Impact of COVID-19 on the social, economic, environmental and energy domains: Lessons learnt from a global pandemic

M. Mofijur[1], I.M. Rizwanul Fattah[1], Md Asraful Alam[2], A. B. M. Saiful Islam[3], Hwai Chyuan Ong[1], S. M. Ashrafur Rahman[4], G. Najafi[5], S. F. Ahmed[6], Md. Alhaz Uddin[7], T.M.I. Mahlia[1]

[1] School of Information Systems and Modelling, Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia

[2] School of Chemical Engineering, Zhengzhou University, Zhengzhou 450001, China

[3]Department of Civil and Construction Engineering, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

[4] Biofuel Engine Research Facility, Queensland University of Technology (QUT), Brisbane, QLD 4000, Australia

[5]Tarbiat Modares University, Tehran, P.O.Box: 14115-111, Iran

[6] Science and Math Program, Asian University for Women, Chattogram 4000, Bangladesh

[7]Department of Civil Engineering, College of Engineering, Jouf University, Sakaka, Saudi Arabia

Corresponding authors:

Dr Md Mofijur Rahman, Email: MdMofijur.Rahman@uts.edu.au;

Dr IM Rizwanul Fattah, Email: IslamMdRizwanul.Fattah@uts.edu.au

Impact of COVID-19 on the social, economic, environmental and energy domains: Lessons learnt from a global pandemic

M. Mofijur[1], I.M. Rizwanul Fattah[1], Md Asraful Alam[2], A. B. M. Saiful Islam[3], Hwai Chyuan Ong[1], S. M. Ashrafur Rahman[4], G. Najafi[5], S. F. Ahmed[6], Md. Alhaz Uddin[7], T.M.I. Mahlia[1]

[1] School of Information Systems and Modelling, Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia

[2] School of Chemical Engineering, Zhengzhou University, Zhengzhou 450001, China

[3]Department of Civil and Construction Engineering, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

[4] Biofuel Engine Research Facility, Queensland University of Technology (QUT), Brisbane, QLD 4000, Australia

[5]Tarbiat Modares University, Tehran, P.O.Box: 14115-111, Iran

[6] Science and Math Program, Asian University for Women, Chattogram 4000, Bangladesh

[7]Department of Civil Engineering, College of Engineering, Jouf University, Sakaka, Saudi Arabia

Corresponding authors:

Dr Md Mofijur Rahman, Email: MdMofijur.Rahman@uts.edu.au;

Dr IM Rizwanul Fattah, Email: IslamMdRizwanul.Fattah@uts.edu.au

Abstract

COVID-19 has heightened human suffering, undermined the economy, turned the lives of billions of people around the globe upside down, and significantly affected the health, economic, environmental and social domains. This study aims to provide a comprehensive analysis of the impact of the COVID-19 outbreak on the ecological domain, the energy sector, society and the economy and investigate the global preventive measures taken to reduce the transmission of COVID-19. This analysis unpacks the key responses to COVID-19, the efficacy of current initiatives, and summarises the lessons learnt as an update on the information available to authorities, business and industry. This review found that a 72-hour delay in the collection and disposal of waste from infected households and quarantine facilities is crucial to controlling the spread of the virus. Broad sector by sector plans for socio-economic growth as well as a robust entrepreneurship-friendly economy is needed for the business to be sustainable at the peak of the pandemic. The socio-economic crisis has reshaped investment in energy and affected the energy sector significantly with most investment activity facing disruption due to mobility restrictions. Delays in energy projects are expected to create uncertainty in the years ahead. This report will benefit governments, leaders, energy firms and customers in addressing a pandemic-like situation in the future.

Keywords: Environmental pollution; Waste generation; Coronavirus vaccine; PM emission; NO_2 emission; Global Pandemic; SARS-CoV-2.

1. Introduction

The newly identified infectious coronavirus (SARS-CoV-2) was discovered in Wuhan and has spread rapidly since December 2019 within China and to other countries around the globe [1, 2]. The source of SARS-CoV-2 is still unclear [3]. Figure 1 demonstrates the initial timeline of the development of SARS-CoV-2 [4]. The COVID-19 pandemic has posed significant challenges to global safety in public health [5]. On 31st January 2020, the World Health Organization (WHO), due to growing fears about the rapid spread of coronavirus, announced a global epidemic and on 11th March, the disease was recognised as a pandemic. COVID-19 clinical trials indicate that almost all patients admitted to hospital have trouble breathing and pneumonia-like symptoms [6]. Clinical diagnosis has identified that COVID-19 (disease caused by SARS-CoV-2) patients have similar indications to other coronavirus affected patients, e.g. Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) [7]. The initial indication of a COVID-19 infection is coughing, fever, and short breath, and in the later stages, it can damage the kidney, cause pneumonia, and unexpected death. The vulnerability of the elderly (>80 years of age) is high, with a fatality rate of ~22% of cases infected by COVID-19 [8]. The total number of confirmed COVID-19 cases has reached over 33 million as of 29th September 2020, with more than 213 countries and regions affected by the pandemic [9]. Over 1,003,569 people have already passed away [9] due to COVID-19. Most countries are currently trying to combat the virus spread by screening for COVID-19 in large numbers and maintaining social distancing policies with an emphasis on the health of human beings.

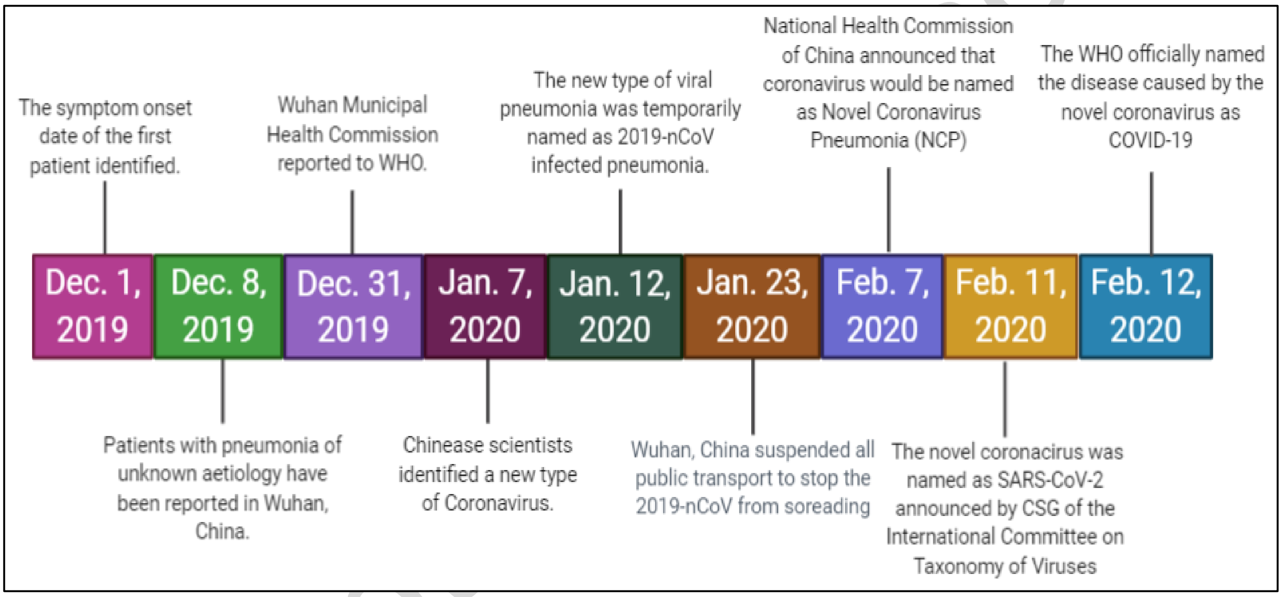


Figure 1. The initial stage development timeline for COVID-19 [4].

Figure 2 shows infections and replication cycle of the coronavirus. In extreme cases, the lungs are the most severely damaged organ of a SARS-CoV-2 infected person (host). The alveoli are porous cup-formed small cavities located in the structure of the lungs where the gas exchange of the breathing process take place. The most common cells on the alveoli are the type II cells.

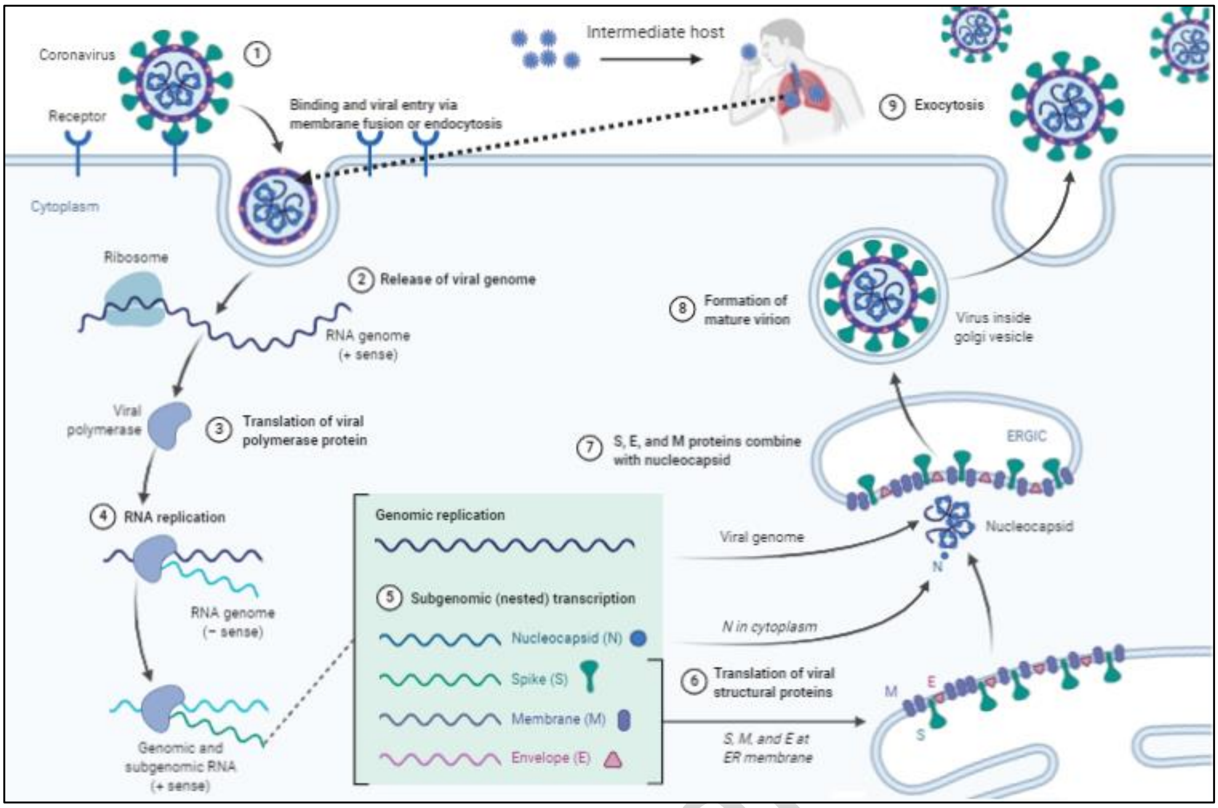


Figure 2. Infections and replication cycle of the coronavirus [10].

It has been reported that travel restrictions play a significant role in controlling the initial spread of COVID-19 [11-15]. It has been reported that staying at home is most useful in controlling both the initial and last phase of infectious diseases [15-17]. However, since the start of the COVID-19 pandemic, quarantines, entry bans, as well as other limitations have been implemented for citizens in or recent travellers to several countries in the most affected areas [18]. Also, most of the industries were shutdown to lower mobility. A potential benefit of these measures is the reduction of pollution by the industrial and transportation sector, improving urban sustainability [19]. Figure 3 shows the global responses to lower the impact of the COVID-19 outbreak. There have been negative economic and social implications due to restrictions and decreased travel readiness worldwide [20]. A fall in the volume of business activity and international events and an increase in online measures could have a long-term impact. The status of global transport and air activity as a result of the COVID-19 pandemic is shown in Figure 4 [21].

Figure 3. Initial preventive measures to lower the COVID-19 outbreak [14].

By March 2020, the average global road haulage activity in regions with lockdowns had declined to almost 50% of the 2019 standard. Air travel has almost completely stopped in certain regions with aviation activity decreasing by over 90% in some European countries. Air activity in China recovered slightly from a low in late February, with lockdown measures somewhat eased. Nevertheless, as lockdowns spread, by the end of Q1 2020, global aviation activity decreased by a staggering 60%.

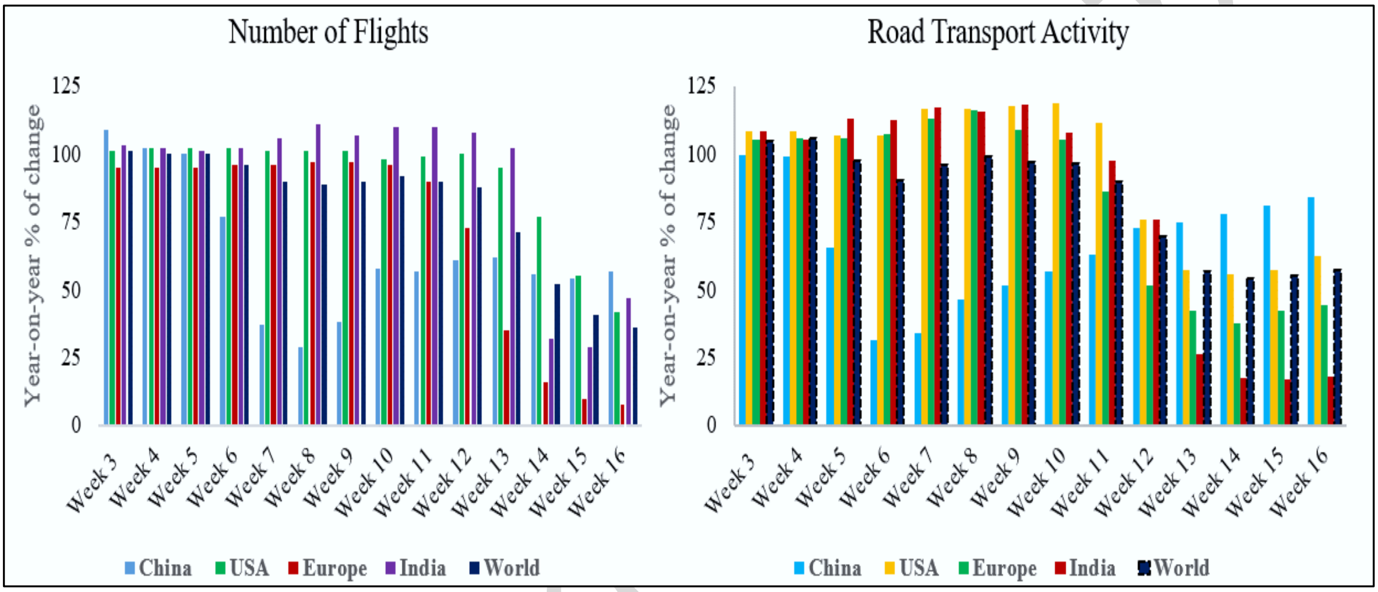


Figure 4. Global transport and aviation activity in the first quarter of the year 2020 [21].

