Mousazadeh, M, Paital, B, Naghdali, Z, Mortezania, Z, Hashemi, M, Karamati Niaragh, E, Aghababaei, M, Ghorbankhani, M, Lichtfouse, E, Sillanpää, M, Hashim, KS and Emamjomeh, MM

Positive environmental effects of the coronavirus 2020 episode: a review

Positive environmental effects of the coronavirus 2020 episode: a review

Milad Mousazadeh[1,2†,] Biswaranjan Paital[3†,] Zohreh Naghdali[1,2], Zohreh Mortezania[4], Marjan Hashemi[5], Elnaz Karamati Niaragh[6], Mohammad Aghababaei[7], Melika Ghorbankhani[8], Eric Lichtfouse[9], Mika Sillanpää[10,11,12,13], Khalid S. Hashim[14], Mohammad Mahdi Emamjomeh[15]*

[1]Student research committee, Qazvin University of Medical Sciences, Qazvin, Iran.
[2]Department of Environmental Health Engineering, School of Health, Qazvin University of Medical Sciences, Qazvin, Iran.
[3]Redox Regulation Laboratory, Odisha University of Agriculture and Technology, College of Basic Science and Humanities, Bhubaneswar-751003, Odisha, India.
[4]Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[5]Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[6]Civil and Environmental Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Hafez Ave., Tehran, 15875-4413, Iran.
[7]Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99163, USA.
[8]MSc in Occupational Safety, Health & Wellbeing at Cardiff Metropolitan University.
[9]Aix-Marseille Univ, CNRS, IRD, INRAE, Coll France, CEREGE, 13100 Aix-en-Provence, France.
[10]Institute of Research and Development, Duy Tan University, Da Nang 550000, Vietnam.
[11]Faculty of Environment and Chemical Engineering, Duy Tan University, Da Nang 550000, Vietnam.
[12]School of Civil Engineering and Surveying, Faculty of Health, Engineering and Sciences, University of Southern Queensland, West Street, Toowoomba, 4350 QLD, Australia.
[13]Department of Chemical Engineering, School of Mining, Metallurgy and Chemical Engineering, University of Johannesburg, P. O. Box 17011, Doornfontein 2028, South Africa.
[14]Department of Civil Engineering, Liverpool John Moores University, Liverpool, UK.
[15]Social Determinants of Health Research Center, Research Institute for Prevention of Non-Communicable Diseases, Qazvin University of Medical Sciences, Qazvin, Iran.

*Corresponding author: m_emamjomeh@yahoo.com

† Co-first author, Milad Mousazadeh and Biswaranjan Paital contributed equally to this work.

Acknowledgments

The support of the Research Vice-Chancellor of Qazvin University of Medical Sciences (IR.QUMS.REC.1399.128) is wholeheartedly appreciated.

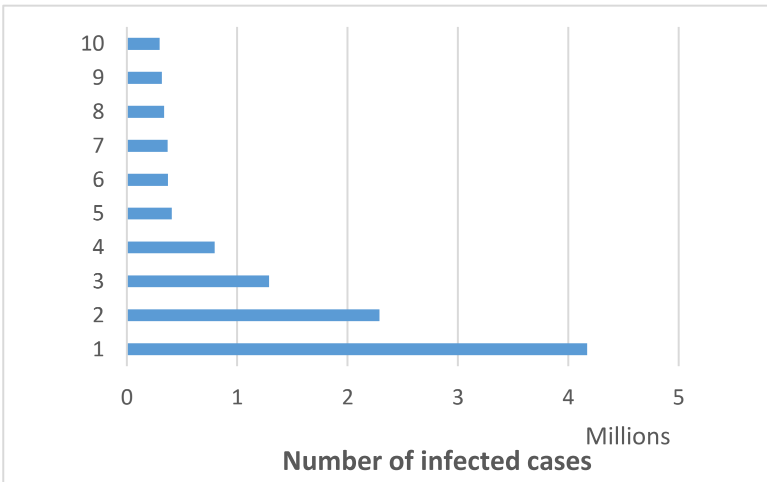
Abstract

The outbreak of COVID-19 has made a global catastrophic situation that caused 1,039,406 deaths out of 35,347,404 infections, and it also caused significant socio-economic losses (poverty would increase from 17.1% to 25.9%). Twelve-month R rolling data (as of 6th October 2020) indicates that although its the spreading rate of COVID-19 is very high, the death rate is still fewer less than 2.94%. However, the lockdown induced numerous positive impacts on the environment, and the energy consumption, which is the research topic of the current study. The outcomes of this study indicated that the lockdown has decreased the electricity demand by 30% in Italy, India, Germany, and the USA, and by. 12 to 20% in France, Germany, Spain, India, and the UK. Additionally, it was found that the expenditure of the fuel supply has been decreased by 4% in 2020 as compared to the previous years (2012 to 2019). More particularly, the global demand for coal fuel has been reduced by 8% in March and April 2020 as compared to the same time in 2019. In terms of harmful emissions, the results of this study indicated that the lockdowns reduced the emissions of nitrous oxides by 20-30% in China, Italy, France, Spain, and by 77.3% in São Paulo, Brazil. Similarly, the particulate matter level has been reduced by 5-15% (in Western Europe) to 200 % in New Delhi, India, which in turn has enhanced the air quality in a never-seen manner in the recent times. In some places, such as New York, USA, CO_2 emission was also reduced by 5-10%. The water quality, in several polluted areas, has also been remarkably enhanced, for example, the dissolved oxygen content in the Ganga River, India has increased by about 80%. Traffic congestion has also been reduced worldwide, and in some areas, it has been reduced by 50%, such as New York and Los Angeles, USA. In summary, the outcomes of this study indicated that although the COVID-19 pandemic damaged the decreased the global by 13 to 32%, it positively influenced all other sectors, which must be considered as the spotlight for the permanent revival of the global ecosystem.

Keyword: COVID-19 benefits; environmental regeneration; renewable energy, air pollution, surface water, traffic congestion

1. Introduction

A novel respiratory infection caused by a virus belonging to the coronavirus family was identified in Wuhan city, China, in late December 2019. The corresponding disease became known as the coronavirus disease or COVID-19 (CDC, 2020; Muhammad, Long, & Salman, 2020; WHO, 2020b). The viral infection has then rapidly spread across the globe, and was declared as a public health emergency of international concern by the world health organization on January 30, 2020 (Chakraborty & Maity, 2020; WHO, 2020c). COVID-19 has generated unprecedented impacts in 216 countries. As of July 24, 2020, rolling data indicate that 15,666,840 people have been infected by the disease, from which 636,789 have died and 9,554,890 recovered (Figure 1, Paital, 2020; Worldometers, 2020).



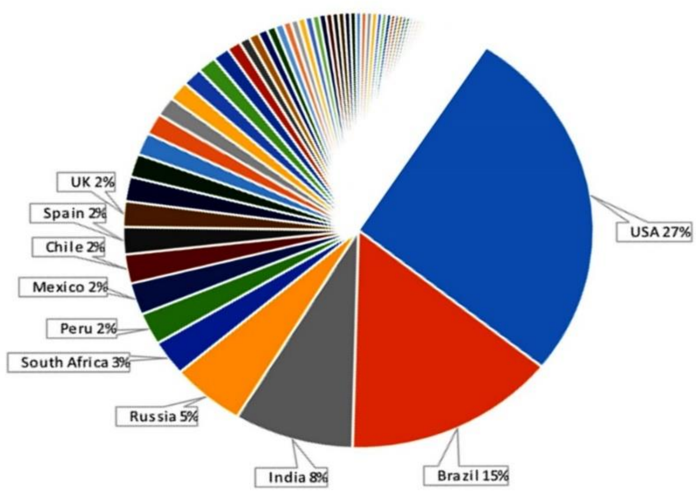


Figure 1. Total number of COVID-19 cases in the major affected countries as of 24 July 2020. The report shows total infected cases for 10 hardest-hit countries worldwide including 4,170,131 (27%) cases in the USA, 2,289,951 (15%) cases in Brazil, 1,290,284 (8%) cases in India, 800,849 (5%) cases in Russia, 408,052 (3%) cases in South Africa, 371,096 (2%) cases in Peru, 370,712 (2%) cases in Mexico, 338,759 (2%) cases in Chile, 317,246 (2%) cases in Spain, and 297,146 (2%) cases in UK. (Worldometers, 2020).

Major international and domestic flights have been cancelled, transport systems including railway services, bus, truck and vehicle transport have been suspended, except goods trains and emergency vehicles. Educational, commercial, sports and spiritual institutions were closed, social gatherings were restricted, and citizens were advised to stay at home. Power plants, manufacturing and industrial facilities halted production, except those related to essential services (Chakraborty & Maity, 2020; Paital, 2020; Saadat, Rawtani, & Hussain, 2020; Zambrano-Monserrate, Ruano, & Sanchez-Alcalde, 2020). These containment measures induced a sharp drop in social, industrial, and economic activities. Nonetheless, lockdown also induced a strong reduction of air pollution due to the massive decrease in the combustion of fossil fuels and, more generally, energy consumption (Zambrano-Monserrate et al., 2020). For instance, decreases in emissions of greenhouse gases such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon dioxide (CO_2) were observed, and CO_2 emissions fell by 18% during February and March 2020 in China (Paital, 2020; Q. Wang & Su, 2020; Zambrano-Monserrate et al., 2020).

Public mobility diminished by up to 90% as a result of lockdown policies, including traffic restrictions and people staying at home. For instance, passenger vehicle traffic in the USA reduced by 40%. With less human activity, noise levels dropped in many cities around the world (Muhammad et al., 2020; Paital, 2020; Zambrano-Monserrate et al., 2020). Social distancing policies have kept people from resorts and beaches around the world while industrial shutdown has paused effluent discharge into water bodies. Such events resulted in water quality improvement due to less pollution observed in different countries such as Mexico, Spain and Ecuador. For example, Venice's canals and the Yamuna river in Delhi, India, is now significantly clearer compared to the past (Paital, Das, & Parida, 2020; Saadat et al., 2020). However, the above positive effects of the COVID-19 pandemic should not be seen as long-term ways to control the environmental pollution because this pandemic will over within a relatively short period of time, and global social and economic activities will return to their normal level. Thus, these short-term positive impacts of COVID-19 should be utilized to develop effective future policies to protect the environment (Allegrante, Auld, & Natarajan, 2020; Chang, Strong, Pakpour, Griffiths, & Lin, 2020; Espejo, Celis, Chiang, & Bahamonde, 2020; Ferguson et al., 2020; Raoofi et al., 2020). These policies must take into account the potential impacts of the massive re-opening of industries after the COVID-19 pandemic to cover the loss during lockdowns, which could result in a rapid increase in environmental pollution.

