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COVID-19 pandemic and global carbon dioxide emissions: A first assessment

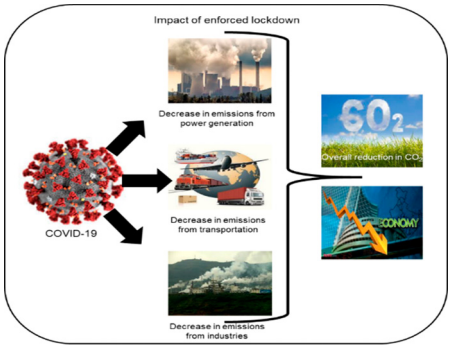
Vineet Singh Sikarwar [a,b,c], Annika Reichert [d], Michal Jeremias [a], Vasilije Manovic [e,*]

[a] Institute of Plasma Physics, Czech Academy of Sciences, Za Slovankou 1782/3, 182 00 Prague 8, Czech Republic
[b] Department of Power Engineering, University of Chemistry and Technology, Technická 5, 166 28 Prague 6, Czech Republic
[c] Department of Green Chemistry and Technology, Ghent University, 9000 Ghent, Belgium
[d] School of Environment, Tsinghua University, Beijing 100084, China
[e] Centre for Climate and Environmental Protection, Cranfield University, Bedford MK43 0AL, United Kingdom

HIGHLIGHTS

- COVID-19 enforced lockdown led to temporary reduction in anthropogenic CO_2 emission.
- Total CO_2 emission reduction of 1749Mt CO_2 (14% year-on-year decline) was estimated.
- Highest emissions reduction found to be caused by drop in surface and air traffic.
- Duration of lockdown and comparable measures directly affected GDP growth rates.
- Virtual infrastructure may serve as an opportunity for long-term decarbonization.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic carbon dioxide emissions are the main cause of global climate change. The COVID-19 pandemic has been one of the worst of its kind in the last century with regard to global deaths and, in the absence of any effective treatment, it led to governments worldwide mandating lock-down measures, as well as citizens voluntarily reducing non-essential trips and activities. In this study, the influence of decreased activity on CO_2 emissions and on the economy was assessed. The US, EU-28, China and India, representing almost 60% of anthropogenic carbon emissions, were considered as reference entities and the trends were extrapolated to estimate the global impact. This study aimed to deduce initial estimates of anthropogenic CO_2 emissions based on the available economic and industrial outputs and activity data, as they could not be directly measured. Sector-wise variations in emissions were modeled by assuming proportionality of the outputs/activities and the resulting emissions. A decline in road traffic was seen up to March 2020 and then a steady growth was observed, with the exception of China where road traffic started to recover by the end of January. The vast majority of passenger flights were grounded and, therefore, global air traffic plummeted by 43.7% from January to May 2020. A considerable drop in coal power production and the annual industrial growth rate was also observed. The overall economic decline led to a drop of 4.9% in annual global gross domestic product (GDP) for Q2 2020. The total global CO_2 emissions reduction for January through April 2020 compared to the year before was estimated to be 1749 Mt. CO_2 (14.3%) with a maximum contribution from the transportation sector (58.3% among total emissions by sector). Like other previous crises, if the economy rebounds as expected the reductions will be temporary. Long-term impacts can be minimized considering the business as well as lifestyle changes for travel, utilizing virtual structures created during this crisis, and switching to sustainable transportation.

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* Corresponding author.
E-mail addresses: sikarwar@ipp.cas.cz (V.S. Sikarwar), v.manovic@cranfield.ac.uk (V. Manovic).

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1. Introduction

The global climate has been experiencing an inevitable change due to the greenhouse gas emissions. Among the anthropogenically emitted greenhouse gases (namely CO_2, CH_4, N_2O, and F-gases), CO_2 has been the main contributor, accounting for almost three quarters of all GHG emissions in 2017 (Sikarwar et al., 2020; Climate Watch, n.d.). Due to their high significance, CO_2 emissions are often studied separately (see e.g. Global Carbon Project) (Global Carbon Project, n.d.), and will also be the focus of this investigation. A report by the Intergovernmental Panel on Climate Change (IPCC) emphatically states that GHGs produced by human activities are the direct cause of an increase in global temperature (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, n.d.). Finding solutions for the climate crisis is an emergency. In 2015, 196 countries unanimously agreed to limit the rise in global temperature by 2 °C (with an ambition to restrict it to 1.5 °C), under the Paris Agreement in the United Nations Framework Convention on Climate Change (COP 21) (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, n.d.; Sikarwar et al., 2021). It is worth noting that CO_2 emissions need to be reduced by 50 to 80% by 2050 to accomplish this objective (Sikarwar and Zhao, 2017). Purchasing goods locally, producing power from renewable energy resources, reducing high-carbon emission transport systems and investing in the green economy (Scarborough et al., 2014) are some of the measures suggested to mitigate rising CO_2 emissions (Barbalat, 2020; Sikarwar et al., 2017). Other short- to mid-term strategies to reduce anthropogenic CO_2 emissions can be the deployment of carbon capture and storage (CCS) technologies (Aminu et al., 2017; Boot-Handford et al., 2014).