The spread of COVID-19 continues to threaten the public health situation severely [11] and greatly affect the global economy. Labour displacement, business closures and stock crashes are just some of the impacts of this global lockdown during the pandemic. According to the International Monetary Fund (IMF), the effect of COVID-19 will result in a worldwide economic decline in 2020 and a decline in the economic growth to 3% [22]. COVID-19 has a detrimental impact on economic growth due to two primary factors. In the beginning, the exponential growth of the global epidemic directly contributed to considerable confusion about instability in the financial and capital markets. Secondly, countries have strictly regulated human movement and transport to monitor the growth of the epidemic and significantly reduced economic activity, putting pressure on both consumer and productive economic activity.

Since the 1970s, the link between economic growth and pollution has been an important global concern. The assessment of energy and financial efficiency is usually connected to environmental pollution research. Green practices at a national level, the inclusion of renewable energy, regulatory pressure and the sustainable use of natural resources are associated with environmental sustainability [23]. One study has shown that environmental pollution increases with economic growth and vice versa [24]. The strict control over movement and business activity due to COVID-19 has led to an economic downturn, which is in turn, expected to reduce environmental pollution. This paper systematically assesses how the novel coronavirus has had a global effect on society, the energy sector and the environment. This study presents data compiled from the literature, news sources and reports (from February 2020 to July 2020) on the management steps implemented across the globe to control and reduce the impact of COVID-19. The study will offer guidelines for nations to assess the overall impact of COVID-19 in their countries.

2. Impact of COVID-19 on the environmental domain

2.1. Waste generation

The generation of different types of waste indirectly creates a number of environmental concerns [25]. The home isolation and pop-up confinement services in countries that have experienced major impacts of COVID-19 are standard practise, as hospitals are given priority to the most serious cases. In some countries, hotels are being used to isolate travellers for at least two weeks on entry. In several countries, such quarantine measures have resulted in consumers increasing their domestic online shopping activity that has increased domestic waste. In addition, food bought online is packaged, so inorganic waste has also increased. Medical waste has also increased. For instance, Wuhan hospitals produced an average of 240 metric tonnes of medical waste during the outbreak compared to their previous average of fewer than 50 tonnes [26]. This unusual situation poses new and major obstacles in the implementation of waste collection services, thus creating a new challenge for waste collection and recycling groups. With the global adaptation to exponential behavioural and social shifts in the face of COVID-19 challenges, municipal services such as waste collection and management need to alter their operations to play an important role in reducing the spread of infectious diseases.

2.1.1 Lifespan of COVID-19 on different waste media

SARS-CoV-2's transmission activity has major repercussions for waste services. SARS-CoV-2 attacks host cells with ACE2 proteins directly. ACE2 is a cell membrane-associated enzyme in the lungs, heart and kidneys. When all the resources in the host cell are infected and depleted, the viruses leave the cell in the so-called shedding cycle [27]. Clinical and virological evidence suggests that the elimination of the SARS-CoV-2 virus is most relevant early on, right before and within a couple of days of the onset of the illness [28]. Fomites are known as major vectors for the replication of other infectious viruses during the outbreak [29]. Evidence from SARS-CoV-2 and other coronaviruses show that they remain effective for up to a few days in the atmosphere and on a variety of surfaces (Figure 5). The survival time of SARS-CoV-2 on hard and plastic surfaces is up to three days indicating that waste materials from COVID-19 patients may contain coronavirus and be a source of infection spread [30]. During the early stages of this epidemic, updated waste disposal methods to tackle COVID-19 were not implemented on the broader community. The concept of clinical waste essentially also applies to waste from contaminated homes and quarantine facilities. Throughout this pandemic, huge volumes of domestic and hospital waste, particularly plastic waste, has been generated. This has already impeded current efforts to reduce plastic waste and decrease its disposal in the environment. More effort should be made to find alternatives to heavily used plastics.

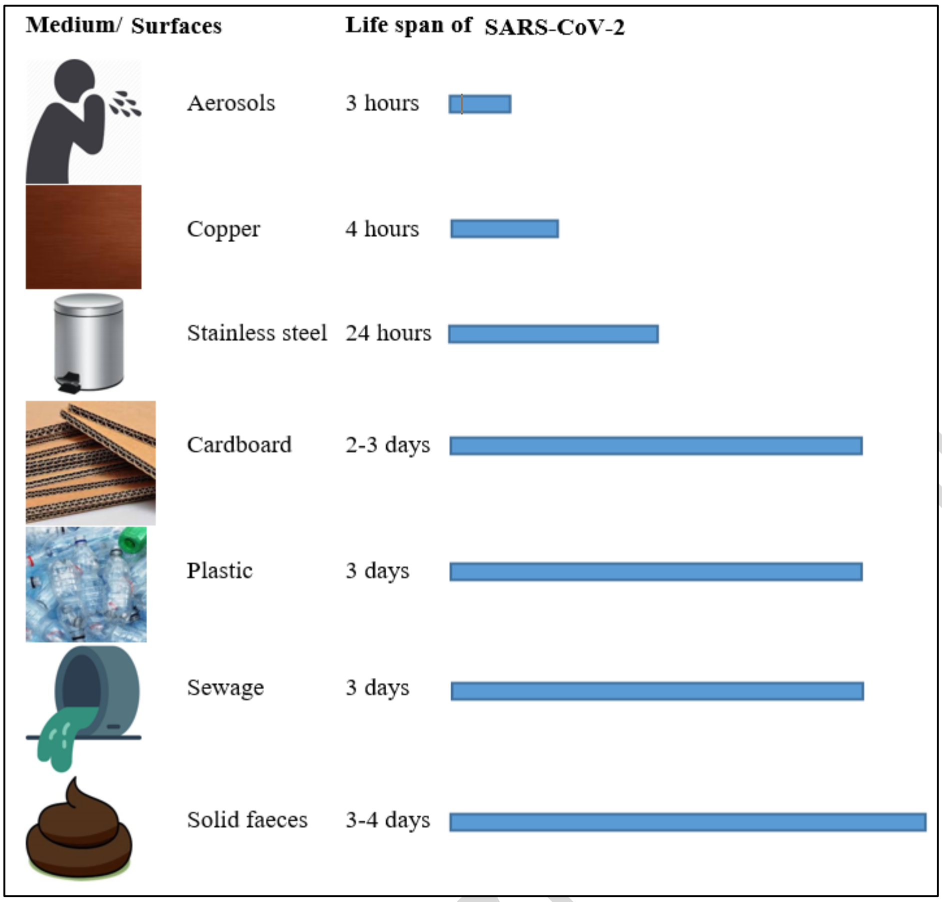


Figure 5. The lifespan of SARS-CoV-2 on different media [30-32]

2.1.2 Waste recycling service

COVID-19 has already had significant effects on waste recycling. Initially, as the outbreak spread and lockdowns were implemented in several countries, both public authorities and municipal waste management officials had to adjust to the situation quickly. Waste disposal has also been a major environmental problem for all technologically advanced nations, as no clear information was available about the retention time of SARS-CoV-2 [33]. Recycling is a growing and efficient means of pollution control, saving energy and conserving natural resources [34]. Recycling projects in various cities have been put on hold due to the pandemic, with officials worried about the possibility of COVID-19 spreading to recycling centres. Waste management has been limited in affected European countries. For example, Italy prohibited the sorting of waste by infected citizens. Extensive waste management during the pandemic is incredibly difficult because of the scattered nature of the cases and the individuals affected. The value of implementing best management practises for waste handling and hygiene to minimise employee exposure to potentially hazardous waste, should be highlighted at this time. Considering the possible role of the environment in the spread of SARS-CoV-2 [35], the processing of both household and quarantine facility waste is a crucial point of control. Association of Cities and Regions for sustainable Resource management (ACR+) has reported on the provision of separate collection services to COVID-19 contaminated households and quarantine facilities to protect frontline waste workers in Europe, as shown in Figure 6. ACR+ also suggests a 72-hour delay in waste disposal (the possible lifespan of COVID-19 in the environment) [27]. Moreover, the collected waste should be immediately transported to waste incinerators or sites without segregation.

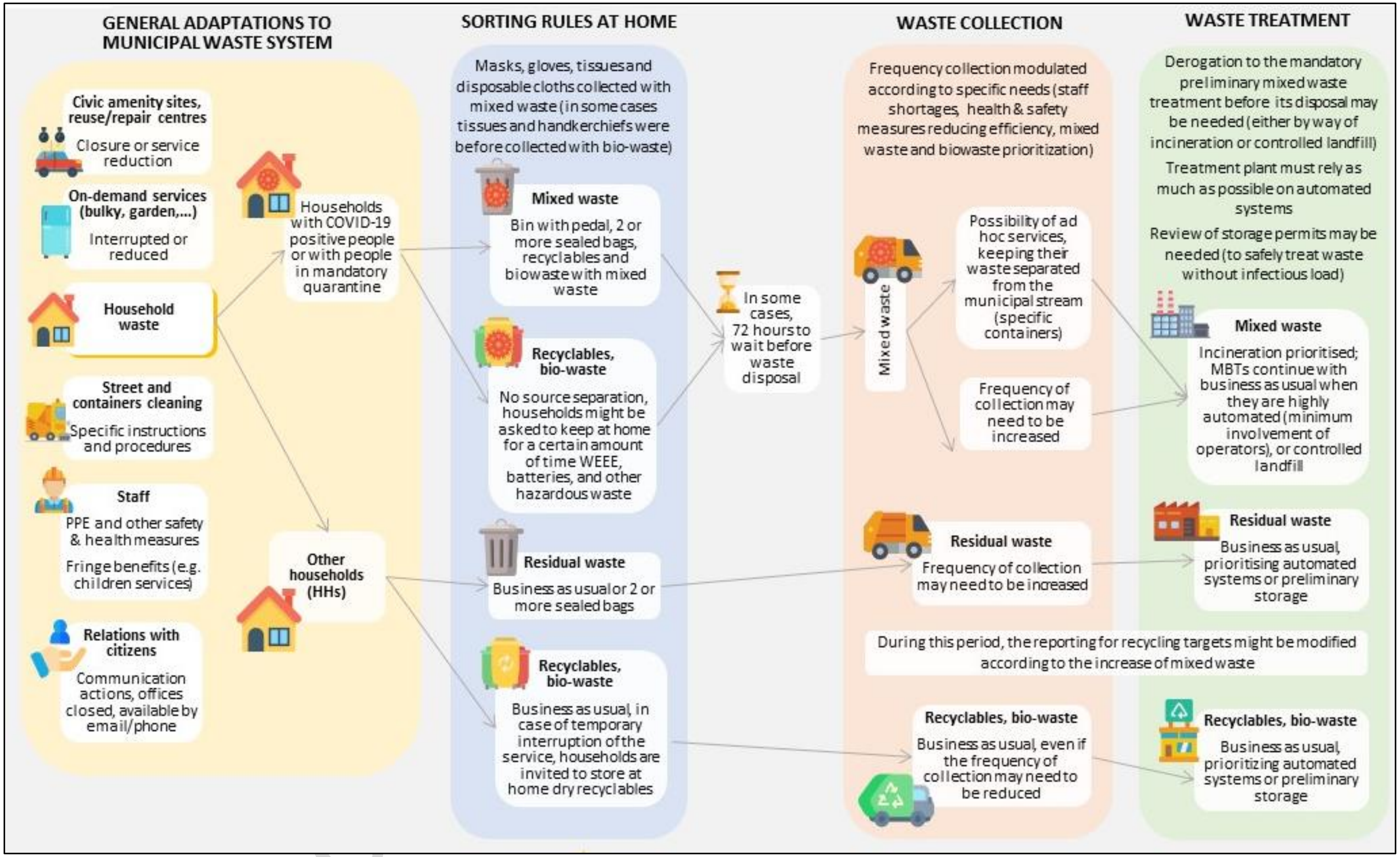


Figure 6. Recommended waste management during COVID-19 [36].

2.2. NO_2 emissions

Without the global pandemic, we had naively anticipated that in 2020 global emissions would rise by around 1% on a five-year basis. Instead, the sharp decline in economic activity in response to the current crisis will most probably lead to a modest drop in global greenhouse emissions. The European Space Agency (ESA), with its head office in Paris, France, is an intergovernmental body made up of 22 European countries committed to exploring the international space. To monitor air pollution in the atmosphere, the ESA uses the Copernicus Sentinel-5P Satellite. In addition to the compound contents measurement, the Copernicus Sentinel-5P troposphere monitor (TROPOMI) and other specified precision equipment measure ozone content, sulphur dioxide, carbon monoxide, and methane. Table 1 shows NO_2 emissions data acquisition by ESA using Sentinel-5P across different regions of Europe [37].

Table 1. NO_2 emissions data acquisition by ESA using Sentinel-5P across different regions of Europe [37].

Country	**Initial data**	**Final data**	**% reduction**
Europe	March 2019	March 2020	Up to 30%
Italy	March 2019	March 2020	Up to 30%
France	March 2019	March 2020	Up to 30%
Spain	March 2019	March 2020	Up to 30%
UK	January 2020	March 2020	Up to 36%

Burning fossil fuels, such as coal, oil, gas and other fuels, is the source of atmospheric nitrogen dioxide [38]. The bulk of the NO_2 in cities, however, comes from emissions from motor vehicles (approximately 80%). Other NO_2 sources include petroleum and metal refining, coal-fired electricity, other manufacturing and food processing industries. Some NO_2 is naturally produced by lightning in the atmosphere and from the soil, water, and plants, which, taken together, constitutes not even 1% of the total NO_2 found in the air of our localities. Due to pollution variations as well as changes in weather conditions, the levels of the NO_2 in our atmosphere differ widely every day. Anthropogenic pollution is estimated to contain around 53 million tonnes of NO_2 annually. Nitrogen dioxide, together with nitrogen oxide (NO), are considered the major components of oxides of nitrogen (NOx) [39, 40]. NO, and NO_2 are susceptible to other chemicals and form acid rain that is toxic to the environment [41, 42], WHO lists NO_2 as one of the six typical air contaminants in the atmosphere. For this reason, the amount of NO_2 in the atmosphere is used as a precise measure for determining whether the COVID-19 outbreak affects environmental pollution.