Otherwise, the world has to wait for another pandemic to minimize environmental pollution. In this context, this study has carefully analyzed the published scientific literature along with the authentic news sources, such as Science magazine, Reuters, BBC News, Times, Hindustan India, India Today, WHO to set a hypothesis, which utilizes the lessons of the lockdowns, to ensure the never-ending environmental regeneration. The studied countries, in this study, were selected according to the level of the lockdowns.

2. Energy

A substantial decline in energy was observed in countries that followed complete or partial lockdown (Figure 2, 3). Specifically, this was caused by total lockdown in India, the USA, China and Italy, where all industries were closed during the first and second phases of lockdown (Cohen, 2020; IEA, 2020). For example, electricity consumption declined to almost 30% in Italy after 40 days of lockdown. Similarly, electricity consumption declined by 15% in France, 12% in Germany, 15% in Spain, 20% in India, and 16% in the UK. Overall, electricity demand during COVID-19 was at least 10% lower in comparison to pre-COVID19 times. The consumption of both fossil fuel and electrical energy has been dramatically reduced in the industry, public offices, educational sectors, and private organizations (Table 1). It was observed that the global expenditure in energy consumption in the above and other sectors did not vary whereas; it was about 5% low in the year 2019. Overall, a reduction of about 30% of energy was observed in 2020 compared to previous years.

Energy reduction is explained by lockdowns (Figure 3). Whereas 5-50% higher energy consumption has been observed in hospitals from 216 affected nations from mid-March 2020 to mid-April 2020, energy consumption has decreased in other sectors. Indeed, a reduction of about 25% on the average in weekly energy consumption has been noticed in 30 fully locked down nations up to mid-April 2020. This energy reduction was nearly 18% in partially locked down countries (Sarkar, 2020; SEI, 2020). In the same vein, global energy expenses decreased by 40% compared to previous years (Table 1). This indicates a stringent reduction in energy consumption was caused. For example, in India where lockdown was implemented quite stringently, peak power demand dropped to 134.89 gigawatts in 2020 as compared to 168.62 gigawatts in 2019, registering a drop of 20 %. Electric energy demand was reduced by 30% nationwide in COVID-19 induced lockdown time as compared to the pre-COVID-19 time (Sarkar, 2020).

A similar trend was also observed for coal consumption. The global demand for coal reduced at least by 8% in March and April 2020 lockdown periods compared to the same time period in 2019. China, a country responsible for 6% of global fossil fuel emissions, experienced a drastic reduction in coal consumption in the first quarter of 2020, of 36% compared to 2019 (Ghosh, 2020; Q. Wang & Su, 2020). In absolute amounts, this translates into a reduction from 80K to 40K tons of burned coal (Paital, 2020; Paital et al., 2020). Similarly, global oil consumption was reduced by 5% in the first quarter during the lockdown, in Europe, North America, and allied countries. Global gas consumption also declined by 2% during the same period (Sarkar, 2020; SEI, 2020).

Under such a global crisis against COVID-19, uses of renewable energy sources have given much emphasis, as household electricity consumption would be elevated at lockdown timings. The use of renewable energy sources over conventional energy resources is another positive effect observed during the COVID-19 period (Hosseini, 2020). Large scale use of solar panels and windmills at household even at industrial sectors are suggested (Destouni & Frank, 2010; Ergun, Owusu, & Rivas, 2019; Li, Chiu, & Lin, 2019) Such steps at

COVID-19 period would lead to establishing a foundation leading to a cleaner as well as a sustainable new epoch in the energy sector.

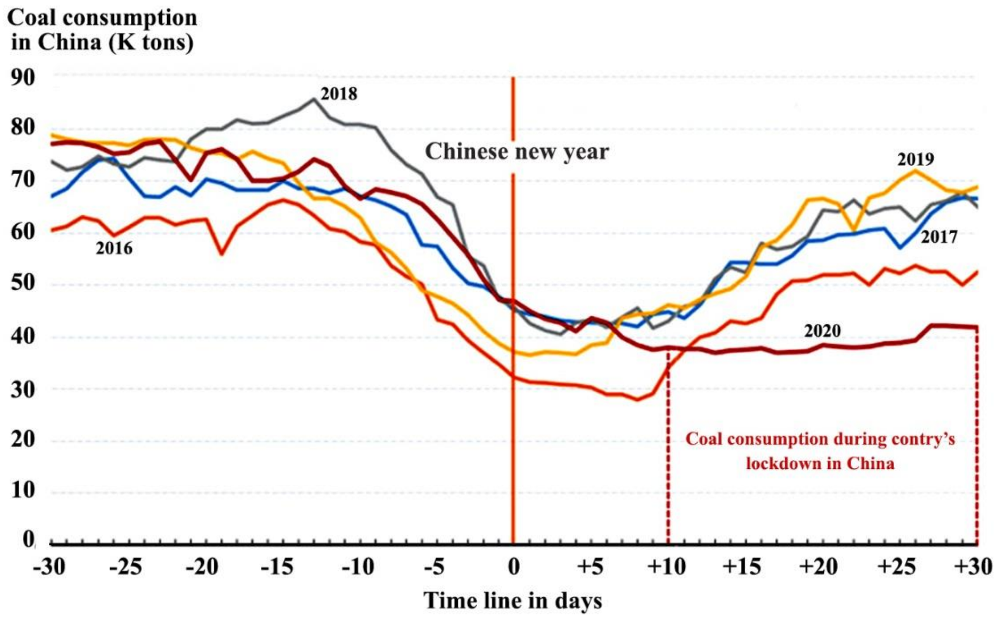


Figure 2. Use of coal fuel in China in 2016-2020. The consumption drop for all years during the Chinese new year is explained by holidays with industrial shutdowns. In 2020 coal consumption is drastically reduced to 40 K tons during the lockdown, 10-30 days after the new year, versus about 80 K tons before the COVID episode. (Ghosh, 2020).

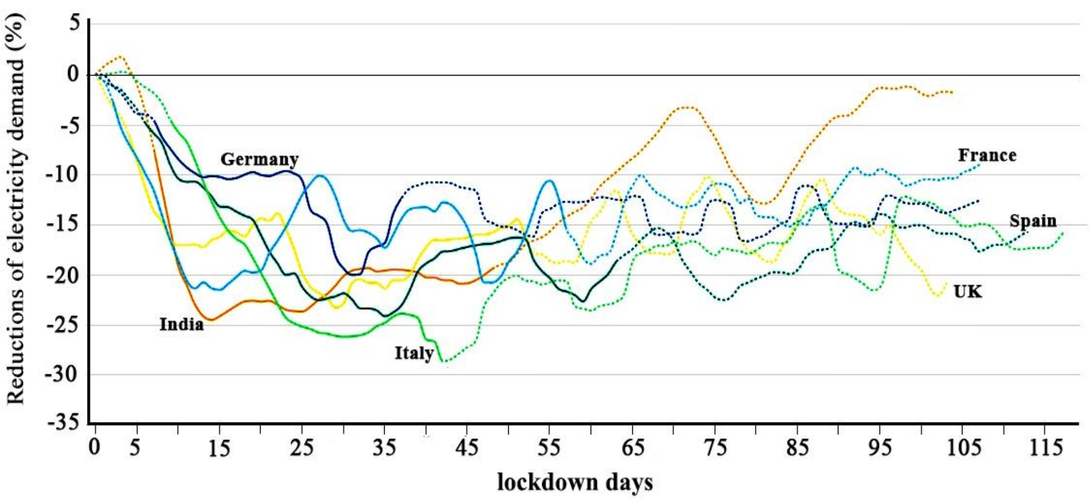


Figure 3. The decline in electricity during COVID-19 lockdown. Dotted lines show partial lockdown, solid lines display full lockdown. Up to 30% reduction in electricity consumption is observed in Italy after 40 days of lockdown. About 15, 12, 15, 20, and 16% reduction in electricity consumption are observed in France, Germany, Spain, India and the UK, respectively. The transition from full to partial lockdown induced a rise, but the electricity consumption still remained 10% lower than that of pre-COVID times. Modified after IEA (2020).

Table 1. Global energy investment from 2017 to 2020. A sharp decrease is observed in 2020 during the COVID episode. Expenditures are approximate, data in 2019 USD billions. Modified after IEA (2020).

Year	**Expenditure in fuel supply (USD billions)**	**Power Sector**	**Energy end-use and efficiency**
2017	850	782	280
2018	854	769	281
2019	854	757	280
2020	595	678	247

It can be seen that the global expenditure on energy consumption remained almost the same in the years 2017, 2018 and 2019. However, expenditure decreased slightly from 2017 to 2020 for power sectors and energy end end-users, this drastically reduced to almost 30% in the year 2020 because of COVID-19 induced lockdowns (IEA, 2020).

3. Air pollution quality

Air pollutants such as NO_2, SO_2, O_3, CO and particulate matter (PM) pose serious health risks. The WHO estimates that 7 million people die from air pollution each year, more than half these deaths being due to ambient in air pollution (WHO, 2020a). Long-standing exposure to fine PM with a diameter lower than 2.5 μm, and O_3, is estimated to cause around 8.8 million deaths every year (Lelieveld et al., 2020). Exposure to NO_2 alone results in 4 million new pediatric asthma cases annually (Achakulwisut, Brauer, Hystad, & Anenberg, 2019).

A major and immediate positive effect of COVID-19 lockdown has been the substantial reduction of air pollution worldwide, notably in major industrialized countries (Table 2). The closure of factories and transportation networks, the largest emitter of greenhouse gases in the United States resulted in a 5-10% decrease of air pollutants, including CO_2 (Chelsea Harvey, 2020; McGrath, 2020). China's heavy industrial zones also showed a 40% reduction in NO_2 concentrations after the lockdown in Wuhan (Q. Wang & Su, 2020).