The recent spread of coronavirus disease, termed COVID-19, has created huge difficulties around the world. The advent of COVID-19 was acknowledged in China in the last week of December 2019. The infection swiftly spread to Europe, South Korea, Japan, and the US among others from January 2020 to mid-February (Le Quéré et al., 2020). Finally, on March 11, 2020, the World Health Organisation (WHO) declared it a global pandemic (John Hopkins Corona Virus Resource Center, n.d.). In the absence of treatment for COVID-19, governments typically opted for a lockdown, initially to stop the spread, and later to slow down the community spread (Bashir et al., 2020). The lockdown measures included the isolation of infected persons, compulsory closure of offices and educational institutions, shutting down many industries, grounding most passenger flights, as well as enforced home confinement (Le Quéré et al., 2020).

These measures caused significant alterations in different sectors, mainly transportation, industrial, residential and public buildings, and power generation around the globe (Global Energy Review, n.d.). There was a marked change in energy demand, which in turn affected CO_2 emissions. Furthermore, COVID-19 affected/disrupted the global economy (Steffen et al., 2020). In April, the WTO forecasted that world trade would decline by 13 to 32% in 2020 (World Trade Organization, n.d.). China took a hit in its exports, which dropped by 17% in the first two months of 2020. More than 26 million people lost their jobs in the US and in other countries in March and April (Global Energy Review, n.d.). Stock markets were extremely volatile as the governments around the globe struggled to tackle the slowdown of the economy (Sarkis et al., 2020).

Major crises, whether pandemics, wars, famines or financial collapses, typically cause temporary drops in primary energy demand that are followed by a rebound toward previous levels once those crises are over (Global Energy Review, n.d.). The impact of lockdown measures and voluntary confinement can offer a first real life quantification of the potential extent that extreme measures could provide with respect to CO_2 emissions based on the current energy mix. This can provide a quantification of the effectiveness of climate measures within the parameters of our current energy mix (mostly involving cultural changes such as home-based work and decreased consumption). Considering vaccines are just being rolled out and their effectiveness in preventing transmission being unclear as of yet, it is, unlike many other crises, very difficult to predict this crisis's length and depth (John Hopkins Corona Virus Resource Center, n.d.). Moreover, the pathway to recovery is ambiguous and so is the impact on CO_2 emissions.

In this study, the alterations in global anthropogenic CO_2 emissions as a result of changes in air traffic, road transport, industry and power generation due to enforced lockdown around the globe are explored. Globally, over 60% of electricity is derived from fossil fuels (coal, gas, and oil). Among those, coal makes up more than half (57%) of global GHG emissions for the electric energy sector and will hence be used as a representative proxy for fossil electricity production in this study (https://ourworldindata.org/grapher/share-elec-by-source, n.d.). Other greenhouse gases, such as CH_4, which are largely attributed to agriculture and fugitive emissions, were excluded from this investigation. In addition, the impact of lockdown on the global economy was considered. The length and depth of this crisis is unclear. Therefore, tracking CO_2 emissions during such enforced changes can help in deciding actions to avoid a surge in CO_2 emissions thereafter.

Le Quéré et al. (2020) have published a thorough study which estimates effect of different lockdown measures during the pandemic on CO_2 emissions. This paper provides an expansion of available data, using different data sources where possible in order to provide additional insight and to compare the findings. This way, the considerable change in CO_2 emissions in the course of the pandemic is confirmed. Furthermore, the data is also put into an economical context.

2. Methodology

The change in CO_2 emissions was assessed in three sectors, namely transportation, power generation and industry. These three sectors were chosen as they are responsible for the major fraction of total anthropogenic CO_2 emissions worldwide. Industry emissions, as given by International Energy Agency (IEA) exclude indirect emissions from power generation, but refer to the large portion of CO_2 emissions produced, e.g., in the manufacturing sector due to chemical reactions and heat generation by fossil fuel combustion (International Energy Agency, n.d.-a). Data sets were prepared using the United States (US), China, India and the European Union (EU-28) as reference entities, which were compared to global data. These four entities represent around 66% of the global GDP and are responsible for more than 50% of total global CO_2 emissions (International Energy Agency, n.d.-a; Trading Economics, n.d.). It is assumed that the alterations in air traffic, surface traffic, industrial growth rate and coal power generation appropriately reflect the resulting change in total CO_2 emissions throughout the pandemic. This analysis assesses emissions changes in all relevant major sectors. Based thereon, the pandemic's or, more precisely, the resulting lockdown measures' influence is investigated.

