderate carbon prices of around 20 \$/t CO_2 are already effective in reducing power sector emissions considerably[7,17]. An important characteristic of carbon pricing, making it indispensable in the medium-term, is that it counteracts the consumer price reductions of fossil fuels resulting from their reduced usage[18].

A complementary way to support power sector decarbonization can make use of the merit order mechanism described before. Supporting investments in low-carbon power generation, especially fast-growing granular power technologies like wind and solar[19], and increasing energy efficiency reduces the residual demand for fossil power generation. Both these measures have the additional benefits of high readiness, fast scalability, high employment intensities and local value added. Furthermore, policies supporting behavioral, social, and structural changes reduce energy demand for attaining service levels and thus reduce future electricity demand growth[20], resulting in decreased import bills for energy importers.

International cooperation is key to help fast growing economies outside the OECD to quickly scale-up these two options, thus also reaching peak emissions as soon as possible (Extended Data Fig. S1) and avoid additional carbon lock-in. Long-term investments funds (supported for example by the EU) could provide credit below the high market interest rates in developing countries, thereby reducing the high capital costs of low-carbon power generation technologies and investments in energy efficiency. These support schemes should incentivize developing countries to introduce carbon pricing schemes in order to avoid risky rebound effects at all scales, by which depressed world market prices of fossil fuels could lead to increased use of these fuels in unregulated regions[21] and sectors[22]. If designed properly, these schemes can enhance international cooperation significantly[23], and contribute to fostering sustainable development post COVID-19 globally.

The power sector has a crucial role for the decarbonization of the entire energy system, and has already been in the midst of a dynamic transformation process before COVID-19. The economic repercussions of the pandemic have led to a very pronounced reduction of fossil-fuel based power generation, illustrating the risks of stranded assets in coal power generation to financial actors. While the uncertainties on near-term projections are considerable, it is possible that power sector CO_2 emissions will not come back to their level of 2018[24]. Various policy instruments could be effective in supporting an accelerated emissions decline over the next few years.

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Methods

Historic data

The analysis builds upon yearly power generation data until 2019 from BP[6]. Power sector data from EMBER for the first half of 2020 for a subset of countries, roughly representing ¾ of global power generation is shown in Fig. 1b) for comparison[9]. Data on CO_2 emissions for 2011-2018 is from IEA[10], and 2019 data is deduced from the generation data in the BP dataset, assuming constant emission factors by fuel.

Projections based on yearly generation estimates

The projections of total demand (and total power generation) in 2020 and 2021 is based on GDP projections by IMF[8], assuming an elasticity of electricity demand to GDP of 0.6.
Demand projections for 2022-2024 assume the average value of 2011-2019 demand increases, resulting in a number comparable to yearly demand increases in the IEA's stated policies scenario[10].

The projections for increased generation from low-carbon technologies for 2020-2024 assume a continuation of the linear trend observed from 2017-2019, with a once-off 40% reduction in the year 2020 to account for the reduced output of nuclear power plants observed in the data for the first half of 2020, as well as interruptions in renewable installations in March and April.

For the projection of emissions in 2020-2024, we distinguish between uncertainty about volumes of fossil generation (being determined by growth of total demand and low-carbon generation), and uncertainty about composition and thus emission intensity of fossil generation (being a question of relative prices). The central three trajectories (red and inner grey lines) all are based on the central estimate on development of fossil generation as displayed in Figure 1, panels a and b. The higher grey line assumes the emissions intensity of fossil generation to stay constant at 2019 levels, as used in previous studies[25], while the lower grey line assumes all generation reductions to be taken up by coal generation, which seems to be more in line with data from the US, India and Europe (Extended Data Fig. 2). The central red line takes an intermediate assumption, namely that the emissions intensity of displaced fossil generation is the mean between the intensity of fossil generation and coal power generation. Additionally, a very high (and a very low) emission estimate result from assuming fossil generation to be higher (or lower) than in the central estimate, by 200/400/800/1200 and 1600 TWh in years 2020-2024 respectively. This reflects the uncertainties about growth of both demand and low-carbon generation, which is in the order of few hundreds of TWh each and increases over time. The very high estimate assumes constant emission intensity of fossil generation, while the very low one assumes all reductions to be from coal generation. Average emissions intensities of generation for both gas and coal are assumed to remain at 2019 levels, while in reality might continue to improve in 2020 over the next years, due to higher variable generation costs of older and less efficient plants.

Comparison with estimates from daily model based on confinement by Le Quéré et al.

The original model by Le Quéré assumed no emission reductions for the power sector for level 1 confinement in neither the low, medium or high specification. We have replicated a simpler version of their model (without disaggregation of China and the US) that – using their specification - is able to replicate the economy-wide yearly reductions mentioned in their paper, and used this to calculate the power sector emission reductions mentioned above in the main text (as the paper and SI of Le Quéré, while showing them in graphs, do not specify numbers on relative yearly reduction per sector). We then adjusted the specifications on sectoral reduction per confinement level (Tables S1,S2) to match the observed emission reductions in the power sectors of the EU, India and the US (Supplementary Figs. S1,S2), arriving at an update estimate broadly matching the alternative top-down methodology from Fig. 1.

Further details on the projections in Figure 1 and comparisons with different specifications of the daily model from Le Quéré et al. 2020 can be found in the Supplementary Information.

Corresponding author

Correspondance to Christoph Bertram (bertram@pik-potsdam.de)

Contributions

C.B. designed the study, with inputs by G.L., F.C., N.B. and F.U.. C.B. and A.M. performed the analysis and produced the figures. C.B. designed the figures and wrote the manuscript with inputs by all co-authors.

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Ethics declarations

Competing interests

The authors declare no competing interests.

Data availability

Power generation data for years up to 2019 is available at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/xlsx/energy-economics/statistical-review/bp-stats-review-2020-all-data.xlsx . Power generation data for the first half of 2020 is available at https://ember-climate.org/wp-content/uploads/2020/08/Ember-Global-Electricity-Review-2020-half-year-data.xlsx . Hourly generation data for the Europe, the US and India are available at https://transparency.entsoe.eu/, https://www.eia.gov/opendata/ and www.carbontracker.in . GDP projections for 2020 and 2021 are available at https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020 . Data on 2019 CO2 emissions and 2020 confinement indices are available at https://www.icos-cp.eu/gcp-covid19 .

Code availability

All code used for data analysis and creating the figures is available at https://github.com/christophbertram/covid-power-sector[26]

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