Table 2. The decline of major air pollutants in early 2020 compared to 2019, and main causes. For instance, Wuhan city, the primary epicenters of the outbreak, has reduced NO_2 by about 40%. Similarly, observations in the USA and India showed a 30-50% reduction.

Country	**Major pollutants reduction**		**Major causes**	**References**
27 countries	NO_2	13-44%	Closure of factories, transportation networks, and companies	(Venter, Aunan, Chowdhury, & Lelieveld, 2020)
	O_3	2-20%		
	$PM_{2.5}$	10-28%		
New York (USA)	CO_2	5-10%	Closure of factories, transportation networks, and companies	(McGrath, 2020)
China, Italy, France, and Spain	NO_2	20-30%	Closure of factories, transportation networks, and companies	(Leung, 2020)
USA	NO_2	30%		
India	NO_2	40-50%		
Delhi (India)	$PM_{2.5}$	200%	Restricted travel including flights, rail, intercity bus services and industrial activity stopped	(Kotnala, Mandal, Sharma, & Kotnala, 2020)
	PM_{10}			
Western Europe	NO_2	30-50%	-	(Menut et al., 2020)
	PM	5-15%		
São Paulo (Brazil)	CO	64.8%	Closure of shopping malls, restaurants, fitness centers, schools, universities, and public transportation restrictions	(Nakada & Urban, 2020)
	NO	77.3%		
	NO_2	54.3%		
Barcelona, Madrid (Spain)	NO_2	50%	Decreases in vehicular mobility and the volume of other relevant activities such as port and airport operations	(Baldasano, 2020)
		62%		
Rio de Janeiro (Brazil)	CO	30.3–48.5%	Vehicle circulation restrictions, suspension of classes, and many other activities	(Dantas et al., 2019; Siciliano, Dantas, da Silva, & Arbilla, 2020)
	NO_2	16.8–53.8%		
	NO_x	24.4- 46.1%		
Wuhan (China)	$PM_{2.5}$	25%	-	(Leung, 2020)
	NO_2	40%	Use of diesel vehicles stopped	

Estimations from the ESA's Sentinel-5P satellite confirm that during late January and early February 2020, levels of NO_2, a well-known pollutant emitted by road transportation, over big cities and industrial zones in many Asian and European countries, were reduced by as much as 40% in comparison with the similar periods in 2019 (Monks, 2020). Bauwens et al. (Bauwens et al., 2020) evaluated the effect of the coronavirus outbreak on changes in NO_2 level over the major epicenters in China, South Korea, Italy, Spain, France, Germany, Iran and the United States by satellite measurements of air quality. They found that emissions declined in all countries by 20-40%. Nonetheless, in Iran, one of the earliest and hardest-hit countries, there was no observed drop in NO_2 emissions. This is thought to be due to the fact that there were no complete lockdowns until the end of March, during the Iranian New Year holidays, and, before that, stay-at-home orders were largely ignored.

With worldwide financial action slowing down as a result of the coronavirus episode, it is not surprising that emissions related to energy and Transport would be diminished (McGrath, 2020). Satellite image data of more than 10,000 air quality measurement stations in 27 countries; indicate a reduction of ground-level NO_2 by 29 % with a 95% confidence interval. Similarly, concentrations of ground-level O_3 were reduced by 11%. Moreover, the $PM_{2.5}$ value decreased by 9% during the initial 14 days of lockdowns (Venter et al., 2020). NASA and ESA data showed that the amount of particles and NO_2 had dropped significantly over China. For instance, $PM_{2.5}$ levels fell by 25%, and NO_2, created primarily by diesel vehicles, dropped by 40% in Wuhan (Leung, 2020). NO_2 levels in China, USA, Europe, and India before and during lockdown are shown in figures 4-6. Accordingly, NO_2 emissions declined by 20-30% in China, Italy, France, and Spain, by 30% in the USA, and by 40-50% in India during lockdown periods.

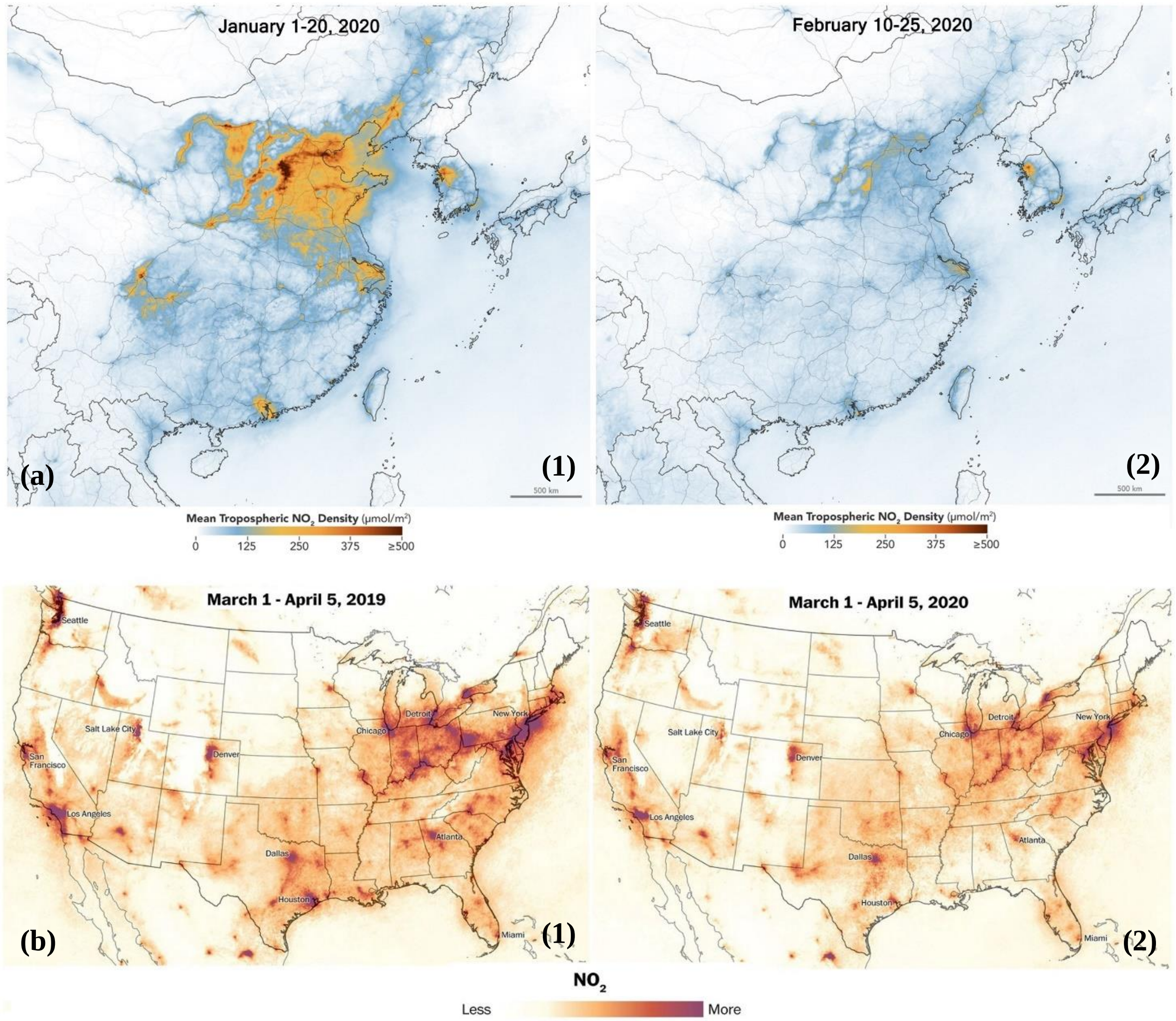


Figure 4. Nitrogen dioxide levels in China, before and during lockdown; and in the USA, in 2019 and 2020. In China, NO_2 declined initially reduction near Wuhan and then rapidly over the whole country. Credit: (NASA, 2020b).