Since anthropogenic CO_2 emissions cannot be directly measured, this article aims to infer preliminary estimations based on available industrial output and activity data. Sector-wise changes in emissions for transportation, industry, and power production were modeled by assuming proportionality of changes in output/activity (a) (given in %) to the resulting emissions. Hence, the change in emissions $\Delta CO_2(s)$ (Mt CO_2) for each sector (s) was calculated as shown in Eq. (1):

$$\Delta CO_2(s) = CO_2(s) \times \Delta a(s) \quad (1)$$

In Eq. (1), $CO_2(s)$ (Mt CO_2) represents the 2019 CO_2 emissions for the same month or time frame. Values for CO_2 emissions by sector were taken from IEA data (International Energy Agency, n.d.-a) and were only available for 2017. Under the assumption that the relative contributions of the sectors remain constant, values per sector for 2019 were derived from the available total emissions value estimated by Global Carbon Project (2019). Since the time frame investigated in

this study was January–April 2020, yearly values were divided by 3 (also see supplementary material).

In order to attain an estimation for total emissions reduction for all sectors until April 2020, estimate values by Le Quéré et al. (2020) for residential and public buildings were used and merged to the newly defined sector "others". The contribution of each sector to the total reduction of emissions was then deduced from the values calculated for January through April of 2020.

Surface and air transport were considered while excluding water transport due to unavailability of quantitative data. Shipping makes up approximately 10% of anthropogenic CO_2 emissions in the transport sector (International Energy Agency, n.d.-b). In order to make an estimation on total emissions changes, it was assumed that water transport was affected in a similar way to land and air, since a disruption in shipping due to production stops and lockdown measures took place (LockTon International, n.d.). International Civil Aviation Organization (ICAO) and Euro Control datasets were used for air traffic to compute the alterations from January 2020 to May 2020 relative to the first week of January 2020 (Eurocontrol, n.d.; International Civil Aviation Organization, n.d.; OAG, n.d.). Global change in surface traffic is based on Apple Mobility data (https://www.apple.com/covid19/mobility, n.d.). These provide the number of routing requests originally compared to the baseline day of 13 January 2020 (set as 100). In order to account for weekly and monthly volatility, data were adjusted to the new baseline average values Jan 13 – March 7 and converted to percent change values. Apple Mobility data was not available for China. Instead, Tomtom congestion data was used (Statista, n.d.). Power generation from coal power plants was considered as an approximation for electricity generation from fossil fuels. The reduction in coal power generation from January to April 2020 was compared to the same period in 2019 where the data were taken from CarbonBrief, National Bureau of Statistics and the International Energy Agency (IEA) (Global Energy Review, n.d.; https://www.carbonbrief.org/analysis-indias-co2-emissions-fall-for-first-time-in-four-decades-amid-coronavirus, n.d.-a; National Bureau of Statistics of China, n.d.-a). Year-on-year growth rates of Total Value Added of industrial enterprises (monthly data) were used as a proxy for change in industrial activity. The total index, largely including manufacturing, mining, and utilities, were used, representing total industrial output (Trading Economics, n.d.; National Bureau of Statistics of China, n.d.-a; https://www.federalreserve.gov/releases/g17/, n.d.). Annual GDP growth (Q1 2020 compared to Q1 2019 and Q2 2020 compared to Q2 2019) was taken from Trading Economics (National Bureau of Statistics of China, n.d.-a; https://www.federalreserve.gov/releases/g17/, n.d.; https://tradingeconomics.com/india/industrial-production, n.d.; Eurostat, n.d.; National Bureau of Statistics of China, n.d.-b; Statista, n.d.). Values and sources used can also be found in the supplementary material.

3. Results and discussion

In this section, the results for each considered sector (transportation, power, and industry) are presented and discussed.

3.1. Transportation sector

The impact of the spread of COVID-19 and subsequent lockdown measures around the world was evaluated from January 2020 to May 2020 as compared to the first week of January 2020. The data set of flight departures from the US, China, EU-28 and India was compared for a period of 154 days. In general, declining trends were observed for all entities with a sharp fall in the month of March for all countries except China as shown in Fig. 1.