NO_2 is an irritating reddish-brown gas with an unpleasant smell, and when cooled or compressed, it becomes a yellowish-brown liquid [7]. NO_2 inflames the lung linings and can decrease lung infection immunity. High levels of NO_2 in the air we breathe can corrode our body's lung tissues. Nitrogen dioxide is a problematic air pollutant because it leads to brown photochemical smog formation, which can have significant impacts on human health. Brief exposure to high concentrations of NO_2 can lead to respiratory symptoms such as coughing, wheezing, bronchitis, flu, etc., and aggravate respiratory illnesses such as asthma. Increased NO_2 levels can have major effects on individuals with asthma, sometimes leading to frequent and intense attacks [38]. Asthmatic children and older individuals with cardiac illness are most vulnerable in this regard. However, its main drawback is that it produces two of the most harmful air pollutants, ozone and airborne particles. Ozone gas affects our lungs and the crops we eat.

2.2.1 NO_2 emissions across different countries

According to the ESA [43], average levels of NO_2 declined by 40% between 13th March 2020 to 13th April 2020. The reduction was 55% compared to the same period in 2019. Figure 7 compares the 2019-2020 NO_2 concentration [43]. The displayed satellite image was captured with the TROPOMI by ESA satellite Sentinel-5P. The percentage reductions in average NO_2 emissions in European countries during the COVID-19 outbreak from 1st April to 30th April 2020 can be seen in Figure 8 [44]. Portugal, Spain, Norway, Croatia, France, Italy, and Finland are the countries that experienced the largest decrease in NO_2 levels, with 58%, 48%, 47%, 43% and 41%, respectively.

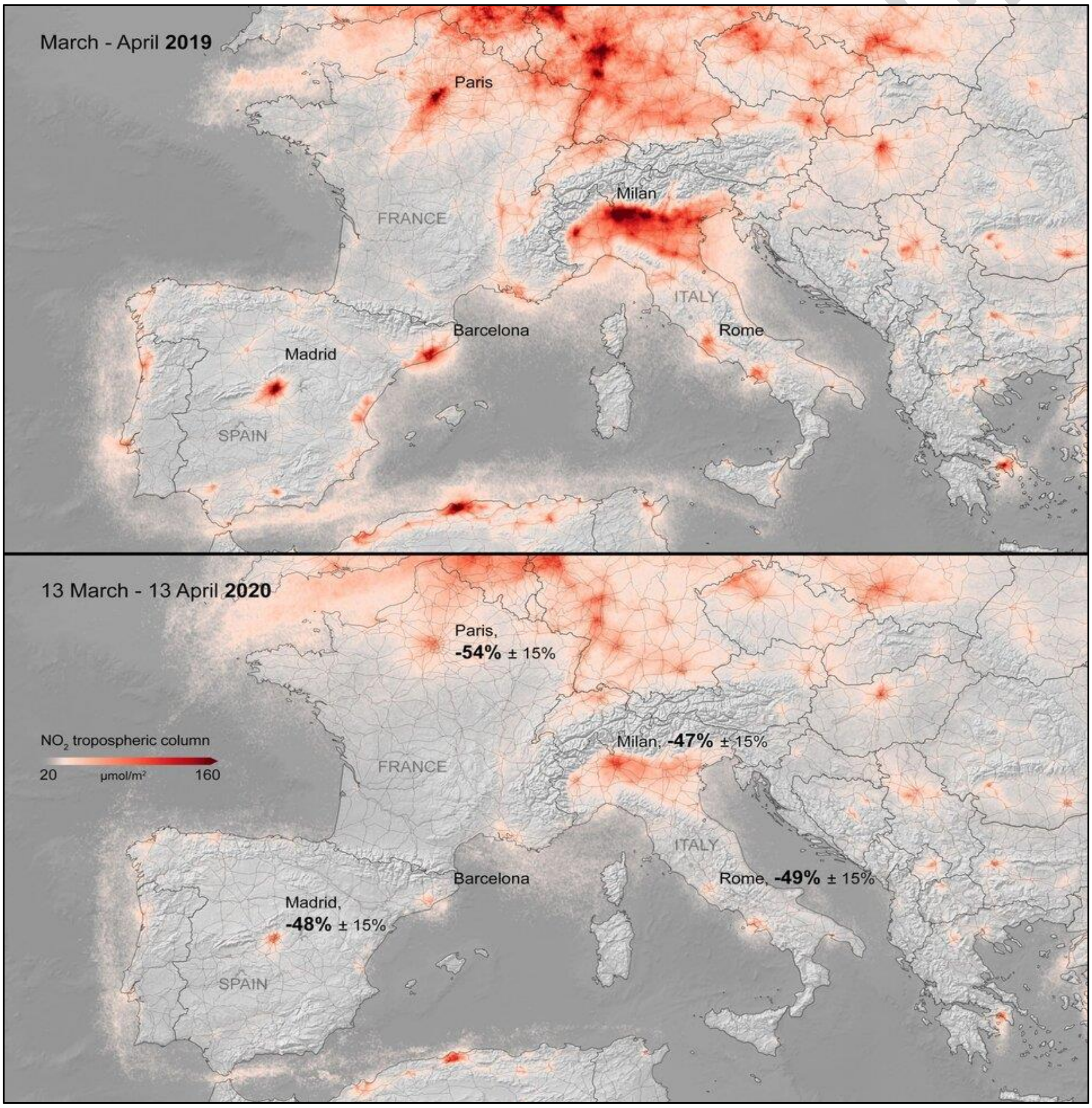


Figure 7. Comparison of the NO_2 concentration between 2019 and 2020 in Europe [43].

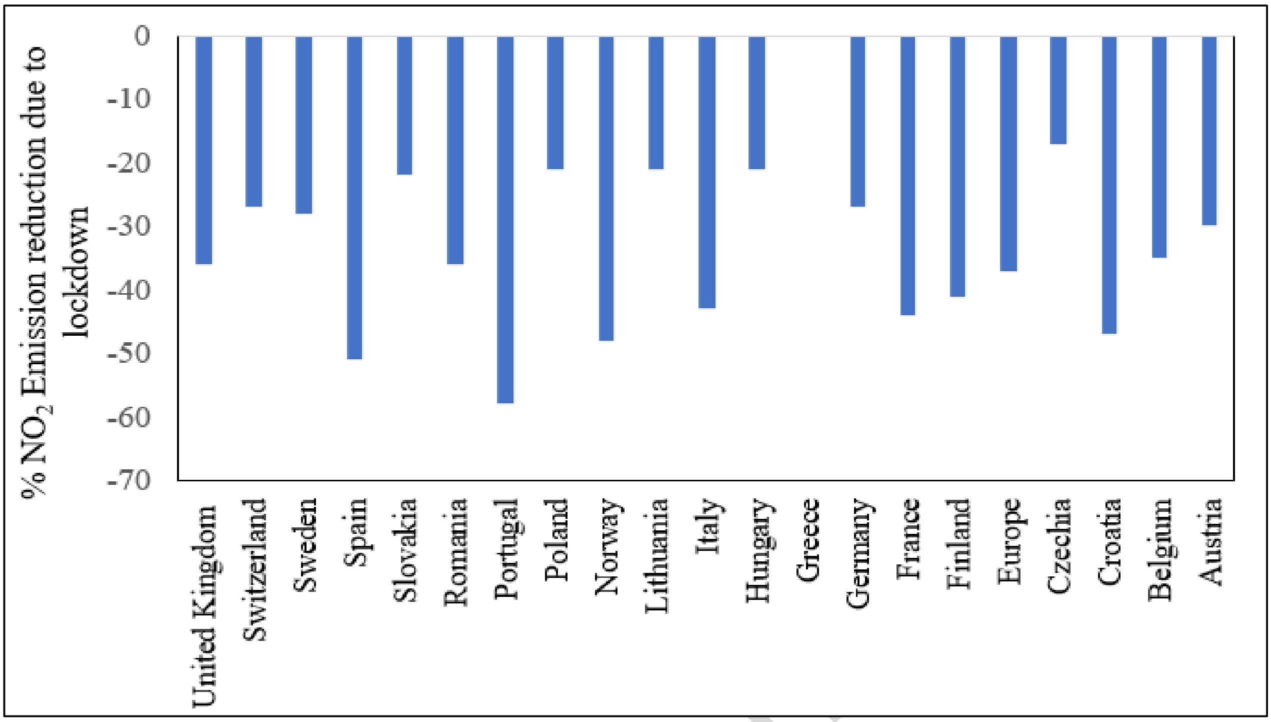
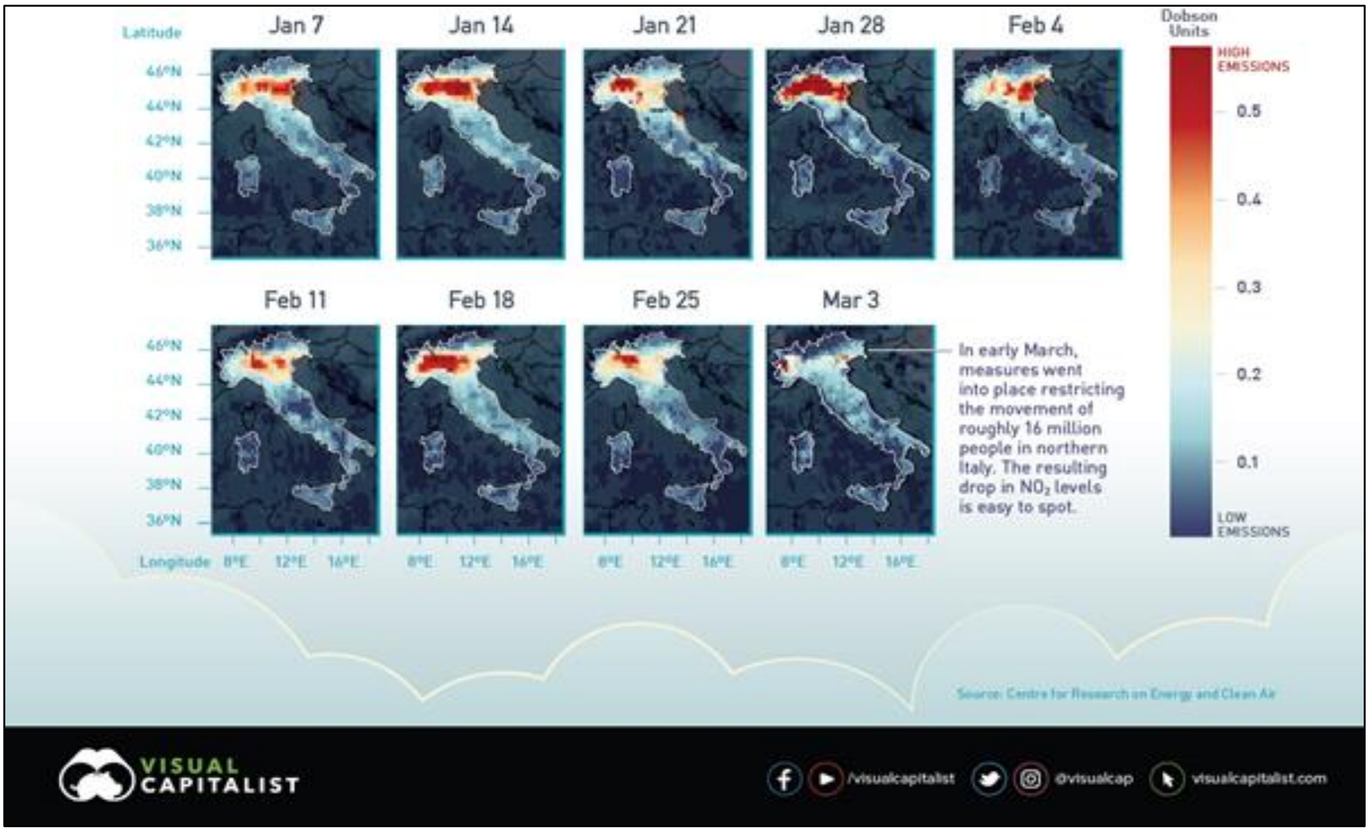
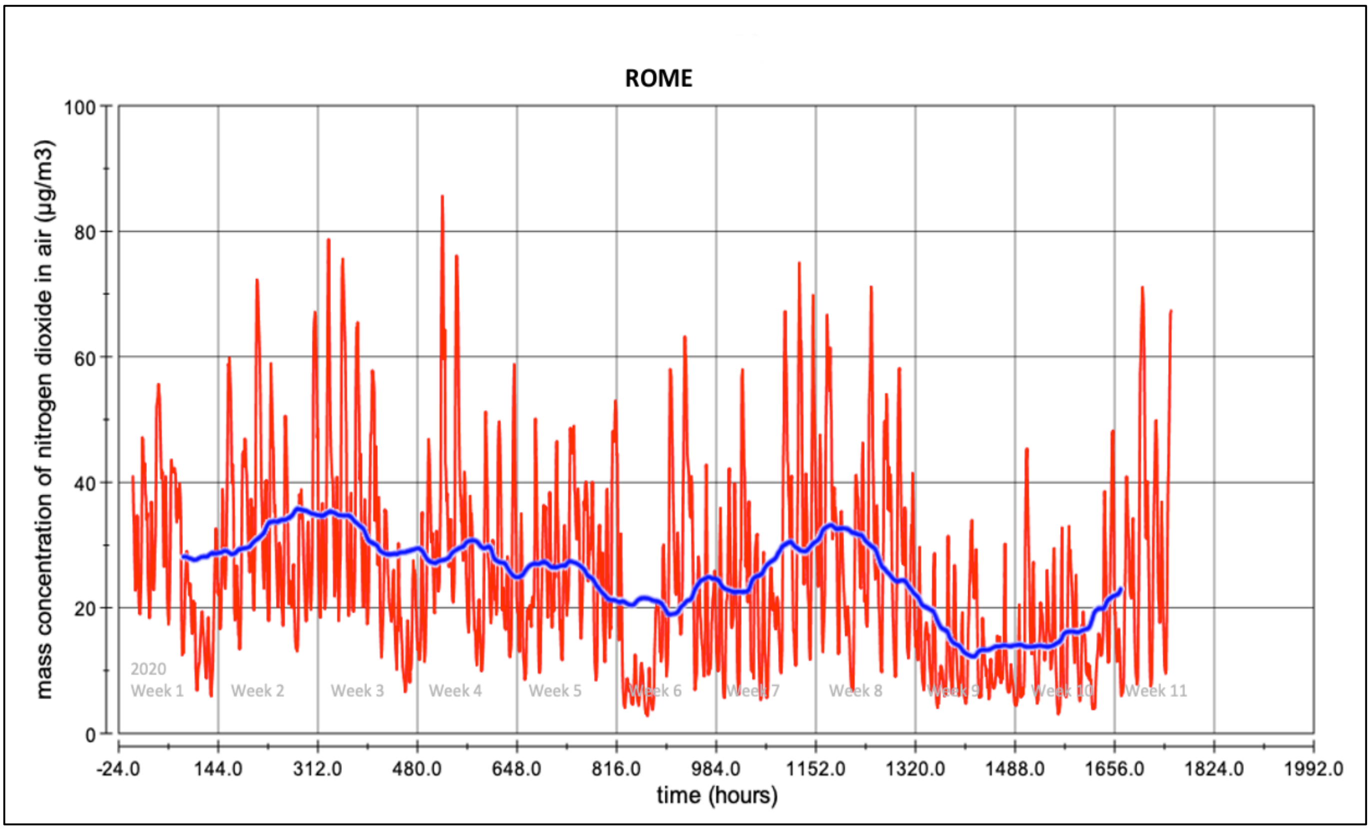


Figure 8. Changes in average NO_2 emission in different countries [44].