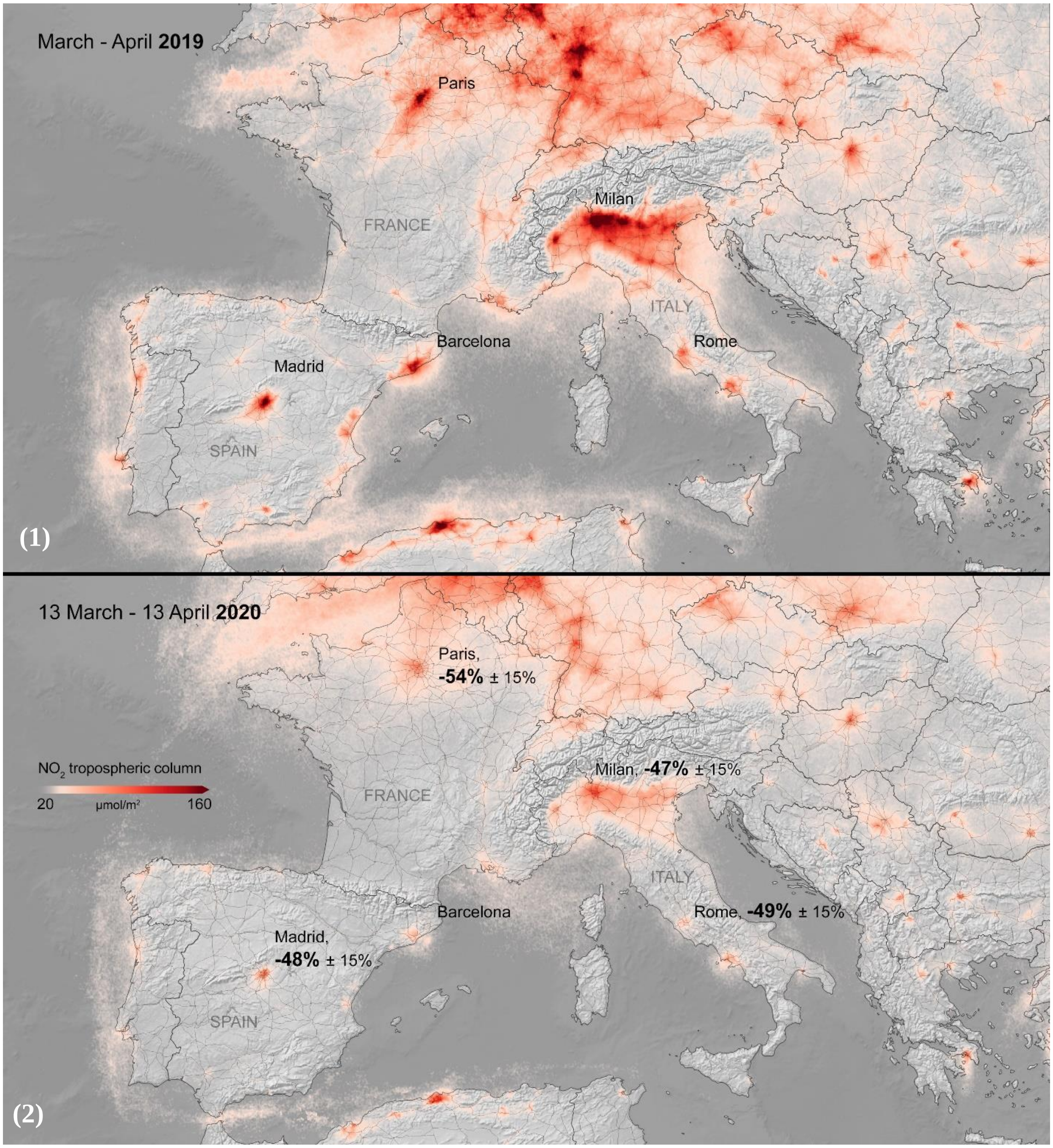


Figure 5. Nitrogen dioxide levels in European countries before and during the lockdown. The mean nitrogen dioxide content in Madrid, Milan and Rome decreased by about 45%, and by 54% in Paris, compared to 2019. From Copernicus Sentinel data 2019-2020 processed by KNMI/ESA (ESA, 2020a).

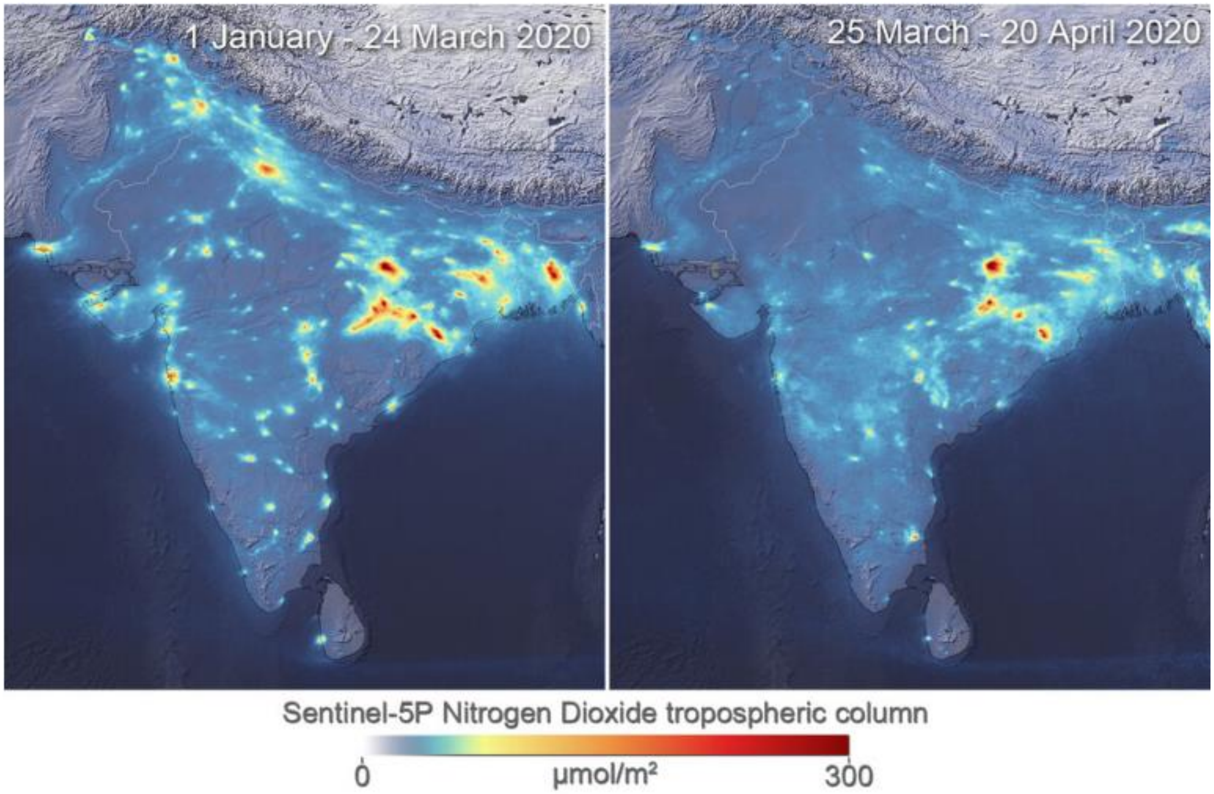


Figure 6. Nitrogen dioxide levels before and during the lockdown in India in 2020. NO_2 mean levels decreased by about 40-50% from the January 1-March 24 periods to the March 25-April 20 period. Noteworthy, high NO_2 concentrations coincide with the location of power plants. They were modified from Copernicus Sentinel data (2019-20), processed by ESA, CC BY-SA 3.0 IGO (ESA, 2020c).

Evidence suggests that the COVID-19 outbreak has resulted in global environmental changes which can be attributed to the complete or partial lockdown of cities worldwide (Chakraborty & Maity, 2020). For instance, Le Quéré et al. (Le Quéré et al., 2020) analyzed global CO_2 emissions from 69 countries, 50 US states, and 30 Chinese provinces, including 85% of the world's population and 97% of global CO_2 emissions, compared to time pre-COVID-19. In early April 2020, compared to the same period in 2019, they found that daily global CO_2 emissions decreased by 17% on the average (Figure 7). Some countries showed a decrease up to 26%. The study also predicted that if lockdown restrictions would continue, an annual global emissions decline of up to 7% could be achieved. In other words, lockdown was efficient to offset global warming.

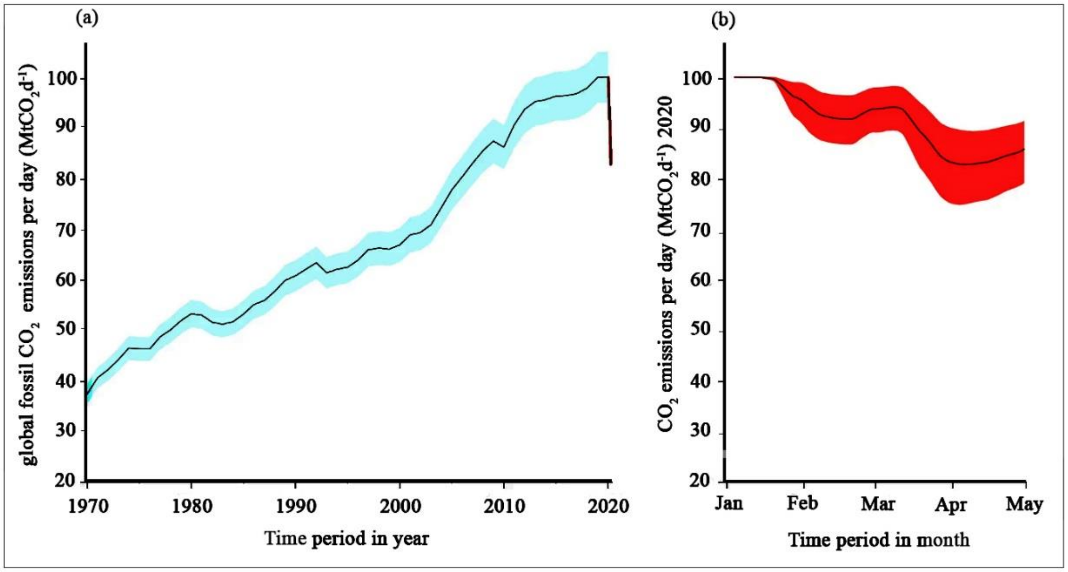


Figure 7. Fossil fuel CO_2 emissions ($MtCO_2$ d^{-1}) for the 1970-2019 timeline compared to during the COVID-19 confinement period (2020). Blue shading showing annual CO_2 emissions from 1970 to 2019 (a). CO_2 emissions have been nearly upward trend every year, with about 100 $MtCO_2$ d^{-1} being released in late 2019. Conversely, since early 2020, red shading shows a significant decrease in carbon emissions during confinement (b). On April 7, 2020, the influence of the confinement on daily global CO_2 emissions was around -17 $MtCO_2$ d^{-1} (-17%) in contrast to the average level of emissions in 2019. Also, during January-April 2020, CO_2 emissions fell by 1.048$MtCO_2$ d^{-1} (8.6%) compared to 2019 levels. Modified after Le Quéré et al. (2020).

A recent study of the impact of COVID-19 lockdown measures revealed amplified average daily ozone concentrations at various urban stations (Sicard et al., 2020). There were ozone increases of 24% in Nice, 14% in Rome, 27% in Turin, 2.4% in Valencia and 36% in Wuhan compared to the same period in 2017-2019. This increase in O_3 concentration is mainly due to the decrease in NOx because at ground-level ozone is created by reactions between NOx and volatile organic compounds (VOC). A study also found that O_3 production during lockdown was higher at the weekends (Sicard et al., 2020). Similar increases of O_3 concentrations were also observed: 20% in Sao Paulo (Nakada & Urban, 2020), 50% in Barcelona (Tobías et al., 2020), 11% in London (Authority, 2020), 17% in 22 Indian cities (Sharma, Zhang, Gao, Zhang, & Kota, 2020), 116% in Wuhan (Lian et al., 2020), 43% in Beijing-Tianjin-Hebei region (Le et al., 2020) and 15% in Almaty (Kerimray et al., 2020). Overall, most air pollutants declined strongly during the COVID episode, with the exception of ozone, which increased notably. As a consequence, and contrary to the common belief, these findings show that decreasing air pollution and offsetting global warming is feasible in a short time period. This of course, has caused negative consequences for the economy, but findings are inspiring to find solutions for a more sustainable society.