This can be attributed to the initiation of lockdown measures in March in those countries. However, a steep drop in China was experienced before the other countries in the month of February as the lockdown began earlier (on 23 January 2020) (International Civil Aviation Organization, n.d.; OAG, n.d.). A slight rise of 4.3% was noted for China in the second and third weeks of January because of the annual Spring Festival. Later, in the beginning of February, March, April and May, air traffic in China reflected a drop by 57.9%, 83.2%, 91.9% and 86.4%, respectively. The extreme drop can be traced back to the lockdown, which caused a large majority of passenger flights to be grounded. Europe was the second continent to experience hit by COVID-19, with France, Germany and Italy reporting the most infected cases (Eurocontrol, n.d.). A drop in air traffic in EU-28 began with 0.5% in January, jumping to 32.8% in mid-March due to the global lockdown, and further plummeting to 88.1% in April and 86.3% in May. The number of infections grew slowly in India and, therefore, the negative change in air traffic began in mid-March (43.4%) (International Civil Aviation Organization, n.d.). Globally, air traffic declined by 8.6% in mid-February to 92.6% in May. An average global negative change of 43.7% was noticed for a period of 154 days from January to May 2020. This reduction in global air traffic has a noticeable influence on CO_2 emissions as discussed in Section 3.2.

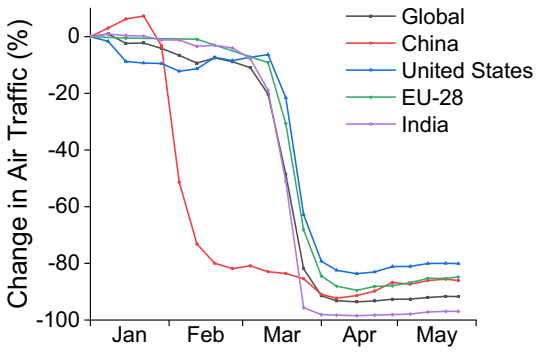

Fig. 1. Change in air traffic from January 2020 to May 2020 relative to first week of January 2020, based on ICAO (International Civil Aviation Organization, n.d.) and Eurocontrol (Eurocontrol, n.d.) data.

The beginning and the extent of spread of COVID-19 varied from country to country. Consequently, the degree and the time of enforced confinement through various lockdown measures were initiated at different times and to different degrees around the world, which can clearly be seen from the alterations in surface traffic (Fig. 2). China was the epicenter of COVID-19 and, therefore, a sharp reduction of 87.3% in surface traffic was seen by mid-January 2020. Later, measures to control the spread were imposed, which was reflected in fairly steady traffic in February. A steep rise from mid-February (−78.4%) to −34.3% to the third week of March followed by a zig-zag rise by the end of April can be explained by partial resumption of work and ease of internal lockdown measures, while maintaining stringent international air traffic lockdown measures (Trading Economics, n.d.; National Bureau of Statistics of China, n.d.-c). Thus, traffic within cities rose back to close-to-normal values (TOMTOM, n.d.). However, such trend was not noted in India and the EU, where the infection arrived later and thus, control measures were delayed. The surface traffic showed a drop in India and EU from mid-February. A fall of 87.3% was experienced by India in mid-March whereas EU suffered 64.4% decrease in road activity during the same time. Slight increases to 82.8% and 48.4% below pre-COVID 19, respectively (or by 4.5% and 16%, respectively) were noticed in India and EU by the end of April, as the lockdown measures were eased. The impact of the epidemic on road traffic in the US became clear by the end of February (https://www.apple.com/covid19/mobility, n.d.). Surface traffic dropped by −57.6% in mid-March as compared to the baseline value and then gradually rose to −37.2% by the end of April. The US suffered the lowest drop, reflecting less stringent confinement measures. Global road traffic began to fall in mid-February until the third week of March (−68.1%) at which point the curve changed direction and started rising again. The global average change was found to be −25.2% for a period of 109 days (13 January – 30 April).

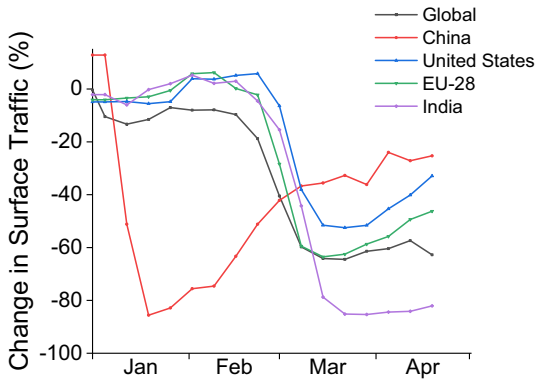

Fig. 2. Change in surface traffic from January 2020 to May 2020 relative to first week of January 2020, based on Apple Mobility data (https://www.apple.com/covid19/mobility, n.d.).