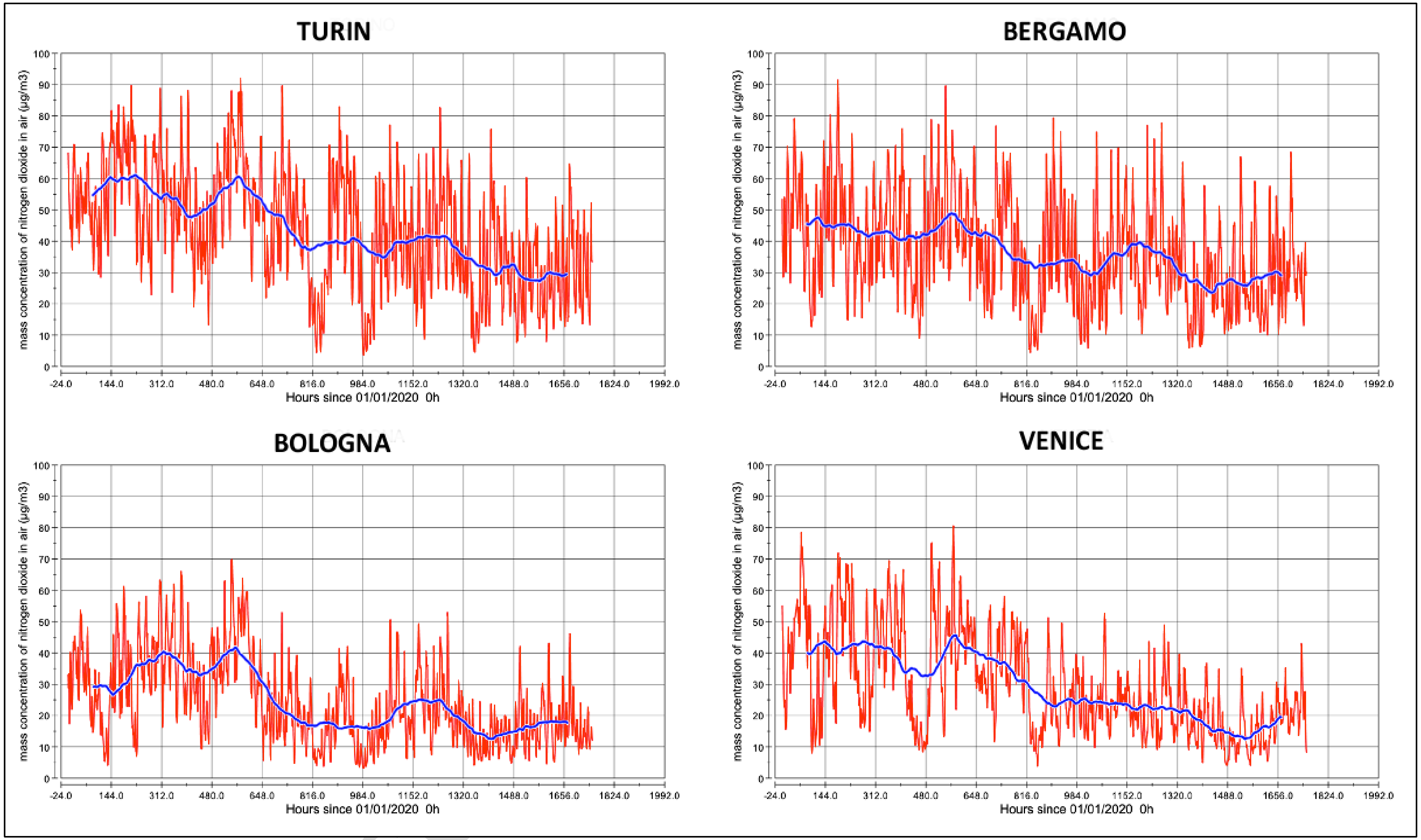
The average 10-day animation of NO_2 emissions throughout Europe (from 1st January to 11th March 2020), demonstrated the environmental impact of Italy's economic downturn, see Figure 9 [43]. In the recent four weeks (Last week of February 2020 to the third week of March 2020) the average concentration of NO_2 in Milan, Italy, has been at least 24% less than the previous four weeks. In the week of 16 – 22 March, the average concentration was 21% lower than in 2019 for the same week. Over the last four weeks of January 2020, NO_2 emissions in Bergamo city has been gradually declining. During the week of 16–22 March, the average concentration was 47% less than in 2019. In Rome, NO_2 rates were 26–35% lower than average in the last four weeks (third week of January 2020 to the third week of February 2020) than they were during the same week of 2019 [45].


Jan 7
Jan 14
Jan 21
Jan 28
Feb 4
Feb 11
Feb 18
Feb 25
Mar 3
Latitude
46°N
44°N
42°N
40°N
38°N
36°N
Longitude
8°E
12°E
16°E
Dobson Units
HIGH EMISSIONS
0.5
0.4
0.3
0.2
0.1
LOW EMISSIONS
In early March, measures went into place restricting the movement of roughly 16 million people in northern Italy. The resulting drop in NO₂ levels is easy to spot.
Source: Centre for Research on Energy and Clean Air
VISUAL CAPITALIST
/visualcapitalist
@visualcap
visualcapitalist.com

(a)


ROME
mass concentration of nitrogen dioxide in air (μg/m3)
0
20
40
60
80
100
2020
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
-24.0
144.0
312.0
480.0
648.0
816.0
984.0
1152.0
1320.0
1488.0
1656.0
1824.0
1992.0
time (hours)

(b)



(c)

Figure 9. Changes of NO_2 emission (a) over entire Italy (b) capital city (c) other cities [43, 45].

Figure 10 shows a comparison of NO_2 volumes in Spain in March 2019 and 2020. As per [43], Spain's NO_2 pollutants decreased by up to 20–30% due to lockdown, particularly across big cities like Madrid, Barcelona, and Seville. ESA Sentinel-5P captured the satellite image using TROPOMI. Satellite images of the 10 days between 14th and 25th March 2020 show that NO_2 tropospheric concentration in the areas of Madrid, Barcelona, Valencia, and Murcia ranges from 0–90 mg/m^3. The NO_2 tropospheric concentration for Seville is almost 0 mg/m^3 for the same time. For March 2019, the average NO_2 tropospheric concentration for the Madrid area was between 90 and 160 mg/m^3. At the same time, the range of NO_2 tropospheric concentration for Barcelona, Valencia, and Seville area was between 90–140 mg/m^3, 90-130 mg/m^3, and 30–50 mg/m^3, respectively.

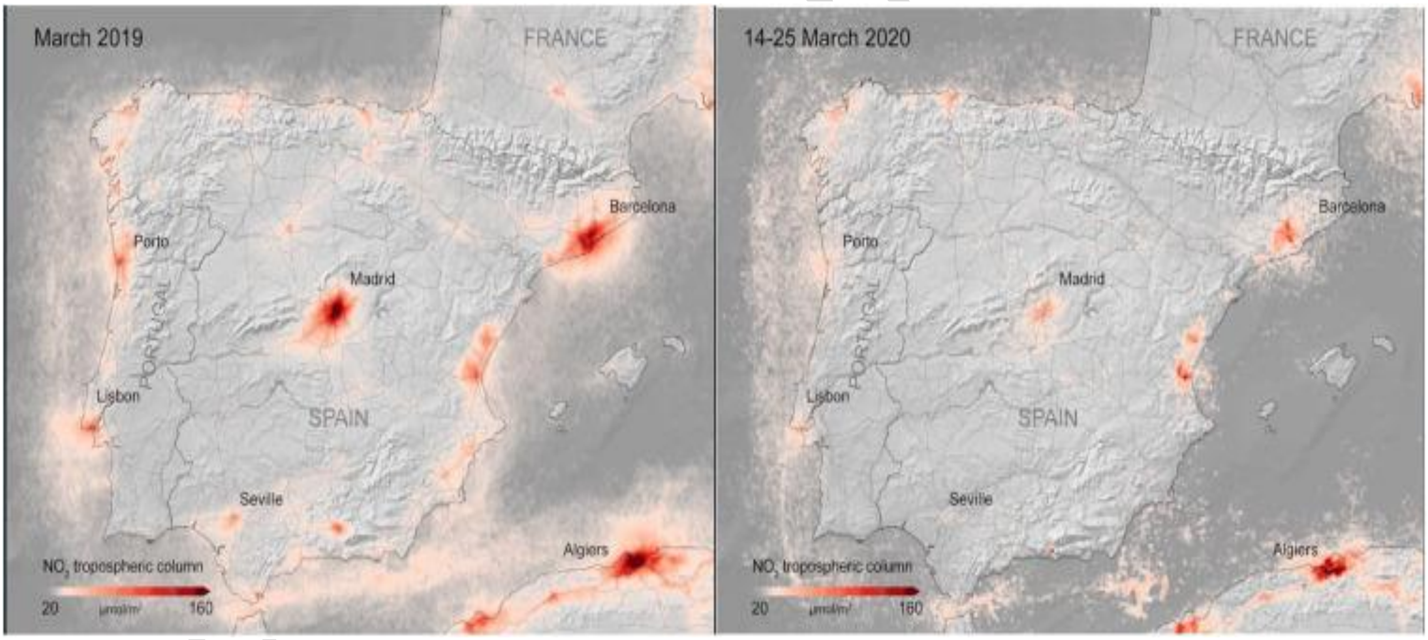


Figure 10. Comparison between before and after lockdown NO_2 emissions in Spain [43].

Figure 11 shows the reduction in the amount of NO_2 emissions in France in March 2019 and 2020 [43]. In France, levels of NO_2 have been reduced by 20% to 30%. The ESA Sentinel-5P satellite image was captured with the TROPOMI. In Paris and other major cities, the emission levels of NO_2 considerably lowered due to lockdown. The three major areas of France where NO_2 tropospheric concentration was significant are Paris, Lyon, Marseille and their surroundings. Satellite images of the ten days between 14^{th} and 25^{th} March 2020 show that NO_2 tropospheric concentration of the Paris, Lyon, Marseille areas ranges 30–90 mg/m^3, 20–40 mg/m^3 and 40–80 mg/m^3, respectively. For March 2019, the average NO_2 tropospheric concentration for the same areas was reported as 100–160 mg/m^3, 30–60 $mg/m^{3,}$ and 90–140 mg/m^3, respectively.