To date, although little data is available, emerging evidence suggests that there may be a positive association between prolonged exposure to air pollution and the death of COVID-19. There is previous evidence from previous coronaviruses (e.g. SARS-CoV-1) that people exposed to polluted air were at higher risk of death. Accordingly, the researchers found that people in areas with more air pollution were twice as likely to be infected as people in areas with less pollution (Cui et al., 2003). In the case of the SARS-CoV-2 virus pandemic, few studies have been investigated on the association between clean air and the reduction in death rates due to COVID-19. Wu et al. (Wu, Nethery, Sabath, Braun, & Dominici, 2020) found that an increase of $\mu g/m^3$ in long-term exposure to $PM_{2.5}$ was associated with an 8% increase in the risk of COVID-19 mortality. As of March 19, 2020, Ogen et al. (Ogen, 2020) observed that 4,443 deaths of COVID-19 occurred in 66 regions of France, Germany, Italy, and Spain. Analyzing NO_2 concentration data from the Sentinel-5 Precursor space-borne satellite, they reported that 83% of these deaths occurred in areas with the highest NO_2 concentration and only 1.5% in areas with the lowest NO_2 concentration.

Research shows that prolonged exposure to air pollution causes chronic inflammation and an increased risk of chronic respiratory disease, both of which are associated with an increased risk of death in COVID-19. Evidence in northern Italy proves this point (Conticini, Frediani, & Caro, 2020). Cocker et al. (Coker et al., 2020) also showed that an increase in a unit concentration of $PM_{2.5}$ was associated with a 9% increase in COVID-19 mortality. Liang et al. (Liang et al., 2020) also found in an extensive study in the US states that urban air pollution may increase the COVID-19 mortality rates. With the increase of the per interquartile range (4.6 ppb) in NO_2, COVID-19 case rate and death rate increased by 11.3% and 16.2%, respectively. There was also a 15% increase in COVID-19 mortality for the increase in the per inter-quartile range in $PM_{2.5}$ (2.6 ug/m^3). In another study in Ghana, there was no link between home air pollution and acute lower respiratory tract infections caused by the COVID-19 (Carrión et al., 2019).

Although it is not yet certain that interventions to improve air quality will reduce the severity of COVID-19 disease, it cannot be ignored. Therefore, we should do our best to improve air quality because it will have the least significant impact on reducing the basic demand for health services during the COVID outbreak. Information, in general, is limited and robust research is needed on changing the level of air pollution and the potential link to COVID-19, which could improve public health policy in this regard.

4. Surface water quality and wastewater surveillance

The COVID-19 pandemic has had beneficiary consequences on surface water quality in some regions as lockdown has improved the water quality of some rivers, canals and seas (Table 3). One of the positive impacts of COVID-19 (Fig. 8) according to satellite images, is that Venice's canals became clearer after one month of lockdown (ESA, 2020b). Niroumand-Jadidi et al. (Niroumand-Jadidi, Bovolo, Bruzzone, & Gege, 2020) reported an almost 50% reduction of total suspended matter (TSM) after lockdown using shallow-water inversion via Planet Scope imagery. Before the COVID-19 periods, the concentration of TSM was 3 g/m^3 on average; however, it was reduced to 1.4 g/m^3 during COVID-19 lockdown. Because of a reduction in boat traffic, sediments have settled, resulting in a reduction in turbidity. Banning tourists during lockdown has also reduced other water pollutants released by them. This clearer water has enabled other creatures such as fish, dolphins and swans to come back to these canals and waterways. Beaches, including Acapulco (Mexico), Barcelona (Spain), and Salinas (Ecuador) have had crystal clear waters since the reduction of tourists (Zambrano-Monserrate et al., 2020).

Figure 8. Venice lagoons and waterways quality (top) in 2019 and (bottom) after a month pandemic lockdown in 2020. Due to lockdown in Venice, Italy's canals, on March 2020, boats traffic (e.g. water buses) dramatically decreased, which prevents reaching the sediments to the top of the water's surface, making the canal's water look cleaner. As the top image shows, captured 13 April 2020, the traffic appears almost empty in the Grand Canal compared to the same time last year. Credit: Copernicus Sentinel data (2019-20)/ESA, CC BY-SA 3.0 IGO (ESA, 2020b).

Table 3. Surface water quality enhancements around the world during the lockdown. Water resources (e.g. beach and lake) in different countries, including, Ecuador, India, Italy, Mexico, Peru, and Spain; and major causes (e.g. tourist reduction and less human activities) of these improvements are listed separately. Based on on-site observation and remote sensing analysis, the water in the canals looks clearer due to the limited movement of boats, fewer tourists, etc. as the spread of the coronavirus and stay at home orders.

Country	Water resources	Major reasons for pollution reduction	References
Ecuador	Salinas Beach	Tourist reduction	(Zambrano-Monserrate et al., 2020)
India	Vembanad Lake	Tourism reduction, Reduction of industrial effluents	(Yunus, Masago, & Hijioka, 2020)
	River Cauvery	Tourist reduction, Less human activity	(DeccanHerald, 2020)
	Ganga River	Reduction of industrial effluents, Reduction of water lifting by industries, Tourist reduction	(Singhal & Matto, 2020)
	Yamuna River	Reduction of industrial effluents, Reduction of water lifting by industries	(Paital et al., 2020)
Italy	Venice's Canals	Boat traffic reduction, Tourist reduction	(Zambrano-Monserrate et al., 2020)
Mexico	Acapulco Beach	Tourist reduction	(Zambrano-Monserrate et al., 2020)
Peru	Rimac River	Reduction of dumping garbage, construction materials or waste from businesses and industrial sectors	(Newsweek, 2020)
Spain	Barcelona Beach	Tourist reduction	(Zambrano-Monserrate et al., 2020)

The other advantage of nationwide lockdown is the improvement of the water quality in some Indian rivers, which are normally exposed to polluted industrial and human effluents (Lokhandwala & Gautam, 2020). For example, the River Cauvery had been polluted by wastewater discharge from homes and resorts on the banks of the river, but the lack of tourists has reduced wastewater discharge keeping the water quality in the "A" category since lockdown (DeccanHerald, 2020). Garg et al. (Garg, Aggarwal, & Chauhan, 2020) analyzed the turbidity level along the Ganga river and its stretches including Haridwar, Kanpur, Prayagraj, and Varanasi using remote sensing data; the reduction of reflectance in the visible and NIR region of Sentinel-2A/B data indicated the turbidity reduction; According to the Centre Pollution Control Board's (CPCB) real-time water quality monitoring data on April 19, the pre-COVID polluted Ganga river has met drinking water standards (with biological oxygen demand level lower than 3 mg/L, dissolved oxygen (DO) greater than 4 mg.L^{-1}, and pH=6 to 8) in a manner never seen before. After a month lockdown, its DO level was improved by 79%. Although more than 80% of pollution in the Ganga River is related to domestic sewage, which has increased during the COVID-19 pandemic, the lack of other sources of pollution, such as industrial effluents and tourism activities, have increased the water quality. Aside from the reduction of industrial effluent, water lifting by industries has also decreased, resulting in a dilution of pollutants in the river (Singhal & Matto, 2020).

Because of lockdown and industrial shutdown in New Delhi, India, the quality of water in the Yamuna River has improved more than fivefold downstream according to a CPCB report (Paital et al., 2020). The mix of detergents and chemicals from industries and sewage produced toxic foam in southeast Delhi's Kalindi Kunj disappeared during the lockdown (Lokhandwala & Gautam, 2020). The highly polluted Rimac River in Peru, which is the main water supply for the capital, Lima, also has experienced improvements in water quality since the lockdown. According to Peru's National Water Authority, because the dumping of garbage, construction materials and waste from businesses and industrial sectors has stopped, this has improved water quality. The volume of solid waste in the La Atarjea water treatment plant has been reduced by 90%; this was also beneficial for the treatment plant (Newsweek, 2020). As a result, less human activity, a reduction in tourism and the reduction of industrial effluents, has led to improvements in water quality in some regions of the world. These quality improvements resulting in transparent waters, also allowed wildlife to find a chance to be free from pollution. Sadly, such environmental effects will be temporary.

Coronavirus may affect the produced wastewater of a community, which would be an opportunity for decision-makers to adopt proper strategies by monitoring the wastewater. Ahmed et al. (Ahmed et al., 2020) detected SARS-CoV-2 in untreated wastewater of Australia using RT-qPCR assay, which confirms the necessity of wastewater-based epidemiology (WBE). Considering the potential role of wastewater in the SARS-CoV-2 transmission, Kitajima et al. (Kitajima et al., 2020) indicated that researches should be conducted to reveal knowledge on the survival and stability of this novel coronavirus in aquatic media; in this regard, wastewater surveillance plays a crucial role providing useful data to possibly distinguish undiagnosed or successive disease in the community; WBE surveillance tool could provide precaution signs on how broadly the virus is circulating in the community. Hart & Halden (Hart & Halden, 2020) conducted a computational modeling study and cost analysis survey to confirm the effectiveness of WBE in tracking COVID-19; they suggested that this tool requires to consider the temperature effects as well. Sharif et al. (Sharif et al., 2020) also applied the existing polio environment surveillance network in Pakistan to evaluate the presence of SARs-CoV-2. Their results indicated that environmental surveillance via wastewater could be effective for decision makers especially in societies where medical testing is limited; however, the quantification method of virus need to be investigated to enhance the sensitivity of SARS-CoV-2 detection in wastewater.

5. Traffic and transport

Transport and mobility of passengers are some of the most vulnerable parts of the COVID-19 period. Declines of commercial flight operation, demands of urban transport, public transport usage, and generally passenger transport, were the adverse impacts of the COVID-19 period on transportation. Also, freightage transit has been affected. On the other hand, these events have led to positive effects on the environment because of less energy demand in the transportation part (Falchetta & Noussan, 2020). Air traffic and public transport demand declined 90% and 80%, respectively in Europe, and Road traffic fell down by 73% in the UK (Budd & Ison, 2020). Even remote working has had positive effects on the environments by reducing transport emissions. Working from home made less traffic pollution and commuting without harming the economy (Crowley, Daly, Doran, & Ryan, 2020).