3.1.1. Coal power generation

It seems reasonable to assume that the temporary partial industry shut-down caused by the global pandemic had a marked impact on coal power generation as depicted in Fig. 3. China, which is the largest consumer of coal in the world, experienced a reduction of about 9% in the first four months of 2020 compared to 2019 (National Bureau of Statistics of China, n.d.-a). This was on account of lower demand in the electricity sector, especially due to shuttered industries. It is worth noting that China only saw a considerable plunge in January and February, resuming regular coal power production relatively quickly (within the months of March and April) and consequently, a smaller drop in coal power generation compared to India, the US and EU was observed in the first four months in 2020. The maximum drop in electricity demand was seen in regions where the service industry forms a major fraction of the economy and where stringent lockdown measures were adopted (Global Energy Review, n.d.). The service industries such as hospitality, tourism, offices, education, etc., were completely shut down, which in turn decreased the electricity demand and thus, directly affected coal power generation. EU, which is largely dependent on the service industry, saw a decline of 20%. Interestingly, the US experienced a fall of about 30% in the first four months of 2020, even though other sectors, such as transport, were not as heavily affected as for instance the EU due to less stringent or consistent lockdown measures. This considerable drop may be attributed to the already growing use and abundance of gas and renewables. While in the EU, coal only accounts for 12–13%, with renewables being the major electricity source (42%), coal still made up almost 20% of the US electricity mix (Global Energy Review, n.d.). However, there has already been a downward trend in coal use (with gas and renewables on the rise) in the US before the pandemic and lockdown. This effect was then amplified by the lockdown, coal power being more cost-intensive to produce (S P Global, n.d.). After a very strict lockdown in India, which included mandatory home confinement and shutting down industrial enterprises, a drop of 10% in coal power generation was experienced (https://www.carbonbrief.org/analysis-indias-co2-emissions-fall-for-first-time-in-four-decades-amid-coronavirus, n.d.-a). Overall, the world observed a drop of 10% in the first quarter of 2020 (International Energy Agency, n.d.-a).

3.1.2. Industry

Industrial enterprises were deeply influenced during the COVID-19 crisis as can be deduced from Fig. 4. The US, EU and India experienced a decline in industrial growth rate from February 2020. However, China showed an opposite trend with positive growth rate since February (National Bureau of Statistics of China, n.d.-b). The US started with −0.8% in January 2020 which rose to 0% and then started dropping from February to April (−15%) as a consequence of dissemination of coronavirus infections throughout the country (https://www.federalreserve.gov/releases/g17/, n.d.). A similar trend was observed for the EU, which started with a slightly negative growth rate (−1.7%) in January and February and then dropped to −19.7% in April (Eurostat, n.d.). On the other hand, India maintained positive growth rates in January (2.1%) and February (4.6%) (https://tradingeconomics.com/india/industrial-production, n.d.). Beginning in March, rates plummeted along with the implementation of lockdown measures to as low as −30% by April. Hence, this drop may be ascribed to the shutdown of industries. In addition, the demand was reduced and labor availability was shaken due to the lockdown conditions. Interestingly, in the epicenter of COVID-19, China, a seemingly less severe drop in industrial activity (growth rate of −13.5%) was observed in January and February. This may be partly attributed to the only available values being averaged over the first two months of the year, flattening the maximum drop (National Bureau of Statistics of China, n.d.-b). Earlier lockdown and a comparatively swift recovery (within 2 months) are shown by an upward trend in the Chinese industrial sector starting in March (−1.1%) and recovering to a positive growth rate by April (3.9%). The world witnessed a drop to −8.5% in April from −5.5% in January 2020 (Trading Economics, n.d.). The closure of industrial enterprises worldwide had a significant impact on global CO_2 emissions, which is discussed in the following section.

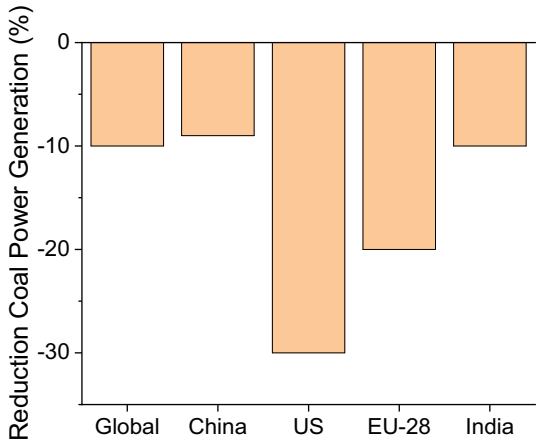

Fig. 3. Reduction in coal power generation from January to April 2020 relative to January to April 2019. Data based on IEA (International Energy Agency, n.d.-a) and CarbonBrief (https://www.carbonbrief.org/analysis-indias-co2-emissions-fall-for-first-time-in-four-decades-amid-coronavirus, n.d.-a).