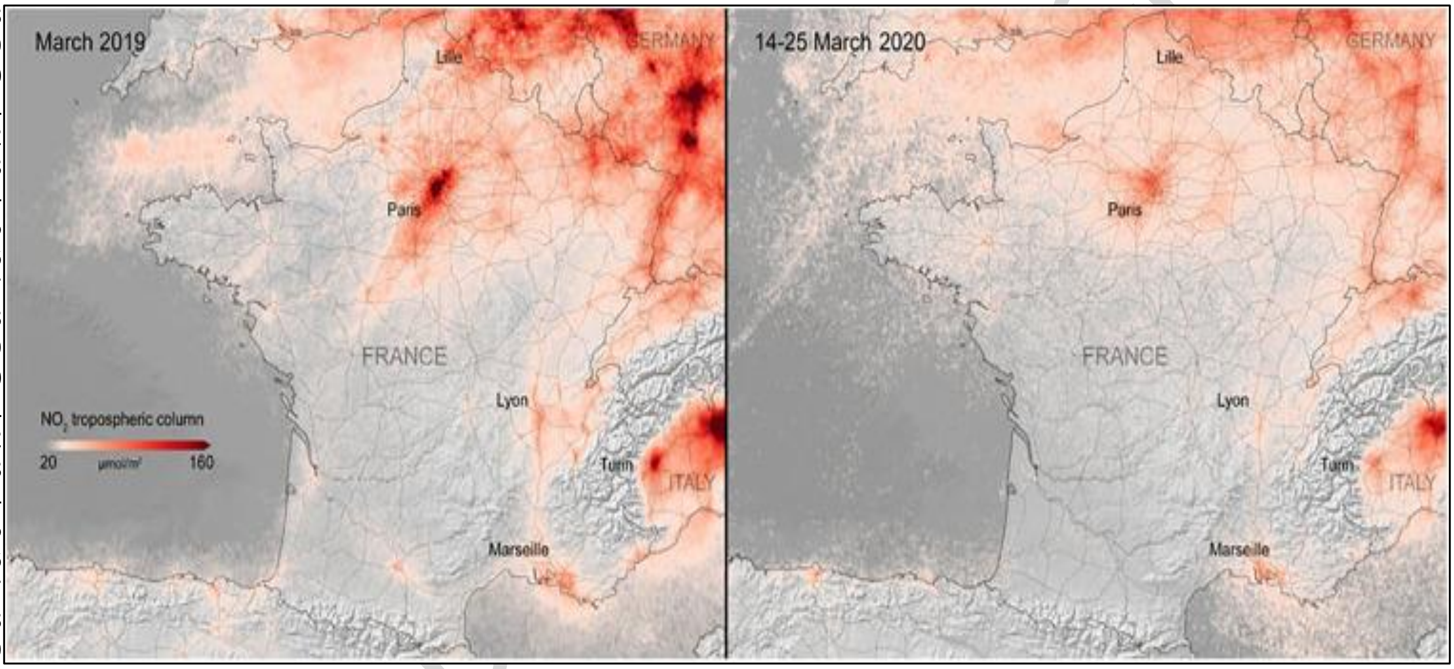
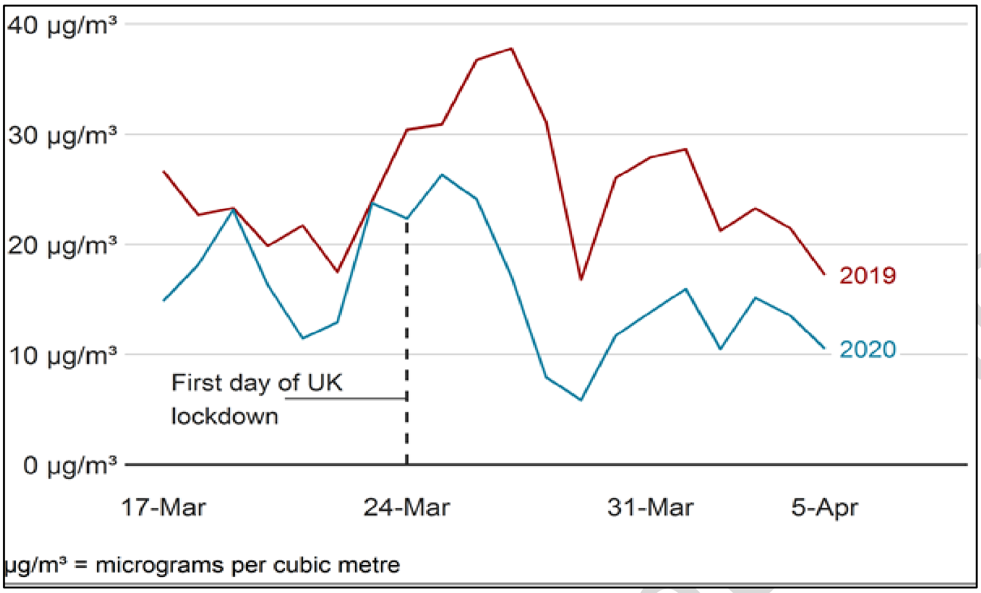
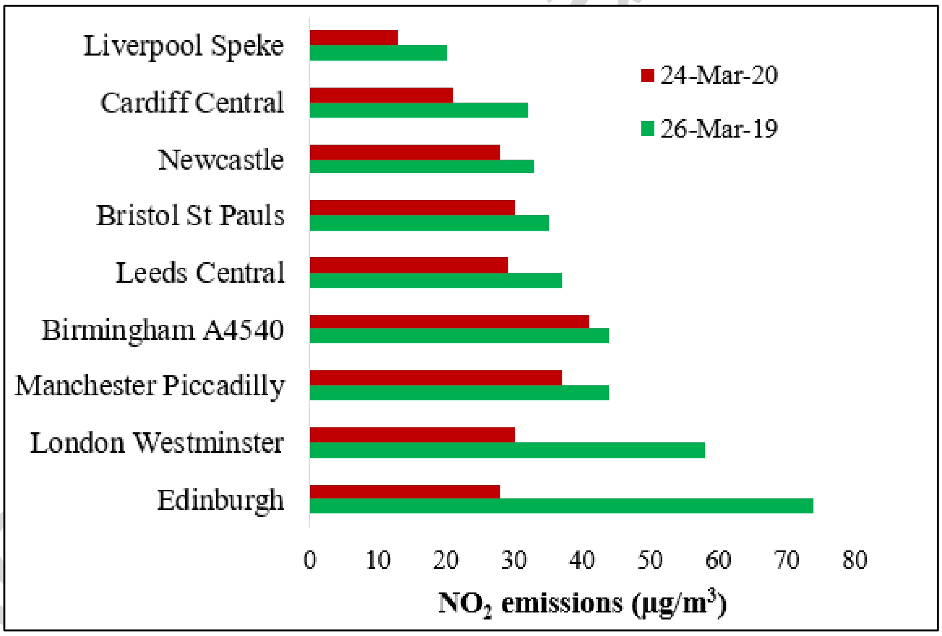


Figure 11. Comparison of NO_2 emissions in France before and after lockdown [43].

Various industries across the UK have been affected by COVID-19, which has influenced air contamination. As shown in Figure 12, there were notable drops in the country's NO_2 emissions on the first day of quarantine [46]. Edinburgh showed the most significant reduction. The average NO_2 emissions on 26^{th} March 2020, were 28 $\mu g/m^3$ while on the same day of 2019, this was 74 $\mu g/m^3$ [46]. The second biggest reduction was observed in London Westminster where emissions reduced from 58 $\mu g/m^3$ to 30 $\mu g/m^3$. Not all cities have seen such a significant decrease, with daily air pollution reducing by 7 μg/m^3 compared to the previous year in Manchester Piccadilly, for example [47].



(a)



(b)

Figure 12. (a) Changes in NO_2 emissions in the UK during lockdown [43]; (b) comparison of NO_2 emissions in 2019 and 2020 [46].

2.3. PM emission

The term particulate matter, referred to as PM, is used to identify tiny airborne particles. PM forms in the atmosphere when pollutants chemically react with each other. Particles include pollution, dirt, soot, smoke, and droplets. Pollutants emitted from vehicles, factories, building sites, tilled areas, unpaved roads and the burning of fossil fuels also contribute to PM in the air [48]. Grilling food (by burning leaves or gas grills), smoking cigarettes, and burning wood on a fireplace or stove also contribute to PM. The aerodynamic diameter is considered a simple way to describe PM's particle size as these particles occur in various shapes and densities. Particulates are usually divided into two categories, namely, PM_{10} that are inhalable particles with a diameter of 10 µm or less and $PM_{2.5}$ which are fine inhalable particle with a diameter of 2.5 µm or less. $PM_{2.5}$ exposure causes relatively severe health problems such as non-fatal heart attacks, heartbeat irregularity, increased asthma, reduced lung function, heightened respiratory symptoms, and premature death [49].

$PM_{2.5}$ also poses a threat to the environment, including lower visibility (haze) in many parts of the globe. Particulates can be transported long distances then settle on the ground or in water sources. In these contexts and as a function of the chemical composition, $PM_{2.5}$ may cause acidity in lakes and stream water, alter the nutrient balance in coastal waters and basins, deplete soil nutrients and damage crops on farms, affect the biodiversity in the ecosystem, and contribute to acid rain. This settling of PM, together with acid rain, can also stain and destroy stones and other materials such as statues and monuments, which include valuable cultural artefacts [50].

2.3.1. PM emission in different countries

Due to the COVID-19 outbreak, PM emission in most countries has been reduced [51-55]. Figure 13 shows the impact of COVID19 on PM emission in a number of some countries around the world [44]. The largest reductions in PM pollution took place in Portugal, with 55%, followed by Norway, Sweden, and Poland with reductions of 32%, 30%, and 28%, respectively. Spain, Poland, and Finland recorded PM emission reductions of 19%, 17% and 16%, respectively. Both Romania and Croatia recorded no changes in PM level, with Switzerland and Hungary recording about a 3% increase in PM emission.

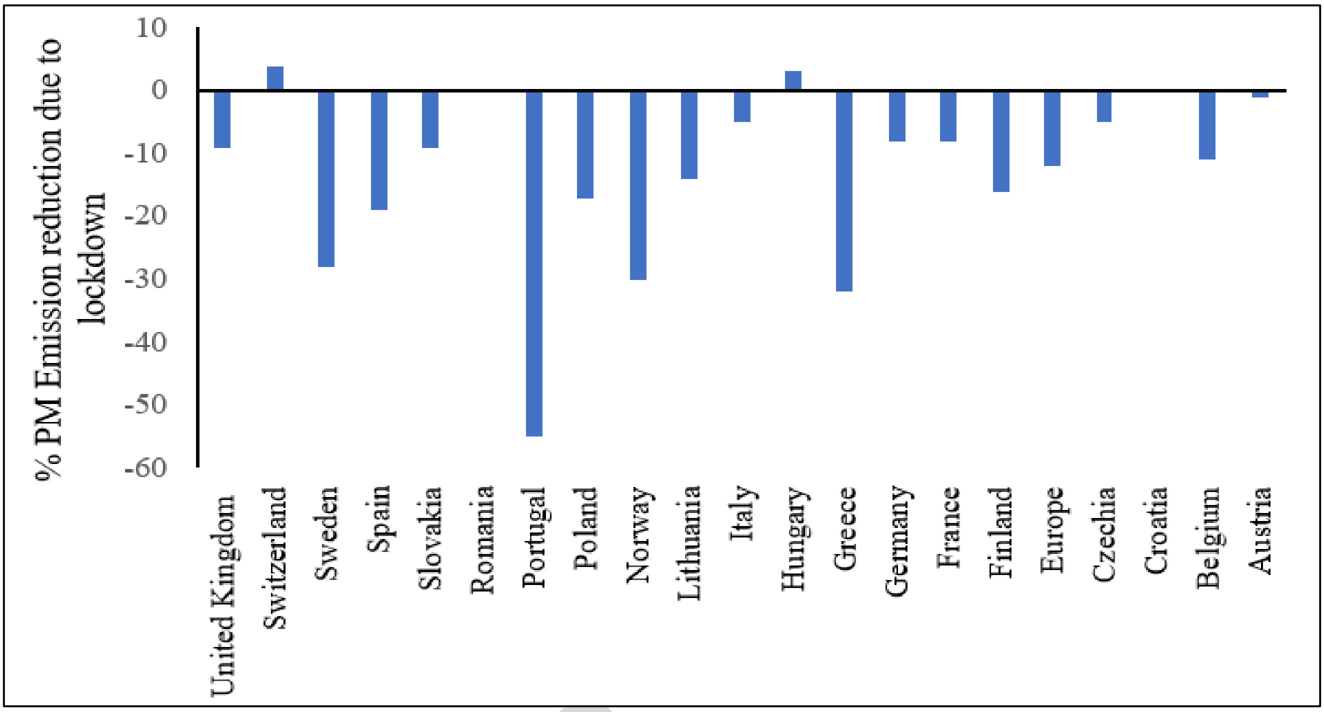


Figure 13. Reduction of PM emission in different countries [44].

PM emissions have been significantly reduced during the epidemic in most regions of Italy. Figure 14 illustrates the changes in COVID-19 containment emissions before and after a lockdown in major cities in Italy. According to a recent study by Sicard et al. [56], lockdown interventions have had a greater effect on PM emission. They found that confinement measures reduce PM_{10} emissions in all major cities by “around 30% to 53%” and “around 35% to 56%”.

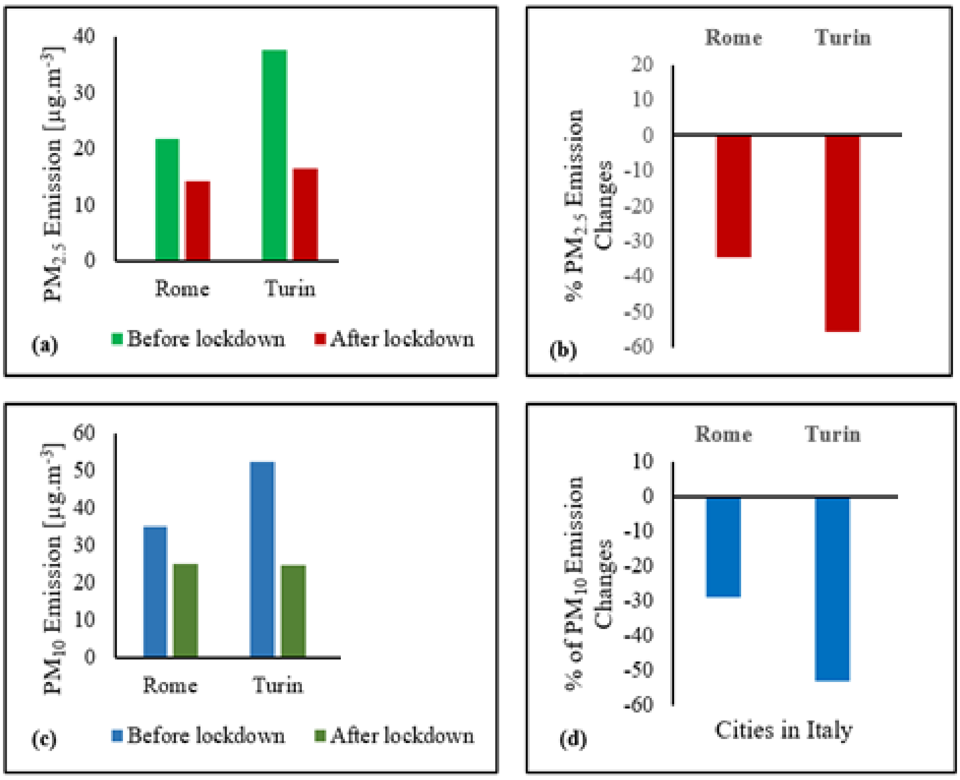


Figure 14. Comparison of PM emission in Italy (a) $PM_{2.5}$ emission (b) Changes of $PM_{2.5}$ emission (c) PM_{10} emission (d) Changes of PM_{10} emission [56].

2.4. Noise emission

Noise is characterised as an undesirable sound that may be produced from different activities, e.g. transit by engine vehicles and high volume music. Noise can cause health problems and alter the natural condition of ecosystems. It is among the most significant sources of disruption in people and the environment [57]. The European Environment Agency (EEA) states that traffic noise is a serious environmental problem that negatively affects the health and security of millions of citizens in Europe. The consequences of long-term exposure to noise include sleep disorders, adverse effects on the heart and metabolic systems, and cognitive impairment in children. The EEA estimates that noise pollution contributes to 48,000 new cases of heart disease and 12,000 early deaths per year. They also reported chronic high irritation for 22 million people and a chronic high level of sleep disorder for 6.5 million people [58].

Most governments have imposed quarantine measures that require people to spend much more time at home. This has considerably reduced the use of private and public transport. Commercial activities have almost completely stopped. In most cities in the world, these changes have caused a significant decline in noise levels. This was followed by a significant decline in pollution from contaminants and greenhouse gas emissions. Noise pollution from sources like road, rail or air transport has been linked to economic activity. Consequently, we anticipate that the levels of transport noise will decrease significantly due to the decreased demand for mobility in the short term [59].