Travel and economic activities have been drastically reduced because of lockdown measures worldwide, leading to a significant decrease in traffic congestion in major cities (Y. Wang et al., 2020). For example, about a 50% decrease in peak traffic congestion was observed in US cities such as New York and Los Angeles. The correlative reduction of pollutants like carbon monoxide (CO) and NO_2 is the main result of this decrease in traffic (NASA, 2020a; Saadat et al., 2020). The average level of CO in New York City has dropped by 50% compared to the previous year during the same period, and similarly, in Madrid, a 75% decrease in the average level of NO_2 was reported in March 2020. Recently, by studying the change in air quality and the potentially avoided cause-specific mortality during the lockdown in China, researchers have shown the health benefits of air quality enhancement due to the decrease in NO_2 and fine PMs (particle maters) from traffic (Chen, Wang, Huang, Kinney, & Paul, 2020). Regardless of having tremendous economic and social impacts, lockdowns have also some benefits in decreasing road crash deaths and disabling injuries by reducing travel during these periods (Worldbank, 2020).

As one of the major side effects of COVID-19 induced lockdowns traffic reduction is a reduction in road traffic accidents. A report provided by the Road Ecology Centre at the University of California at Davis shows an almost 50% reduction in collisions and injury/fatal accidents as well as a $40 million per day savings to the California public after the state’s shelter-in-place order on 19 March. According to this report, the same reduction was seen in the Sacramento-region. Fig. 9 shows California's crashes during "Shelter-in-Place" orders, from March 2020 to April 2020, the top graph showing the number of crashes per day and the number of collisions/day where an injury/fatality happened. The bottom graph presents all crashes by area. It seems that heavy rains in the San Diego and Los Angeles areas caused a spike in crashes between March 5th and 10th, including injury/fatality crashes in both graphs (Shilling & Waetjen, 2020). The figure, however, points to a significant reduction in collisions, particularly following heavy rains. Traffic maps created based on peak time travel at 8 am on April 8th, 2019, and at the same time for the same roads on April 6th, 2020, show significant reductions (more than 90%) in traffic across some congested European cities including Paris, Madrid, Rome and London (see Fig. 10) (Dickson, 2020). In Istanbul, traffic density before and after schools was shut down by the government was about 65% and 27% on March 16 (the day schools were closed). From March 5th to March 15th, 1 fatality was recorded in 790 accidents, whereas between March 16th – 26th 520 accidents occurred. Accidents dropped down to 34% during coronavirus related restriction (Dağ, 2020). The long-term impact of the COVID-19 pandemic on traffic, transport, and mobility is hard to assess at present. However, some pre-existing trends, such as the rise of sustainable mobility and remote working, have the potential to be established more strongly during the COVID-19 pandemic, leading to lasting effects on reducing carbon emissions as well as air pollution (Shi & Fang, 2020; Worldbank, 2020).

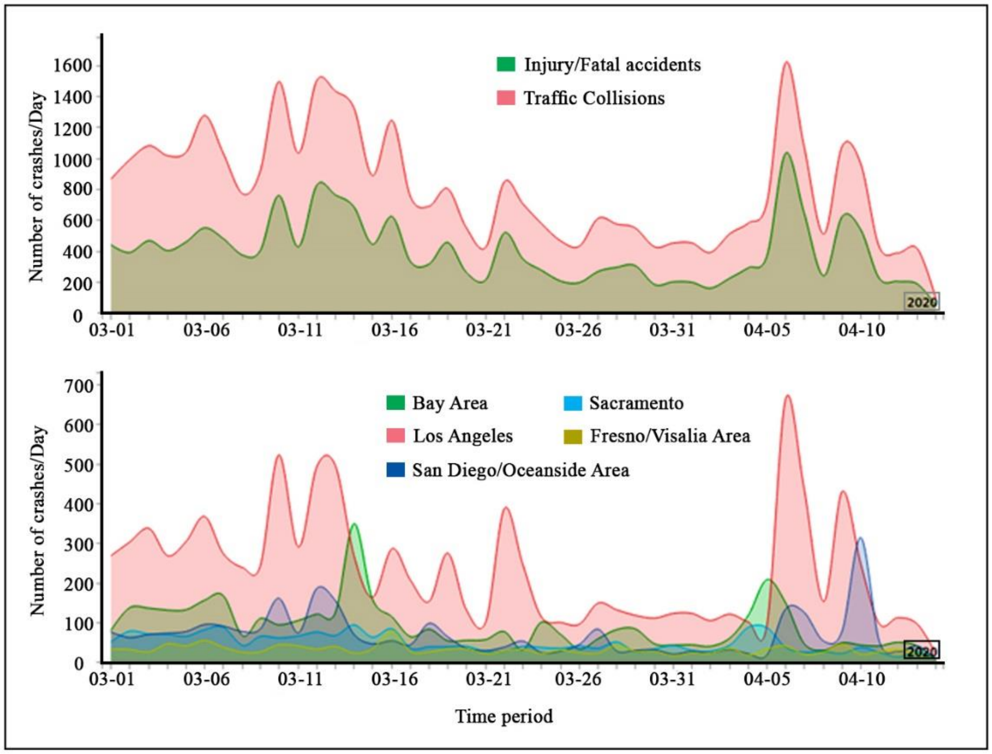


Figure 9. California Crashes During "Shelter-in-Place" Orders, when heavy rains in Southern California brought a brief return to "normal" conditions: (top) the number per day of all crashes and the number of collisions/day where an injury/fatality happened, (bottom) the rates of crashes occurred between March to April 2020. Both graphs show a significant reduction in collisions, particularly following heavy rains, implying the positive impact of the pandemic. They were modified after Shilling & Waetjen (Shilling & Waetjen, 2020).

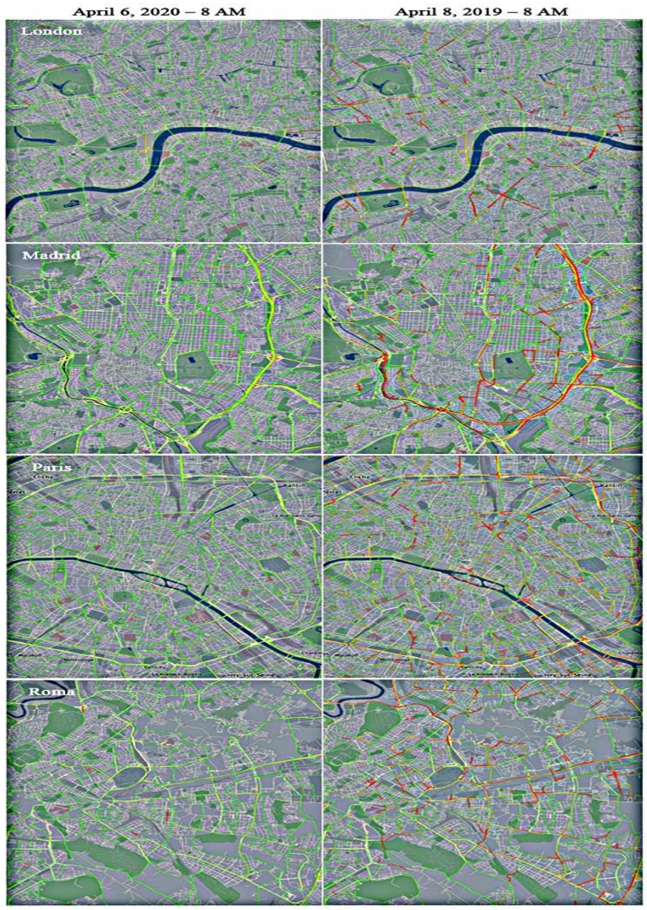


Figure. 10. Traffic maps of some congested European cities, including London, Madrid, Paris, and Roma. Green, yellow, and red routes show clear, moderate, and heavy congestions, respectively. As can be seen in the all mentioned cities, the pandemic lockdown significantly decreases traffic on April 6, 2020, in comparison with April 8, 2019. While the reduction in traffic was more than 96% in Madrid, Paris, and Roma, it was around 90% in London. It was modified after Dickson (Dickson, 2020).

A report by the World Trade Organization, the disruption of economic activity owing to the COVID-19 pandemic, has caused an estimated fall in world trade of between 13% and 32% (WTO, 2020). Therefore, considering that the maritime industry handles over 80% of worldwide trade (UNCTAD, 2018), this expected recession in global trade suggests a considerable decrease in human-based marine activity. As mentioned previously, Fig. 8 shows the positive environmental impact of COVID-19 on the Canal City of Venice, Italy, the decrease in commercial boating activities because of reduced tourism allowing the canal water to clear (Saadat et al., 2020). To the best of the authors' knowledge, there is no study available on the impact of the COVID-19 pandemic on ocean pollutions; similar reductions are likely since maritime transportation has decreased significantly.

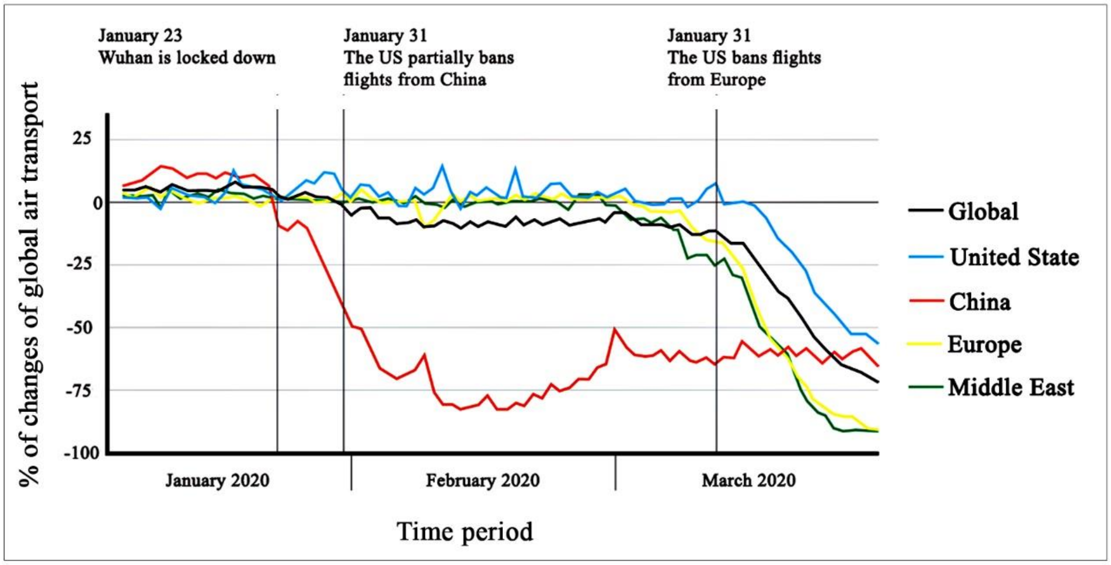


Figure 11. Comparison of airline travel for the COVID-19 period to the same day in 2019. The global aviation industry slash flights as COVID-19 hits travel demand. In the context of the COVID-19 episode, strict lockdown laws have been enacted in some cities around the world. On 23 January 2020, the lockdown was implemented in Wuhan, which, as it turns out significantly reduced air travel up to -75% - the biggest reduction to date by a China- in mid-February 2020. As of January 31, 2020, the United States imposed strict rules such as a flight ban from Europe and China, which did not see significant changes, but about two months later (late March) drastically reduce about -50% was likely due to the US government's lockdown has been observed. They were modified after Wastnage (Wastnage, 2020).