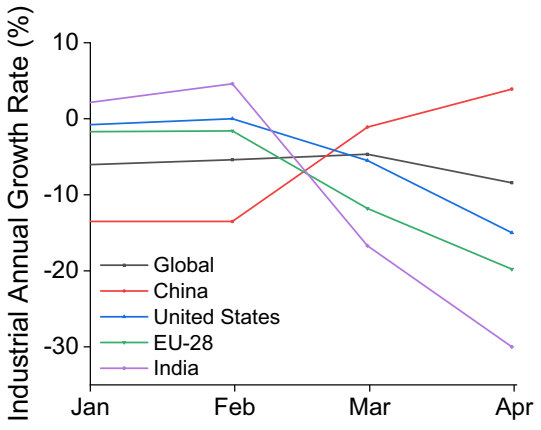

Fig. 4. Industrial annual growth rate from January to April 2020 relative to January to April 2019 (Trading Economics, n.d.; National Bureau of Statistics of China, n.d.-a; https://www.federalreserve.gov/releases/g17/, n.d.; https://tradingeconomics.com/india/industrial-production, n.d.; Eurostat, n.d.).

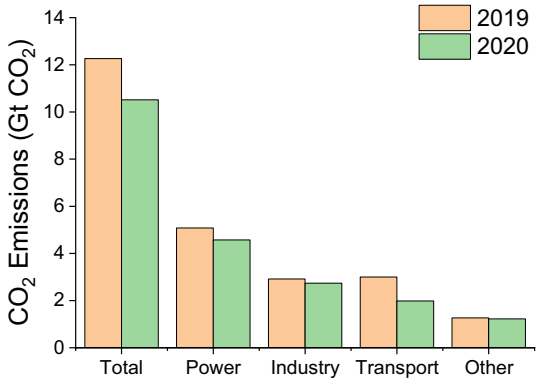

Fig. 5. Sector-wise absolute CO_2 emissions globally from January to April 2020 with respect to January to April 2019.

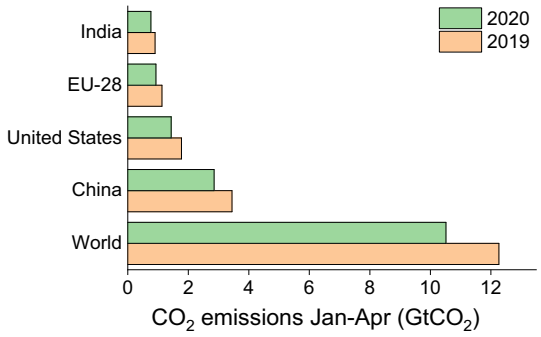

Fig. 7. Country-wise CO_2 emissions from January to April 2020 relative to January to April 2019.

3.2. Carbon dioxide emissions

Figs. 5 and 6 display that the maximum reduction in CO_2 emissions (1020 Mt. CO_2) was contributed by the transportation sector compared to the other sectors. As the confinement was enforced, many passenger flights were grounded and people were instructed or even mandated to stay at home, depending on domestic countermeasures. Consequently, a considerable reduction in emissions (~58% of total reduction by sector for Jan – Apr 2020) can be inferred in this sector (International Energy Agency, n.d.-a). Carbon dioxide emissions from coal power generation experienced a decrease by 508 Mt. CO_2 from January 2020 to April 2020 compared to the same time frame in 2019. As discussed in the previous sections, lower electricity demand led to this 10% decrease in coal power generation, accounting for 29% of the total emissions reduction. In addition, industrial enterprises were either shut down or reduced production. This caused a CO_2 reduction of 179 Mt. CO_2 from industry, which contributes 10% of the total emissions reduction. Overall, a total reduction of 1749 Mt. CO_2 or 14.3% was calculated, which can be traced mainly to the COVID-19-induced lockdown from January to April 2020. The value for global emissions reduction was extrapolated from the four largest emitters (making up almost 60% of all CO_2 emissions worldwide), assuming that comparable measures were taken in all CO_2 emitting countries. Hence, a slight overestimation is possible. Since almost all significant CO_2 emissions contributors (90–95%) (https://ourworldindata.org/co2-emissions, n.d.), were economically able to implement lockdown measures, the aforementioned extrapolation imparts a realistic model. However, a scenario assuming that 10% of CO_2 emitters did not or not effectively enforce lockdown measures was also examined. This would result in a total reduction of 1575 Mt. CO_2 or 12.8%.

The four entities, namely the US, EU-28, India and China, evaluated in this study, account for more than 50% of global CO_2 emissions. China, on the top of the list of CO_2-emitting countries, showed the highest absolute emissions reduction (589 Mt. CO_2) in the first four months of 2020 compared to the same period in 2019, as reflected in Fig. 7. It was the epicenter of the COVID-19 pandemic with a huge manufacturing base, and thus suffered the most among all nations evaluated in this study. The emissions dropped from 1775 Mt. CO_2 to 1433 Mt. CO_2 in the US whereas they fell from 1129 Mt. CO_2 to 930 Mt. CO_2 in the EU (International Energy Agency, n.d.-a; US Energy Information Administration, n.d.). A reduction of 138 Mt. CO_2 was experienced by India (https://www.carbonbrief.org/analysis-indias-co2-emissions-fall-for-first-time-in-four-decades-amid-coronavirus, n.d.-b).