For example, it was obvious that environmental noise in Italy was reduced after 8th March 2020 (the lockdown start date) due to a halt in commercial and recreational activities. A seismograph facility in Lombardy city in Italy that was severely affected by the COVID-19 pandemic indicated how the quarantine measures reduce both traffic and noise emissions. The comparison of the 24-hour seismic noise data before and after the lockdown period indicates a considerable drop in environmental noise in Italy [60].

3. Impact of COVID-19 on the socio-economic domain

COVID-19 has created a global health crisis where countless people are dying, human suffering is spreading, and people's lives are being upended [61]. It is not only just a health crisis but also a social and economic crisis, both of which are fundamental to sustainable development [17]. On 11th March 2020, when WHO declared a global pandemic, 118,000 reported cases spanning 114 countries with over 4,000 fatalities had been reported. It took 67 days from the first reported case to reach 100,000 cases, 11 days for the second 100,000, and just four days for the third [62]. This has overwhelmed the health systems of even the richest countries with doctors being forced to make the painful decision of who lives and who dies. The COVID-19 pandemic has pushed the world into uncertainty and countries do not have a clear exit strategy in the absence of a vaccine. This pandemic has affected all segments of society. However, it is particularly damaging to vulnerable social groups, including people living in poverty, older persons, persons with disabilities, youths, indigenous people and ethnic minorities. People with no home or shelter such as refugees, migrants, or displaced persons will suffer disproportionately, both during the pandemic and in its aftermath. This might occur in multiple ways, such as experiencing limited movement, fewer employment opportunities, increased xenophobia, etc. The social crisis created by the COVID-19 pandemic may also increase inequality, discrimination and medium and long-term unemployment if not properly addressed by appropriate policies.

The protection measures taken to save lives are severely affecting economies all over the world. As discussed previously, the key protection measure adopted universally is the lockdown, which has forced people to work from home wherever possible. Workplace closures have disrupted supply chains and lowered productivity. In many instances, governments have closed borders to contain the spread. Other measures such as travel bans and the prohibition of sporting events and other mass gatherings are also in place. In addition, measures such as discouraging the use of public transport and public spaces, for example, restaurants, shopping centres and public attractions are also in place in many parts of the world. The situation is particularly dire in hospitality-related sectors and the global travel industry, including airlines, cruise companies, casinos and hotels which are facing a reduction in business activity of more than 90% [63]. The businesses that rely on social interactions like entertainment and tourism are suffering severely, and millions of people have lost their jobs. Layoffs, declines in personal income, and heightened uncertainty have made people spend less, triggering further business closures and job losses [64].

A key performance indicator of economic health is Gross Domestic Product (GDP), typically calculated on a quarterly or annual basis. IMF provides a GDP growth estimate per quarter based on global economic developments during the near and medium-term. According to its estimate, the global economy is projected to contract sharply by 3% in 2020, which is much worse than the 2008 global financial crisis [65]. The growth forecast was marked down by 6% in the April 2020 World Economic Outlook (WEO) compared to that of the October 2019 WEO and January 2020 WEO. Most economies in the advanced economy group are expected to contract in 2020, including the US, Japan, the UK, Germany, France, Italy and Spain by 5.9%, 5.4%, 6.5%, 7.0%, 7.2%, 9.1%, and 8.0% respectively. Figure 15a shows the effect of COVID-19 on the GDP of different countries around the globe. On the other hand, economies of emerging market and developing economies, excluding China, are projected to contract by only 1.0% in 2020. The economic recovery in 2021 will depend on the gradual rolling back of containment efforts in the latter part of 2020 that will restore consumer and investor confidence. According to the April 2020 WEO, the level of GDP at the end of 2021 in both advanced and emerging market and developing economies is expected to remain below the pre-virus baseline (January 2020 WEO Update), as shown in Figure 15b.

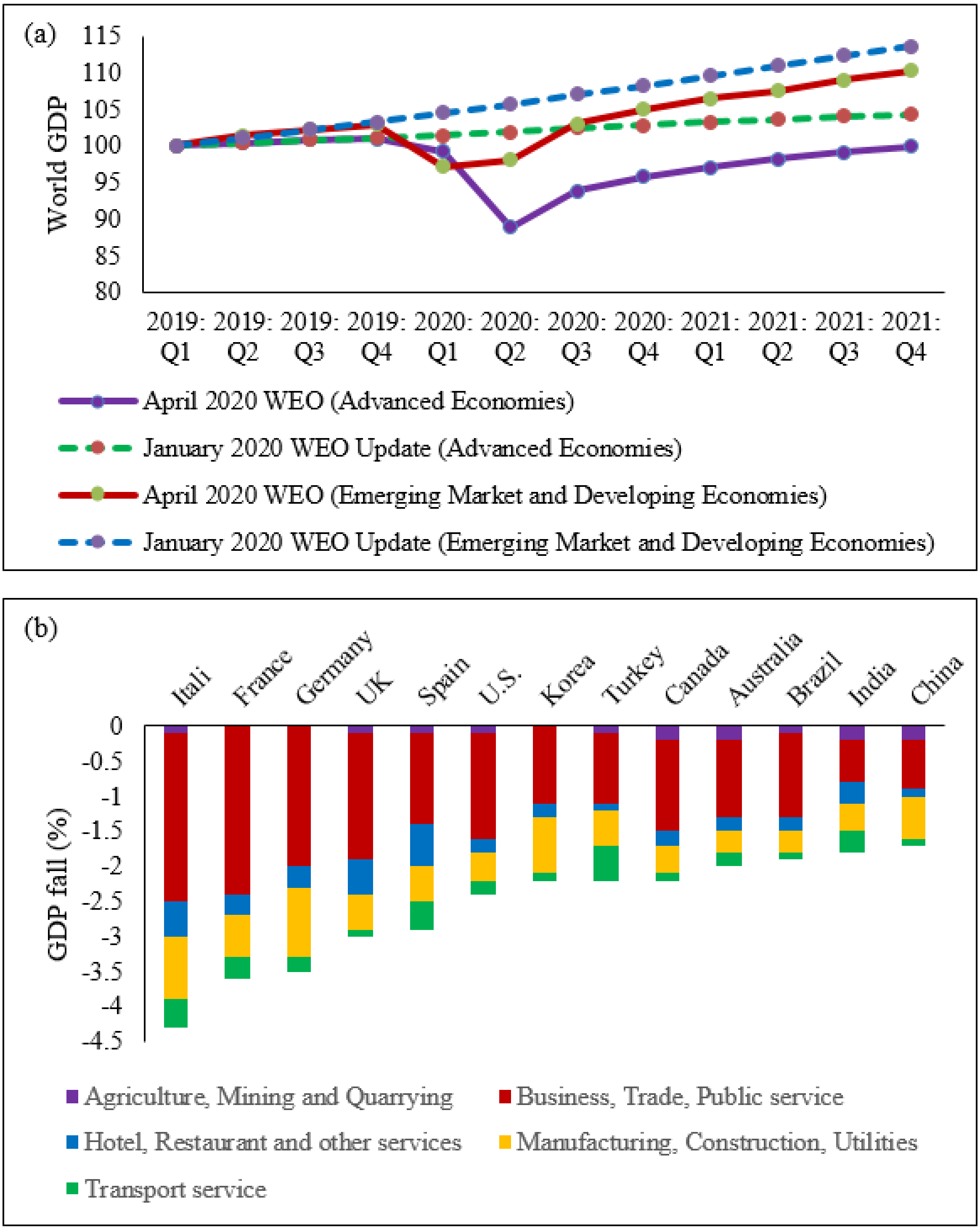


Figure 15. (a) Quarterly World GDP. 2019:Q1 =100, dashed line indicates estimates from January 2020 WEO; (b) GDP fall due to lockdown in selected countries.

A particular example of a country hardest hit by COVID-19 is Italy. During the early days of March, the Italian government imposed quarantine orders in major cities that locked down more than seventeen million people [66]. The mobility index data by Google for Italy shows there has been a significant reduction in mobility (and therefore economic activity) across various facets of life. The reported decline of mobility in retail and recreation, grocery and pharmacy, transit stations and workplaces were 35%, 11%, 45% and 34% respectively [67]. The Italian economy suffered great financial damage from the pandemic. The tourism, and hospitality sectors were among those most severely affected by foreign countries prohibiting travel to and from Italy, and by the government's national lockdowns in early March [68]. A March 2020 study in Italy showed that about 99% of the companies in the housing and utility sector said the epidemic had affected their industry. In addition, transport and storage was the second most affected sector. Around 83% of companies operating in this sector said that their activities had been affected by the coronavirus [69] pandemic. In April 2020, Italian Minister Roberto Gualtieri estimated a 6% reduction in the GDP for the year 2020 [70]. The government of Italy stopped all unnecessary companies, industries and economic activities on 21st March 2020. Therefore The Economist estimates a 7% fall in GDP in 2020 [71]. The Economist predicted that the Italian debt-to-GDP ratio would grow from 130% to 180% by the end of 2020 [68] and it is also assumed that Italy will have difficulty repaying its debt [70].

4. Impact of COVID-19 on the energy domain

COVID-19 has not only impacted health, society and the economy but it has also had a strong impact on the energy sector [72, 73]. World energy demand fell by 3.8% in the first quarter (Q1) of 2020 compared with Q1 2019. In Q1 of 2020, the global coal market was heavily impacted by both weather conditions and the downturn in economic activity resulting in an almost 8% fall compared to Q1 2019. The fall was primarily in the electricity sector as a result of substantial declines in demand (-2.5%) and competitive advantages from predominantly low-cost natural gas. The market for global oil has plummeted by almost 5%. Travel bans, border closures, and changes in work routines significantly decreased the demand for the use of personal vehicles and air transport. Thus rising global economic activity slowed down the use of fuel for transportation [74]. In Q1 2020, the output from nuclear energy plants decreased worldwide, especially in Europe and the US, as they adjusted for lower levels of demand. Demand for natural gas dropped significantly, by approximately 2% in Q1 2020, with the biggest declines in China, Europe, and the United States. In the Q1 2020, the need for renewable energy grew by around 1.5%, driven in recent years by the increasing output of new wind and solar plants. Renewable energy sources substantially increased in the electricity generation mix, with record hourly renewable energy shares in Belgium, Italy, Germany, Hungary, and East America. The share of renewable energy sources in the electricity generation mix has increased. Table 2 shows the effect of COVID-19 outbreak on the energy demand around the world.

Table 2. Impact of COVID-19 on global energy sector [28, 75-80].

Country	Lockdown start	Lockdown end	Energy demand
Australia	23rd March 2020	15th May 2020 (Stage 1, for NSW)	NSW: Weekday: 8%–10%↓ (morning) 6%–8%↓ (afternoon) Weekend: 5%–6%↓ (most of the day)
Belgium	18th March 2020	19th April 2020	Substantial ↓ in the industrial and commercial load of 70%
China	23rd January 2020	8th April 2020	8%↓ (Jan & Feb compared to the same time in 2019)
France	17th March 2020	11th May 2020	6%–12%↓ (electricity demand)
Germany	20th March 2020	20th April 2020	4%–6% ↓ (electricity demand)
India	25th March 2020	4th May 2020	30%↓
Italy	9th March 2020	4th May 2020	10.1%↓ (March) 22%↓(from 22nd March)
Portugal	13th March 2020	11th April 2020	Overall energy demand ↓

Singapore	7th April 2020	1st June 2020	8%–9%↓
Spain	14th March 2020	25th April 2020	3%↓ (March) 20%↓ (April), 72%↑ (PV generation)
Netherlands	16th March 2020	28th April 2020	Overall energy demand ↓
UK	24th March 2020	11th May 2020	10%↓ (after 23rd March)
US	20th March 2020	29th April 2020	4.2% ↓ (retail sales of electricity)

Different areas have implemented lockdown of various duration. Therefore, regional energy demand depends on when lockdowns were introduced and how lockdowns influence demand in each country. In Korea and Japan, the average impact on demand is reduced to less than 10%, with lower restrictions. In China, where the first COVID-19 confinement measures were introduced, not all regions faced equally stringent constraints. Nevertheless, virus control initiatives have resulted in a decline of up to 15% in weekly energy demand across China. In Europe, moderate to complete lockdowns were more radical. On average, a 17% reduction in weekly demand was experienced during temporary confinement periods. India's complete lockdown has cut energy requirements by approximately 30%, which indicates yearly energy needs are lowered by 0.6% for each incremental lockdown week [21].

The International Energy Agency (IEA) has predicted an annual average decline in oil production of 9% in 2020, reflecting a return to 2012 levels. Broadly, as electricity demand has decreased by about 5% throughout the year, coal production may fall by 8%, and the output of coal-fired electricity generation could fall by more than 10%. During the entire year, gas demand may fall far beyond Q1 2020 due to a downward trend in power and industrial applications. Nuclear energy demand will also decrease in response to reduced electricity demand. The demand for renewable energies should grow due to low production costs and the choice of access to many power systems. Khan et al. [81] reported that international trade is significantly and positively dependent on renewable energy. In addition, sustainable growth can be facilitated through the consumption of renewable energy which improves the environment, enhances national image globally and opens up international trade opportunities with environmentally friendly countries [82]. As such, policies that promote renewables can result in economic prosperity, create a better environment as well as meet critical goals for sustainable development [83].

5. Preventive measures to control COVID-19 outbreak

COVID-19 is a major crisis needing an international response. Governments will ensure reliable information is provided to assist the public in combating this pandemic. Community health and infection control measures are urgently needed to reduce the damage done by COVID-19 and minimise the overall spread of the virus. Self-defence techniques include robust overall personal hygiene, face washing, refraining from touching the eyes, nose or mouth, maintaining physical distance and avoiding travel. In addition, different countries have already taken preventive measures, including the implementation of social distancing, medicine, forestation and a worldwide ban on wildlife trade. A significant aim of the community health system is to avoid SARS-CoV-2 transmission by limiting large gatherings. COVID-19 is transmitted by direct communication from individual to individual. Therefore, the key preventive technique is to limit mass gatherings. Table 3 shows the impact of lockdown measures on the recovery rate of COVID-19 infections. The baseline data for this table is the median value, for the corresponding day of the week, during the 5-week period 3rd January to 6th February 2020.

Table 3. Mobility Index Report of different countries [84-86].