Because airlines are a significant factor in the international spread of COVID-19, governments have levied stringent restrictions on air travel, in other words, international air travel more or less ceased (Lau et al., 2020). As shown in Fig. 11, the global change in air traffic in early lockdown was around under 25%, and in the following the global air, transportations were gradually decreased to 0% in February 2020. China, however, had an abrupt decrease (more than -75%) in late January to mid-February. From early to late March, the US, Europe, and the Middle East decreased air travel by– around 50 %, these decreases reducing CO and NO_2 in air. At this time, there was also an almost 50% reduction in collisions and injury/fatal accidents. Generally, as severe disruption occurs in industrial operations owing to epidemic or pandemic outbreaks, the transport volume is reduced, and thereby, positive impacts on the environment are appeared (Loske, 2020). Though, positive impacts of COVID-19 on the environment such as the low generation of GHG emission are expected to have a reverse trend by returning to normal conditions. Therefore, the progress of green new action is indispensable (Tardivo, Martín, & Zanuy, 2020).

6. Conclusion

COVID-19 has imparted many positive changes in the chemical composition of the environment worldwide. COVID-19 induced lockdowns have resulted in 20 to 77% reductions in emissions of nitrogen oxides, reducing by 16 to 60% in different cities. Emissions of CO_2 were also reduced between 5-10%. Similarly, the particulate matter level globally was found to reduce by 9 to 200%, and New Delhi, India witnessed the highest levels of change ever seen. The reduction of CO levels has also followed a similar trend, the level of reduction between 30 to 60%. This might be due to reductions in the use of fossil fuels as the expenditure of the global fuel supply has decreased by 4% in 2020 in comparison to the same time in 2019. This is supported by an 8% reduction in the use of coal by April 2020 as compared to April 2019. A drastic reduction in vehicular operation also was a contributing factor regarding reductions in air pollution, as traffic congestion decreased worldwide up to 50%. The quality of several water bodies has improved seeing an increase of up to 79% dissolved oxygen levels. Conventional energy demands, for example, electricity, has also declined by almost 30% in many countries: a 12 to 20% drop in consumption of electricity has been recorded in most countries. Despite the disruption to economic activity (13 to 32%) globally, COVID-19 has created enormous positive effects on the environment, which must be considered as spotlights for the better management of the environment in the future.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

References:

Achakulwisut, P., Brauer, M., Hystad, P., & Anenberg, S. C. (2019). Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. *The Lancet Planetary Health, 3*(4), e166-e178.

Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W., . . . Li, J. (2020). First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. *Science of The Total Environment*, 138764.

Allegrante, J. P., Auld, M. E., & Natarajan, S. (2020). Preventing COVID-19 and Its Sequela:“There Is No Magic Bullet... It's Just Behaviors”. *American Journal of Preventive Medicine*.

Authority, G. L. (2020). Estimation of changes in air pollution in London during the COVID19 outbreak https://www.london.gov.uk/sites/default/files/london_response_to_aqeg_call_for_evidence_april_2020.pdf Accessed date: 8 July 2020.

Baldasano, J. M. (2020). COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain). *Science of The Total Environment*, 140353.

Bauwens, M., Compernolle, S., Stavrakou, T., Müller, J. F., Van Gent, J., Eskes, H., . . . Vlietinck, J. (2020). Impact of coronavirus outbreak on NO2 pollution assessed using TROPOMI and OMI observations. *Geophysical Research Letters*, e2020GL087978.

Budd, L., & Ison, S. (2020). Responsible Transport: A post-COVID agenda for transport policy and practice. *Transportation Research Interdisciplinary Perspectives, 6*, 100151.

Carrión, D., Kaali, S., Kinney, P. L., Owusu-Agyei, S., Chillrud, S., Yawson, A. K., . . . Lee, A. G. (2019). Examining the relationship between household air pollution and infant microbial nasal carriage in a Ghanaian cohort. *Environment international, 133*, 105150.

CDC. (2020). Interim Clinical Guidance for Management of Patients with Confirmed Coronavirus Disease (COVID-19)

https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html Accessed date: 22 July 2020.

Chakraborty, I., & Maity, P. (2020). COVID-19 outbreak: Migration, effects on society, global environment and prevention. *Science of The Total Environment*, 138882.

Chang, K.-C., Strong, C., Pakpour, A. H., Griffiths, M. D., & Lin, C.-Y. (2020). Factors related to preventive COVID-19 infection behaviors among people with mental illness. *Journal of the Formosan Medical Association*.

Chelsea Harvey, E. (2020). How the Coronavirus Pandemic Is Affecting CO2 Emissions

https://www.scientificamerican.com/article/how-the-coronavirus-pandemic-is-affecting-co2-emissions/ Accessed 22 July 2020.

Chen, K., Wang, M., Huang, C., Kinney, P. L., & Paul, A. T. (2020). Air Pollution Reduction and Mortality Benefit during the COVID-19 Outbreak in China. *medRxiv*.

Cohen, A. (2020). Energy Demand Will Never Be The Same After COVID-19, IEA Report Finds

https://www.forbes.com/sites/arielcohen/2020/05/05/energy-demand-will-never-be-the-same-after-covid-19-iea-report-finds/#695666674d22 Accessed date: 22 July 2020.

Coker, E. S., Cavalli, L., Fabrizi, E., Guastella, G., Lippo, E., Parisi, M. L., . . . Vergalli, S. (2020). The effects of air pollution on COVID-19 related mortality in northern Italy. *Environmental and Resource Economics, 76*(4), 611-634.

Conticini, E., Frediani, B., & Caro, D. (2020). Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy? *Environmental pollution*, 114465.

Crowley, F., Daly, H., Doran, J., & Ryan, G. (2020). *COVID-19, social distancing, remote work and transport choice*. Retrieved from

Cui, Y., Zhang, Z.-F., Froines, J., Zhao, J., Wang, H., Yu, S.-Z., & Detels, R. (2003). Air pollution and case fatality of SARS in the People's Republic of China: an ecologic study. *Environmental Health, 2*(1), 1-5.

Dağ, B. (2020). Traffic accidents reduced in Istanbul amid COVID-19. https://www.aa.com.tr/en/latest-on-coronavirus-outbreak/traffic-accidents-reduced-in-istanbul-amid-covid-19/1782717 Access date: 22 July 2020.

Dantas, G., Siciliano, B., Freitas, L., de Seixas, E. G., da Silva, C. M., & Arbilla, G. (2019). Why did ozone levels remain high in Rio de Janeiro during the Brazilian truck driver strike? *Atmospheric Pollution Research, 10*(6), 2018-2029.

DeccanHerald. (2020). Coronavirus lockdown: Water quality improves at River Cauvery

https://www.deccanherald.com/state/mangaluru/coronavirus-lockdown-water-quality-improves-at-river-cauvery-828138.html Access date: 22 July 2020.

Destouni, G., & Frank, H. (2010). Renewable Energy. *AMBIO, 39*(1), 18-21. doi:10.1007/s13280-010-0059-7

Dickson, I. (2020). Before and after COVID-19: Europe's traffic congestion mapped

https://360.here.com/covid-19-impact-traffic-congestion Accessed date: 22 July 2020.

Ergun, S. J., Owusu, P. A., & Rivas, M. F. (2019). Determinants of renewable energy consumption in Africa. *Environmental Science and Pollution Research, 26*(15), 15390-15405.

ESA. (2020a). Air pollution remains low as Europeans stay at home. http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Air_pollution_remains_low_as_Europeans_stay_at_home Access date: 22 July 2020.
ESA. (2020b). http://www.esa.int/ESA_Multimedia/Images/2020/04/Deserted_Venetian_lagoon Access date: 3 June 2020.
ESA. (2020c). Nitrogen dioxide concentrations over India. http://www.esa.int/ESA_Multimedia/Images/2020/04/Nitrogen_dioxide_concentrations_over_India Access date: 22 July 2020.
Espejo, W., Celis, J. E., Chiang, G., & Bahamonde, P. (2020). Environment and COVID-19: Pollutants, impacts, dissemination, management and recommendations for facing future epidemic threats. *Science of The Total Environment, 747*, 141314.
Falchetta, G., & Noussan, M. (2020). The Impact of COVID-19 on Transport Demand, Modal Choices, and Sectoral Energy Consumption in Europe. *IAEE Energy Forum*.
Ferguson, N., Laydon, D., Nedjati Gilani, G., Imai, N., Ainslie, K., Baguelin, M., . . . Cuomo-Dannenburg, G. (2020). Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand.
Garg, V., Aggarwal, S. P., & Chauhan, P. (2020). Changes in turbidity along Ganga River using Sentinel-2 satellite data during lockdown associated with COVID-19. *Geomatics, Natural Hazards and Risk, 11*(1), 1175-1195.
Ghosh, I. (2020). These satellite photos show how COVID-19 lockdowns have impacted global emissions

https://www.weforum.org/agenda/2020/03/emissions-impact-coronavirus-lockdowns-satellites/ Access date: 22 July 2020.
Hart, O. E., & Halden, R. U. (2020). Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges. *Science of The Total Environment*, 138875.
Hosseini, S. E. (2020). An Outlook on the Global Development of Renewable and Sustainable Energy at the Time of Covid-19. *Energy Research & Social Science*, 101633.
IEA. (2020). Reductions of electricity demand after implementing lockdown measures in selected countries, weather corrected, 0 to 118 days

https://www.iea.org/data-and-statistics/charts/reductions-of-electricity-demand-after-implementing-lockdown-measures-in-selected-countries-weather-corrected-0-to-118-days Access date: 22 July 2020.
Kerimray, A., Baimatova, N., Ibragimova, O. P., Bukenov, B., Kenessov, B., Plotitsyn, P., & Karaca, F. (2020). Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan. *Science of The Total Environment*, 139179.
Kitajima, M., Ahmed, W., Bibby, K., Carducci, A., Gerba, C. P., Hamilton, K. A., . . . Rose, J. B. (2020). SARS-CoV-2 in wastewater: State of the knowledge and research needs. *Science of The Total Environment*, 139076.
Kotnala, G., Mandal, T., Sharma, S., & Kotnala, R. (2020). Emergence of Blue Sky Over Delhi Due to Coronavirus Disease (COVID-19) Lockdown Implications. *Aerosol Science and Engineering*, 1.
Lau, H., Khosrawipour, V., Kocbach, P., Mikolajczyk, A., Ichii, H., Zacharksi, M., . . . Khosrawipour, T. (2020). The association between international and domestic air traffic and the coronavirus (COVID-19) outbreak. *Journal of Microbiology, Immunology and Infection*.
Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J., Abernethy, S., Andrew, R. M., . . . Canadell, J. G. (2020). Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, 1-7.