The world saw a significant upheaval in the environment (air and surface traffic, power generation and industrial growth) and economy due to voluntary as well as mandated measures in the face of COVID-19. Passenger flights were grounded and consequently, the world has seen a considerable drop in air traffic with an average reduction of 43.7% as shown in Fig. 1. On the other hand, surface traffic started dropping from February (third week) and reached −63.2% by the end of April with an average reduction of 25.2%. This has caused CO_2 emissions from the sector to drop by −5.5% in February as depicted in Fig. 8. Apart from air and surface traffic, industrial growth took a hit as year-on-year growth rate reached −8.5% in April. This may have resulted from interrupted supply chains coupled with reduced purchasing power and unavailability of sufficient labor. Moreover, reduced electricity demand led to a decrease in global coal power generation, which fell by 10% relative to the same period in 2019, causing CO_2 emissions to plummet by 16.8% in March and 29.7% in April with regard to the same months in 2019. This drop in CO_2 emissions is significant, but had an adverse impact on the economy as discussed in the next section.

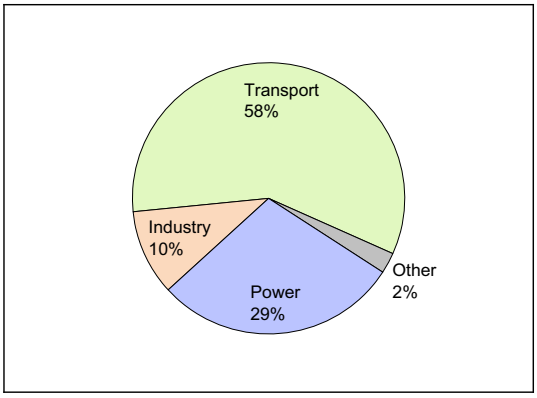

Fig. 6. Sector-wise contribution to reduction in CO_2 emissions.

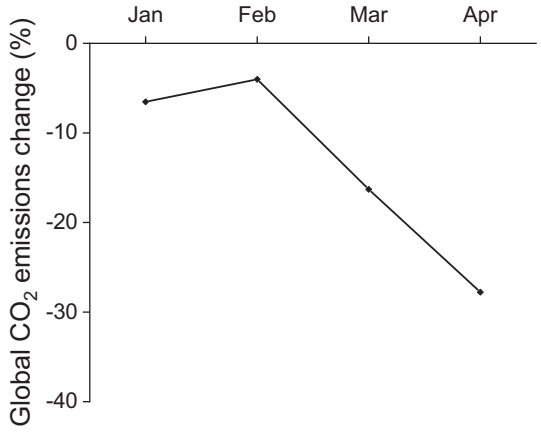

Fig. 8. Global change in CO_2 emissions for Q1 2020 relative to Q1 2019.

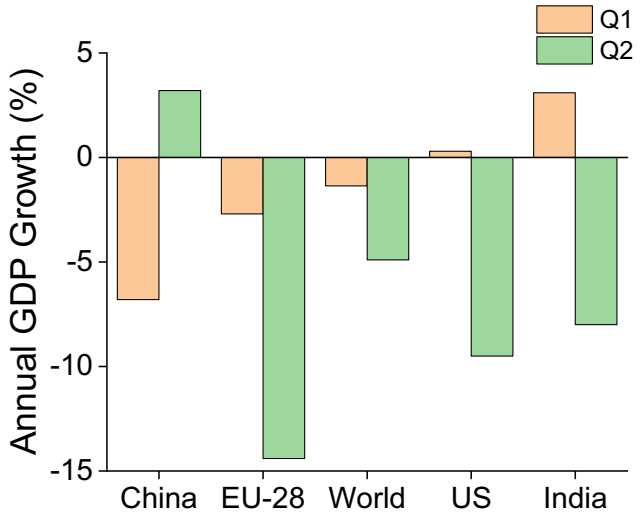

Fig. 9. Annual GDP growth rate for Q1 and Q2 2020 with respect to 2019.