Country	Total population	Mobility rate	Recovery rate	Total Cases	Total recovered
Argentina	45,195,774	-56%	42.63%	153,520	65,447
Australia	25,499,884	-41%	64.02%	13,948	8,929
Austria	9,006,398	-100%	89.11%	20,338	18,124
Belgium	11,589,623	-105%	26.68%	65,199	17,394
Brazil	212,559,417	-48%	67.81%	2,348,200	1,592,281
Canada	37,742,154	-67%	87.34%	113,206	98,873
Chile	19,116,201	-110%	91.91%	341,304	313,696

Colombia	50,882,891	-73%	48.76%	233,541	113,864
Czech Republic	10,708,981	-29%	62.48%	15,081	9,422
Denmark	5,792,202	-93%	91.83%	13,438	12,340
Finland	5,540,720	-93%	93.67%	7,388	6,920
France	65,273,511	-100%	44.77%	180,528	80,815
Germany	83,783,942	-99%	92.44%	205,968	190,400
Greece	10,423,054	-32%	33.23%	4,135	1,374
Hong Kong	7,496,981	-10%	59.29%	2,373	1,407
Hungary	9,660,351	-49%	75.14%	4,424	3,324
India	1,380,004,385	-65%	63.49%	1,339,176	850,303
Indonesia	273,523,615	-77%	56.90%	97,286	55,354
Ireland	4,937,786	-79%	90.40%	25,845	23,364
Israel	8,655,535	-31%	45.06%	59,475	26,797
Italy	60,461,826	-52%	80.70%	245,590	198,192
Japan	126,476,461	-33%	76.29%	27,956	21,328
Malaysia	32,365,999	-53%	96.74%	8,884	8,594
Mexico	128,932,753	-69%	64.16%	378,285	242,692
Netherlands	17,134,872	-97%	11.65%	52,837	6,158
New Zealand	4,822,233	-21%	97.24%	1,556	1,513
Norway	5,421,241	-100%	95.40%	9,092	8,674
Philippines	109,581,078	-87%	32.84%	78,412	25,752
Poland	37,846,611	-36%	76.06%	42,622	32,419
Portugal	10,196,709	-65%	69.80%	49,692	34,687
Singapore	5,850,342	-105%	90.55%	49,888	45,172
South Africa	59,308,690	-74%	58.24%	421,996	245,771
South Korea	51,269,185	-4%	91.30%	14,092	12,866
Spain	46,754,778	-67%	47.07%	319,501	150,376
Switzerland	8,654,622	-101%	88.92%	34,302	30,500
Taiwan	23,816,775	4%	96.07%	458	440
Thailand	69,799,978	-36%	94.73%	3,282	3,109
USA	331,002,651	-56%	47.74%	4,248,759	2,028,361
UK	67,886,011	-82%	0.48%	297,914	1,427
Vietnam	97,338,579	15%	87.53%	417	365

As of today, no COVID-19 vaccine is available. Worldwide scientists are racing against time to develop the COVID-19 vaccine, and WHO is now monitoring more than 140 vaccine candidates. As of 29th September 2020, about 122 candidates have been pre-clinically checked, i.e. determining whether an immune response is caused when administering the vaccine to animals [87]. About 45 candidates are in stage I where tests on a small number of people are conducted to decide whether it is effective [87]. About 29 candidates are in Phase II where hundreds of people are tested to assess additional health issues and doses [87]. Only 14 candidates are currently in Phase III, where thousands of participants are taking a vaccine to assess any final safety concerns, especially with regard to side effects [87]. 3 candidates are in Phase IV, where long-term effects of the vaccines on a larger population is observed [87]. The first generation of COVID-19 vaccines is expected to gain approval by the end of 2020 or in early 2021 [88]. It is anticipated that these vaccines will provide immunity to the population. These vaccines can also reduce the transmission of SARS-CoV-2 and lead to a resumption of a pre-COVID-19 normal. Table 4 shows the list of vaccines that have been passed in the pre-clinical stage. In addition, according to the COVID-19 vaccine and therapeutics tracker, there are 398 therapeutic drugs in development. Of these, 83 are in the pre-clinical phase, 100 in Phase I, 224 in Phase II, 119 in Phase III and 46 in Phase IV [87].

Table 4. List of vaccines that have passed the pre-clinical stage [87].

Name	**Organisation**	**Technology**	**Stage**	**Clinical Trial #**
Oral Polio Vaccine	Bandim Health Project	Repurposed	Phase IV	NCT04445428
Bacille Calmette-Guerin	Multiple Organisations	Repurposed	Phase III/IV	NCT04328441
Measles-Mumps-Rubella Vaccine	Multiple Organisations	Repurposed	Phase III	NCT04357028
IMM-101	Multiple Organisations	Repurposed	Phase III	NCT04442048
BACMUNE (MV130)	Inmunotek S.L., BioClever 2005 S.L.	Repurposed	Phase III	NCT04452643
mRNA-1273	Multiple Organisations	RNA-based vaccine	Phase I/II/III	NCT04283461
CoronaVac	Sinovac Biotech Co., Butantan Institute	Inactivated virus	Phase I/II/III	NCT04352608
AZD1222 (ChAdOx1 nCoV-19)	Multiple Organisations	Non-replicating viral vector	Phase I/II/III	NCT04324606
NasoVAX	Altimmune, Inc.	Repurposed	Phase II	NCT04442230
LV-SMENP-DC	Shenzhen Geno-Immune Medical Institute	Modified APC	Phase I/II	NCT04276896
Ad5-nCoV	Multiple Organisations	Non-replicating viral vector	Phase I/II	NCT04313127
INO-4800	Multiple Organisations	DNA-based	Phase I/II	NCT04336410

Unnamed Inactive Vaccine - Wuhan	Wuhan Institute of Biological Products, Sinopharm	Inactivated virus	Phase I/II	ChiCTR2000031809
BBIBP-CorV	Beijing Institute of Biological Products, Sinopharm	Inactivated virus	Phase I/II	ChiCTR2000032459
BNT162 (a1, b1, b2, c2)	Biontech RNA Pharmaceuticals GmbH, Pfizer	RNA-based vaccine	Phase I/II	EudraCT 2020-001038-36
KBP-COVID-19	Kentucky BioProcessing, Inc.	Protein subunit	Phase I/II	NCT04473690
LUNAR-COV19 (ARCT-021)	Arcturus Therapeutics, Inc., Duke-NUS	RNA-based vaccine	Phase I/II	NCT04480957
COVAC 1	Imperial College London, Morningside Ventures	RNA-based vaccine	Phase I/II	IRAS-Number: 279315
AG0301-COVID19	AnGes, Inc., Japan Agency for Medical Research and Development	DNA-based	Phase I/II	NCT04463472
V-SARS	Immunitor LLC	Inactivated virus	Phase I/II	NCT04380532
AV-COVID-19	Aivita Biomedical, Inc.	Modified APC	Phase I/II	NCT04386252
Unnamed Inactive Vaccine - Yunnan	Multiple Organisations	Inactivated virus	Phase I/II	NCT04412538
Gam-COVID-Vac	Gamaleya Research Institute of Epidemiology and Microbiology, Health Ministry of the Russian Federation, Acellena Contract Drug Research and Development	Non-replicating viral vector	Phase I/II	NCT04437875
AlloStim	Immunovative Therapies, Ltd., Mirror Biologics, Inc.	Other	Phase I/II	NCT04441047
GX-19	Genexine, Inc.	DNA-based	Phase I/II	NCT04445389
BBV152A, B, C	Bharat Biotech International Limited, Indian Council of Medical Research	Inactivated virus	Phase I/II	NCT04471519
bacTRL-Spike	Multiple Organisations	DNA-based	Phase I	NCT04334980
NVX-CoV2373	Novavax	Protein subunit	Phase I	NCT04368988
COVID-19/aAPC Vaccine	Shenzhen Geno-Immune Medical Institute	Modified APC	Phase I	NCT04299724

Unnamed VLP Vaccine	Medicago Inc.	Virus-like particle	Phase I	NCT04450004
CVnCoV	CureVac AG, Coalition for Epidemic Preparedness Innovations (CEPI)	RNA-based vaccine	Phase I	NCT04449276
SCB-2019	Clover Biopharmaceuticals	Protein subunit	Phase I	NCT04405908
COVAX-19	Multiple Organisations	Protein subunit	Phase I	NCT04428073

In addition to the above, forestation and a worldwide ban on wildlife trade can also play a significant role in reducing the spread of different viruses. More than 30% of the ground area is covered with forests. The imminent increase in population contributes to deforestation in agriculture or grazing for food, industries and property. The rise in ambient temperature, sea levels and extreme weather events affects not only the land and environment but also public health [89, 90]. Huge investment has been made into treatments, rehabilitation and medications to avoid the impact of this epidemic. However, it is important to focus on basic measures, e.g. forestation and wildlife protection. The COVID-19 infection was initially spread from the Seafood Market, Wuhan, China. Therefore, China temporarily banned wildlife markets in which animals are kept alive in small cages. It has been reported that 60% of transmittable diseases are animal-borne, 70% of which are estimated to have been borne by wild animals [72]. Deforestation is also related to various kinds of diseases caused by birds, bats, etc. [91]. For example, COVID-19 is a bat-borne disease that is transmitted to humans. Therefore, several scientists have advised various countries to ban wildlife trade indefinitely so that humans can be protected from new viruses and global pandemics like COVID-19.

6. Conclusion

In this article, comprehensive analyses of energy, environmental pollution, and socio-economic impacts in the context of health emergency events and the global responses to mitigate the effects of these events have been provided. COVID-19 is a worldwide pandemic that puts a stop to economic activity and poses a severe risk to overall wellbeing. The global socio-economic impact of COVID-19 includes higher unemployment and poverty rates, lower oil prices, altered education sectors, changes in the nature of work, lower GDPs and heightened risks to health care workers. Thus, social preparedness, as a collaboration between leaders, health care workers and researchers to foster meaningful partnerships and devise strategies to achieve socio-economic prosperity, is required to tackle future pandemic-like situations. The impact on the energy sector includes increased residential energy demand due to a reduction in mobility and a change in the nature of work. Lockdowns across the globe have restricted movement and have placed people primarily at home, which has, in turn, decreased industrial and commercial energy demand as well as waste generation. This reduction in demand has resulted in substantial decreases in NO_2, PM, and environmental noise emissions and as a consequence, a significant reduction in environmental pollution. Sustainable urban management that takes into account the positive benefits of ecological balance is vital to the decrease of viral infections and other diseases. Policies that promote sustainable development, ensuring cities can enforce recommended measures like social distancing and self-isolation will bring an overall benefit very quickly. The first generation of COVID-19 vaccines is expected to gain approval by the end of 2020 or in early 2021, which will provide immunity to the population. It is necessary to establish preventive epidemiological models to detect the occurrence of viruses like COVID-19 in advance. In addition, governments, policymakers, and stakeholders around the world need to take necessary steps, such as ensuring healthcare services for all citizens, supporting those who are working in frontline services and suffering significant financial impacts, ensuring social distancing, and focussing on building a sustainable future. It is also recommended that more investment is required in research and development to overcome this pandemic and prevent any similar crisis in the future.

References

1. Zhou, P., et al., *A pneumonia outbreak associated with a new coronavirus of probable bat origin.* Nature, 2020. **579**(7798): p. 270-273.
2. Kabir, M.T., et al., *nCOVID-19 Pandemic: From Molecular Pathogenesis to Potential Investigational Therapeutics.* Frontiers in cell and developmental biology, 2020. **8**: p. 616-616.
3. Gorbalenya, A.E., et al., *The species Severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2.* Nature Microbiology, 2020. **5**(4): p. 536-544.
4. Yan, Y., et al., *The First 75 Days of Novel Coronavirus (SARS-CoV-2) Outbreak: Recent Advances, Prevention, and Treatment.* International Journal of Environmental Research and Public Health, 2020. **17**(7): p. 2323.
5. Wang, D., et al., *Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus–Infected Pneumonia in Wuhan, China.* JAMA, 2020. **323**(11): p. 1061-1069.
6. Holshue, M.L., et al., *First case of 2019 novel coronavirus in the United States.* New England Journal of Medicine, 2020. **382**(10): p. 929-936.
7. Wang, Q. and M. Su, *A preliminary assessment of the impact of COVID-19 on environment – A case study of China.* Science of The Total Environment, 2020. **728**: p. 138915.
8. Abdullah, S., et al., *Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic.* Science of The Total Environment, 2020. **729**: p. 139022.
9. Worldometer, *Reported Cases and Deaths by Country, Territory, or Conveyance. https://www.worldometers.info/coronavirus/. Date accessed: 22nd September, 2020.* 2020.
10. Acter, T., et al., *Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: A global health emergency.* Science of The Total Environment, 2020. **730**: p. 138996.
11. Chinazzi, M., et al., *The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak.* Science, 2020. **368**(6489): p. 395-400.
12. Aldila, D., et al., *A mathematical study on the spread of COVID-19 considering social distancing and rapid assessment: The case of Jakarta, Indonesia.* Chaos, Solitons & Fractals, 2020. **139**: p. 110042.
13. Beck, M.J. and D.A. Hensher, *Insights into the impact of COVID-19 on household travel and activities in Australia – The early days under restrictions.* Transport Policy, 2020. **96**: p. 76-93.
14. Bruinen de Bruin, Y., et al., *Initial impacts of global risk mitigation measures taken during the combatting of the COVID-19 pandemic.* Safety Science, 2020. **128**: p. 104773.
15. de Haas, M., R. Faber, and M. Hamersma, *How COVID-19 and the Dutch 'intelligent lockdown' change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands.* Transportation Research Interdisciplinary Perspectives, 2020. **6**: p. 100150.
16. Cohen, M.J., *Does the COVID-19 outbreak mark the onset of a sustainable consumption transition?* Sustainability: Science, Practice and Policy, 2020. **16**(1): p. 1-3.
17. Pirouz, B., et al., *Investigating a Serious Challenge in the Sustainable Development Process: Analysis of Confirmed cases of COVID-19 (New Type of Coronavirus)*