Le, T., Wang, Y., Liu, L., Yang, J., Yung, Y. L., Li, G., & Seinfeld, J. H. (2020). Unexpected air pollution with marked emission reductions during the COVID-19 outbreak in China. *Science*.

Lelieveld, J., Pozzer, A., Pöschl, U., Fnais, M., Haines, A., & Münzel, T. (2020). Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective. *Cardiovascular Research*.

Leung, F. (2020). COVID-19 Reveals Unexpected Benefit: Reduced Emissions

https://earth.org/covid-19-reveals-unexpected-benefit-reduced-emissions/ Accessed date: 22 July 2020.

Li, Y., Chiu, Y.-h., & Lin, T.-Y. (2019). Research on New and Traditional Energy Sources in OECD Countries. *International journal of environmental research and public health, 16*(7), 1122.

Lian, X., Huang, J., Huang, R., Liu, C., Wang, L., & Zhang, T. (2020). Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city. *Science of The Total Environment*, 140556.

Liang, D., Shi, L., Zhao, J., Liu, P., Sarnat, J. A., Gao, S., . . . Chang, H. H. (2020). Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States. *The Innovation*, 100047. doi:https://doi.org/10.1016/j.xinn.2020.100047

Lokhandwala, S., & Gautam, P. (2020). Indirect impact of COVID-19 on environment: A brief study in Indian context. *Environmental research, 188*, 109807.

Loske, D. (2020). The impact of COVID-19 on transport volume and freight capacity dynamics: An empirical analysis in German food retail logistics. *Transportation Research Interdisciplinary Perspectives, 6*, 100165.

McGrath, M. (2020). https://www.bbc.com/news/science-environment-51944780 Accessed date: 22 July 2020.

Menut, L., Bessagnet, B., Siour, G., Mailler, S., Pennel, R., & Cholakian, A. (2020). Impact of lockdown measures to combat Covid-19 on air quality over western Europe. *Science of The Total Environment*, 140426.

Monks, P. (2020). Coronavirus: lockdown's effect on air pollution provides rare glimpse of low-carbon future

https://theconversation.com/coronavirus-lockdowns-effect-on-air-pollution-provides-rare-glimpse-of-low-carbon-future-134685 Accessed date: 22 July 2020.

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of The Total Environment*, 138820.

Nakada, L. Y. K., & Urban, R. C. (2020). COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. *Science of The Total Environment*, 139087.

NASA. (2020a). Airborne Nitrogen Dioxide Plummets Over China

https://www.nasa.gov/feature/nasa-monitors-environmental-signals-from-global-response-to-covid-19 Accessed date: 22 July 2020.

NASA. (2020b). https://earthobservatory.nasa.gov/images Accessed date: 2 June 2020.

Newsweek. (2020). https://www.newsweek.com/peruvian-river-waste-reduction-coronavirus-1501256 Access date: 2 June 2020.

Niroumand-Jadidi, M., Bovolo, F., Bruzzone, L., & Gege, P. (2020). Physics-based Bathymetry and Water Quality Retrieval Using PlanetScope Imagery: Impacts of 2020 COVID-19 Lockdown and 2019 Extreme Flood in the Venice Lagoon. *Remote Sensing, 12*(15), 2381.

Ogen, Y. (2020). Assessing nitrogen dioxide (NO2) levels as a contributing factor to the coronavirus (COVID-19) fatality rate. *Science of The Total Environment*, 138605.

Paital, B. (2020). Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. *Science of The Total Environment*, 139088.

Paital, B., Das, K., & Parida, S. K. (2020). Inter nation social lockdown versus medical care against COVID-19, a mild environmental insight with special reference to India. *Science of The Total Environment*, 138914.

Raoofi, A., Takian, A., Sari, A. A., Olyaeemanesh, A., Haghighi, H., & Aarabi, M. (2020). COVID-19 pandemic and comparative health policy learning in Iran. *Archives of Iranian Medicine, 23*(4), 220-234.

Saadat, S., Rawtani, D., & Hussain, C. M. (2020). Environmental perspective of COVID-19. *Science of The Total Environment, 728*, 138870. doi:https://doi.org/10.1016/j.scitotenv.2020.138870

Sarkar, S. (2020). Emissions dive as Covid-19 smashes energy demand

https://indiaclimatedialogue.net/2020/05/01/carbon-emissions-dive-as-covid-19-smashes-energy-demand/ Accessed date: 22 July 2020.

SEI. (2020). COVID-19 impacts: Energy demand and emissions across Europe

https://www.smart-energy.com/industry-sectors/energy-grid-management/covid-19-impacts-emissions-across-europe-electricity-demand/ Accessed date: 22 July 2020.

Sharif, S., Ikram, A., Khurshid, A., Salman, M., Mehmood, N., Arshad, Y., . . . Rehman, L. (2020). Detection of SARS-Coronavirus-2 in wastewater, using the existing environmental surveillance network: An epidemiological gateway to an early warning for COVID-19 in communities. *medRxiv*.

Sharma, S., Zhang, M., Gao, J., Zhang, H., & Kota, S. H. (2020). Effect of restricted emissions during COVID-19 on air quality in India. *Science of The Total Environment, 728*, 138878.

Shi, Z., & Fang, Y. (2020). Temporal relationship between outbound traffic from Wuhan and the 2019 coronavirus disease (COVID-19) incidence in China. *medRxiv*.

Shilling, F., & Waetjen, D. (2020). Special Report (Update): Impact of COVID19 Mitigation on Numbers and Costs of California Traffic Crashes.

Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., . . . Calatayud, V. (2020). Amplified ozone pollution in cities during the COVID-19 lockdown. *Science of The Total Environment*, 139542.

Siciliano, B., Dantas, G., da Silva, C. M., & Arbilla, G. (2020). Increased ozone levels during the COVID-19 lockdown: Analysis for the city of Rio de Janeiro, Brazil. *Science of The Total Environment*, 139765.

Singhal, S., and , & Matto, M. (2020). COVID-19 lockdown: A ventilator for rivers. https://www.downtoearth.org.in/blog/covid-19-lockdown-a-ventilator-for-rivers-70771 Access date: 22 July 2020. *Down To Earth magazine*.

Tardivo, A., Martín, C. S., & Zanuy, A. C. (2020). Covid-19 impact in Transport, an essay from the Railways' system research perspective. *Pract. Pipeline*.

Tobías, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M. C., . . . Querol, X. (2020). Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Science of The Total Environment*, 138540.

UNCTAD, W. (2018). United nations conference on trade and development. *Review of Maritime Transport*.

Venter, Z. S., Aunan, K., Chowdhury, S., & Lelieveld, J. (2020). COVID-19 lockdowns cause global air pollution declines with implications for public health risk. *medRxiv*.

Wang, Q., & Su, M. (2020). A preliminary assessment of the impact of COVID-19 on environment–A case study of China. *Science of The Total Environment*, 138915.

Wang, Y., Yuan, Y., Wang, Q., Liu, C., Zhi, Q., & Cao, J. (2020). Changes in air quality related to the control of coronavirus in China: Implications for traffic and industrial emissions. *Science of The Total Environment*, 139133.

Wastnage, J. (2020). WHAT WILL THE AIRLINE INDUSTRY LOOK LIKE POST COVID-19? WHY THE ERA OF CHEAP FLIGHTS MAY BE OVER

https://www.ussc.edu.au/analysis/what-will-the-airline-industry-look-like-post-covid-19-why-the-era-of-cheap-flights-may-be-over Access date: 23 July 2020.

WHO. (2020a). Air pollution

https://www.who.int/health-topics/air-pollution#tab=tab_1 Accessed date: 23 July 2020.

WHO. (2020b). Rolling updates on coronavirus disease (COVID-19)

https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen Accessed date: 23 July 2020.

WHO. (2020c). Statement on the second meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV)

https://www.who.int/news-room/detail/30-01-2020-statement-on-the-second-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-ncov) Accessed date: 23 July 2020.

Worldbank. (2020). Can COVID-19 teach us something for the road safety epidemic?

https://blogs.worldbank.org/transport/can-covid-19-teach-us-something-road-safety-epidemic Access date: 23 July 2020.

Worldometers. (2020). COVID-19 CORONAVIRUS PANDEMIC

www.worldometers.info/coronavirus Access date: 23 July 2020.

WTO. (2020). Trade set to plunge as COVID-19 pandemic upends global economy

https://www.wto.org/english/news_e/pres20_e/pr855_e.htm Accessed date: 23 July 2020.

Wu, X., Nethery, R. C., Sabath, B. M., Braun, D., & Dominici, F. (2020). Exposure to air pollution and COVID-19 mortality in the United States. *medRxiv*.

Yunus, A. P., Masago, Y., & Hijioka, Y. (2020). COVID-19 and surface water quality: Improved lake water quality during the lockdown. *Science of The Total Environment*, 139012.

Zambrano-Monserrate, M. A., Ruano, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the environment. *Science of The Total Environment*, 138813.