4. Economy

COVID-19 induced a supply-demand shock throughout the planet. Supply-side shock was created by deliberate lockdowns, thus shutting down malls, restaurants, etc. At the same time, demand-side shock was brought about by industries being (partly) shut down, leading to lower availability of disposable income (Hepburn et al., 2020). The unemployment rate rose throughout the world with the US unemployment at 26 million since the inception of lockdown measures (Newyork Times, n.d.). The annual GDP growth in the US for Q1 and Q2 in 2020 with respect to Q1 2019 was found to be 0.3% and − 9.5% respectively, as reflected in Fig. 9 (US Department of Commerce, n.d.; https://tradingeconomics.com/united-states/gdp-growth, n.d.; Federal Reserve Bank of St. Louis, n.d.). EU-28 suffered a decline of 2.7% in Q1 and a drop of 14.4% in Q2 in 2020. China witnessed a drop of 6.8% in Q1 while a rise of 3.7% in Q2 2020 w.r.t. 2019 (Trading Economics, n.d.; National Bureau of Statistics of China, n.d.-c). China, which strongly depends on its manufacturing industry, did not have enough demand from the US and EU, thus generating a huge macroeconomic challenge (National Bureau of Statistics of China, n.d.-c; https://tradingeconomics.com/china/gdp-growth, n.d.). Indian annual GDP growth for Q1 2020 was 3.1% whereas Q2 2020 was around −8% with respect to 2019 (https://tradingeconomics.com/india/gdp-growth, n.d.). Due to lockdown measures implemented to varying degrees globally, the world suffered a drop of 1.3% and 4.9% respectively in Q1 and Q2 in 2020. The duration of lockdowns and comparable measures directly influenced the GDP growth rates.

5. Conclusions and perspectives

In this work, the impact of enforced lockdowns in January 2020 through April 2020 during the COVID-19 pandemic on CO_2 emissions and on the economy was assessed. The US, EU-28, China and India were considered as reference entities and the trends were used to deduce the global influence. A drop in surface traffic was seen until March 2020 and then a steady rise was observed, with the exception of China, where surface traffic already began rising by the end of January. This was due to the early lockdown and consequently, an early recovery period. The vast majority of passenger flights were grounded and, therefore, the world witnessed a decline of 43.7% in air traffic from January to May 2020. A significant drop of 10% was noticed for global coal power generation, with the US being the most impacted nation with a 30% drop in the first four months of 2020. All nations were found to have a negative industrial annual growth rate with a global drop of 8.5% to April 2020. China was the first country affected by the pandemic. It was also the first to start recovery on account of Chinese government's legitimately adopted approach with pervasive and compulsory contact tracking, coercive insulation of "close contacts", rigorous border closures, etc. Its growth rate started rising after February and culminated in a 3.9% increase by the end of April. It thereby offsets the global values to some extent by its early activity drop and following rise. The overall economic collapse led to a drop of 0.9% and 4.9% in annual global GDP growth for Q1 and Q2 2020, compared to Q1 and Q2 2019 respectively. The total global CO_2 reduction in January – April 2020 compared to 2019 was estimated as more than 1749 Mt. CO_2 (14.3% drop) with a maximum contribution from the transportation sector (58%), followed by coal power generation (29%) and industry (10%).

Therefore, transportation was assessed as the key source of more than half the reduction in emissions during the pandemic. This strongly indicates that the alteration of standard working patterns and the reduction of commuting to work, increased work from home and online meetings or site visits can have a tangible effect on GHG emissions. Due to their substantial cost-efficiency, these newly created or expanded virtual platforms have great potential to be maintained after ease of lock-down and travel bans. Also, lifestyle changes for travel such as walking and cycling would not only fulfill the requirement of social distancing but would also contribute to emissions reductions.

As evidenced from previous crises, emissions will most probably rebound once the economic rebuilding takes its pace. As the changes in environment (e.g., reduced carbon emissions) are caused by enforced lockdowns and not due to fundamental alterations in economic, energy or transport systems, they are temporary in nature. However, some inspiration from this unfortunate period can be taken. Profound and sustained decreases in emissions are needed to achieve the target set in the Paris Agreement by the IPCC. The COVID-19 pandemic can serve as an opportunity to rebuild the economy based on green and low-carbon approaches.

The trajectory of reconstructing the economy should be thoughtful with more focus on renewables to achieve greater energy security. Governments around the world should not overreact and avoid short-cuts to grow the economy quickly. They should utilize this opportunity to devise pathways for an environmentally-friendly and sustainable transition to the green economy. More importantly, the new policies should be framed in a manner to endure any future crisis.

CRediT authorship contribution statement

Vineet Singh Sikarwar: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization. **Annika Reichert:** Conceptualization, Methodology, Investigation, Writing – original draft, Visualization. **Michal Jeremias:** Conceptualization, Validation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Vasilije Manovic:** Conceptualization, Writing – review & editing, Supervision.

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. Supplementary data

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Sikarwar, Vineet Singh; Reichert, Annika; Jeremias, Michal; Manovic, Vasilije

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