Through a Binary Classification Using Artificial Intelligence and Regression Analysis. Sustainability, 2020. **12**(6): p. 2427.
18. Sohrabi, C., et al., *World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19).* International Journal of Surgery, 2020. **76**: p. 71-76.
19. Jiang, P., et al., *Spatial-temporal potential exposure risk analytics and urban sustainability impacts related to COVID-19 mitigation: A perspective from car mobility behaviour.* Journal of Cleaner Production, 2021. **279**: p. 123673.
20. Leal Filho, W., et al., *COVID-19 and the UN Sustainable Development Goals: Threat to Solidarity or an Opportunity?* Sustainability, 2020. **12**(13): p. 5343.
21. International Energy Agency (IEA), *Global Energy Review 2020, IEA, Paris https://www.iea.org/reports/global-energy-review-2020. Date accessed: 21st September, 2020.* 2020.
22. International Monetary Fund (IMF), *World Economic Outlook, April 2020: The Great Lockdown. https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020. Date accessed: 22nd September, 2020.* 2020.
23. Khan, S.A.R., et al., *Determinants of economic growth and environmental sustainability in South Asian Association for Regional Cooperation: evidence from panel ARDL.* Environmental Science and Pollution Research, 2020.
24. Cai, C., et al., *Temperature-responsive deep eutectic solvents as green and recyclable media for the efficient extraction of polysaccharides from Ganoderma lucidum.* Journal of Cleaner Production, 2020. **274**: p. 123047.
25. Schanes, K., K. Dobernig, and B. Gözet, *Food waste matters - A systematic review of household food waste practices and their policy implications.* Journal of Cleaner Production, 2018. **182**: p. 978-991.
26. Zambrano-Monserrate, M.A., M.A. Ruano, and L. Sanchez-Alcalde, *Indirect effects of COVID-19 on the environment.* Science of The Total Environment, 2020. **728**: p. 138813.
27. Nghiem, L.D., et al., *The COVID-19 pandemic: Considerations for the waste and wastewater services sector.* Case Studies in Chemical and Environmental Engineering, 2020. **1**: p. 100006.
28. AEMO, *COVID-19 demand impact in Australia. https://aemo.com.au/en/news/demand-impact-australia-covid19. Date accessed: 21st September, 2020.* 2020.
29. Park, G.W., et al., *Evaluation of a new environmental sampling protocol for detection of human norovirus on inanimate surfaces.* Applied and Environmental Microbiology, 2015. **81**(17): p. 5987-5992.
30. Chin, A.W.H., et al., *Stability of SARS-CoV-2 in different environmental conditions.* The Lancet Microbe, 2020. **1**(1): p. e10.
31. van Doremalen, N., et al., *Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1.* New England Journal of Medicine, 2020. **382**(16): p. 1564-1567.
32. Ye, Y., et al., *Survivability, Partitioning, and Recovery of Enveloped Viruses in Untreated Municipal Wastewater.* Environmental Science and Technology, 2016. **50**(10): p. 5077-5085.
33. Liu, M., et al., *Waste paper recycling decision system based on material flow analysis and life cycle assessment: A case study of waste paper recycling from China.* Journal of Environmental Management, 2020. **255**: p. 109859.
34. Ma, B., et al., *Recycle more, waste more? When recycling efforts increase resource consumption.* Journal of Cleaner Production, 2019. **206**: p. 870-877.

35. Qu, G., et al., *An Imperative Need for Research on the Role of Environmental Factors in Transmission of Novel Coronavirus (COVID-19).* Environmental Science and Technology, 2020. **54**(7): p. 3730-3732.
36. ACR+, *Municipal waste management and COVID-19. URL: https://www.acrplus.org/en/municipal-waste-management-covid-19. Date accessed: 22nd September, 2020*. 2020.
37. Financial Times, *Coronavirus: Is Europe losing Italy? https://www.ft.com/content/f21cf708-759e-11ea-ad98-044200cb277f. Date accessed: 21st September, 2020*, in *Financial Times*. 2020.
38. Munawer, M.E., *Human health and environmental impacts of coal combustion and post-combustion wastes.* Journal of Sustainable Mining, 2018. **17**(2): p. 87-96.
39. M Palash, S., et al., *Impacts of biodiesel combustion on NOx emissions and their reduction approaches.* Renewable and Sustainable Energy Reviews, 2013. **23**(0): p. 473-490.
40. Fattah, I.M.R., et al., *Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions.* Renewable and Sustainable Energy Reviews, 2013. **18**: p. 552-567.
41. Mofijur, M., et al., *A study on the effects of promising edible and non-edible biodiesel feedstocks on engine performance and emissions production: A comparative evaluation.* Renewable and Sustainable Energy Reviews, 2013. **23**(0): p. 391-404.
42. Ashraful, A.M., et al., *Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review.* Energy Conversion and Management, 2014. **80**: p. 202-228.
43. European Space Agency (ESA). *Sentinel-5P. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P. Date accessed: 21st September, 2020*. 2020.
44. Myllyvirta, L., *11,000 air pollution-related deaths avoided in Europe as coal, oil consumption plummet. https://energyandcleanair.org/air-pollution-deaths-avoided-in-europe-as-coal-oil-plummet/. Date accessed: 21st September, 2020*. 2020.
45. Atmosphere Monitoring Service. *Air quality information confirms reduced activity levels due to lockdown in Italy. https://atmosphere.copernicus.eu/air-quality-information-confirms-reduced-activity-levels-due-lockdown-italy. Date accessed: 21st September, 2020*. 2020.
46. Khoo, A., *Coronavirus lockdown sees air pollution plummet across UK. https://www.bbc.com/news/uk-england-52202974. Date accessed: 21st September, 2020*, in *BBC News*. 2020.
47. Statista, *COVID-19 lockdown affect on nitrogen dioxide (NO2) emissions in UK cities in March 2020 compared with March 2019. https://www.statista.com/statistics/1111519/no2-emissions-decrease-due-to-lockdown-united-kingdom/. Date accessed: 21st September, 2020*. 2020.
48. Baensch-Baltruschat, B., et al., *Tyre and road wear particles (TRWP) - A review of generation, properties, emissions, human health risk, ecotoxicity, and fate in the environment.* Science of The Total Environment, 2020. **733**: p. 137823.
49. Weitekamp, C.A., et al., *Health effects from freshly emitted versus oxidatively or photochemically aged air pollutants.* Science of The Total Environment, 2020. **704**: p. 135772.
50. Awad, O.I., et al., *Particulate emissions from gasoline direct injection engines: A review of how current emission regulations are being met by automobile manufacturers.* Science of The Total Environment, 2020. **718**: p. 137302.

51. Chatterjee, A., et al., *High rise in carbonaceous aerosols under very low anthropogenic emissions over eastern Himalaya, India: Impact of lockdown for COVID-19 outbreak.* Atmospheric Environment, 2020: p. 117947.
52. Ghahremanloo, M., et al., *Impact of the COVID-19 outbreak on air pollution levels in East Asia.* Science of The Total Environment, 2021. **754**: p. 142226.
53. Gualtieri, G., et al., *Quantifying road traffic impact on air quality in urban areas: a Covid19-induced lockdown analysis in Italy.* Environmental Pollution, 2020: p. 115682.
54. Sharifi, A. and A.R. Khavarian-Garmsir, *The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management.* Science of The Total Environment, 2020: p. 142391.
55. Srivastava, A., *COVID-19 and Air Pollution and Meteorology-an intricate relationship: a review.* Chemosphere, 2020: p. 128297.
56. Sicard, P., et al., *Amplified ozone pollution in cities during the COVID-19 lockdown.* Science of The Total Environment, 2020. **735**: p. 139542.
57. Zambrano-Monserrate, M.A. and M.A. Ruano, *Does environmental noise affect housing rental prices in developing countries? Evidence from Ecuador.* Land Use Policy, 2019. **87**: p. 104059.
58. Lillywhite, R., *Air quality and wellbeing during Covid-19 lockdown. https://www.newswise.com/coronavirus/air-quality-and-wellbeing-during-covid-19-lockdown/?article_id=730455. Date accessed: 21st September, 2020*, in *Newswise*. 2020: USA.
59. Ro, C., *Is Coronavirus Reducing Noise Pollution? https://www.forbes.com/sites/christinero/2020/04/19/is-coronavirus-reducing-noise-pollution/#2fe787d5766f. Date accessed: 21st September, 2020*, in *Forbes*. 2020.
60. Bressan, D., *Coronavirus Lockdowns Cause Worldwide Decrease In Man-Made Seismic Noise. https://www.forbes.com/sites/davidbressan/2020/04/04/coronavirus-lockdowns-cause-worldwide-decrease-in-man-made-seismic-noise/#1643453464da. Date accessed: 21st September, 2020*, in *Forbes*. 2020.
61. Nicola, M., et al., *The socio-economic implications of the coronavirus pandemic (COVID-19): A review.* International Journal of Surgery, 2020. **78**: p. 185-193.
62. United Nations Development Programme (UNDP), *The Social and Economic Impact of Covid-19 in the Asia-Pacific Region. https://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/the-social-and-economic-impact-of-covid-19-in-asia-pacific.html. Date accessed: 21st September, 2020*. 2020.
63. Fernandes, N., *Economic effects of coronavirus outbreak (COVID-19) on the world economy. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3557504. Date accessed: 21st September, 2020*. 2020.
64. Ghosh, I. *The Road to Recovery: Which Economies are Reopening? https://www.visualcapitalist.com/the-road-to-recovery-which-economies-are-reopening-covid-19/. Date accessed: 21st September, 2020*. 2020 [cited 2020 10th June]; Available from: https://www.visualcapitalist.com/the-road-to-recovery-which-economies-are-reopening-covid-19/.
65. International Monetary Fund (IMF), *World Economic Outlook, April 2020: The Great Lockdown. URL: https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020. Date accessed: 21st September, 2020*. 2020.
66. Andrews, F., *Before and after: Italy's tourist attractions left deserted amid coronavirus lockdown. https://www.thenational.ae/lifestyle/travel/before-and-after-italy-s-tourist-*

attractions-left-deserted-amid-coronavirus-lockdown-1.991274. Date accessed: 21st September, 2020, in *The National*. 2020: Abu Dhabi.
67. Rubino, d.M., *Coronavirus, il decreto del governo: tutte le misure per la zona arancione e quelle per il resto d'Italia. URL: https://www.repubblica.it/cronaca/2020/03/08/news/coronavirus_i_decreti_del_governo-250617415/. Date accessed: 21st September, 2020*, in *la Repubblica*. 2020.
68. Brunton, J., *Nothing less than a catastrophe': Venice left high and dry by coronavirus. https://www.theguardian.com/travel/2020/mar/17/nothing-less-than-a-catastrophe-venice-left-high-and-dry-by-coronavirus. date accessed: 21st September, 2020*, in *The Guardian*. 2020.
69. Statista, *Perceived impact of coronavirus (COVID-19) among Italian companies in March 2020, by macro sector. https://www.statista.com/statistics/1103017/perceived-impact-of-coronavirus-covid-19-among-italian-companies-by-sector/. Date accessed: 21st September, 2020*. 2020.
70. Bertacche, M., R. Orihuela, and J. Colten, *Italy Struck by Deadliest Day as Virus Prompts Industry Shutdown. https://www.bloomberg.com/news/articles/2020-03-21/germany-plans-extra-spending-of-eu150-billion-scholz-says. Date accessed: 21st September, 2020*, in *Bloomberg*. 2020.
71. Horowitz, J., *Italy Locks Down Much of the Country's North Over the Coronavirus. URL: https://www.nytimes.com/2020/03/07/world/europe/coronavirus-italy.html. Date accessed: 21st September, 2020*, in *The New York Times*. 2020.
72. Chakraborty, I. and P. Maity, *COVID-19 outbreak: Migration, effects on society, global environment and prevention.* Science of The Total Environment, 2020. **728**: p. 138882.
73. Abu-Rayash, A. and I. Dincer, *Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic.* Energy Research & Social Science, 2020. **68**: p. 101682.
74. Madurai Elavarasan, R., et al., *COVID-19: Impact Analysis and Recommendations for Power Sector Operation.* Applied Energy, 2020: p. 115739.
75. CIS Editorial, *Coronavirus impact on energy markets. URL: https://www.icis.com/explore/resources/news/2020/04/08/10482507/topic-page-coronavirus-impact-on-energy-markets. Date accessed: 2nd September, 2020*. 2020.
76. Eurelectric, *Impact of COVID 19 on customers and society. URL: https://cdn.eurelectric.org/media/4313/impact_of_covid_19_on_customers_and_society-2020-030-0216-01-e-h-584D2757.pdf. Date accessed: 28th Spetember, 2020*. 2020.
77. Livemint. *India's energy demand falls by 30% due to covid-19 lockdown. URL: https://www.livemint.com/news/world/lockdown-cuts-india-s-energy-demand-by-30-says-iea-11588235067694.html. Date accessed: 28th September, 2020*. 2020.
78. Renewable Energy World, *Renewables achieve clean energy record as COVID-19 hits demand. URL: https://www.renewableenergyworld.com/2020/04/06/renewables-achieve-clean-energy-record-as-covid-19-hits-demand/. Date accessed: 28th September, 2020*. 2020.
79. S&P Global, *Japan, Singapore lockdowns to stifle Asian gas, power demand further. https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/040720-japan-singapore-lockdowns-to-stifle-asian-gas-power-demand-further. Date accessed: 21st September, 2020*. 2020.
80. Madurai Elavarasan, R., et al., *COVID-19: Impact analysis and recommendations for power sector operation.* Applied energy, 2020. **279**: p. 115739-115739.
81. Khan, S.A.R., et al., *Investigating the effects of renewable energy on international trade and environmental quality.* Journal of Environmental Management, 2020. **272**: p. 111089.

82. Khan, S.A.R., et al., *A state-of-the-art review and meta-analysis on sustainable supply chain management: Future research directions.* Journal of Cleaner Production, 2021. **278**: p. 123357.
83. Khan, S.A.R., et al., *Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth.* Sustainable Development, 2020. **28**(4): p. 833-843.
84. Ghosh, I. *The Road to Recovery: Which Economies are Reopening? URL: https://www.visualcapitalist.com/the-road-to-recovery-which-economies-are-reopening-covid-19/. Date accessed: 22nd September, 2020*. 2020 [cited 2020 25th July, 2020]; Available from: https://www.visualcapitalist.com/the-road-to-recovery-which-economies-are-reopening-covid-19/.
85. Johns Hopkins University (JHU). *COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU). https://coronavirus.jhu.edu/map.html. Date accessed: 25th July, 2020*. 2020.
86. Worldometer, *Reported Cases and Deaths by Country, Territory, or Conveyance. https://www.worldometers.info/coronavirus/. Date accessed: 25th July, 2020.* 2020.
87. Biorender, *COVID-19 Vaccine & Therapeutics Tracker. URL: https://biorender.com/covid-vaccine-tracker. Date accessed: 28th September, 2020*. 2020.
88. Peiris, M. and G.M. Leung, *What can we expect from first-generation COVID-19 vaccines?* The Lancet, 2020.
89. Ruscio, B.A., et al., *One Health - a strategy for resilience in a changing arctic.* Int J Circumpolar Health, 2015. **74**: p. 27913.
90. Arora, N.K. and J. Mishra, *COVID-19 and importance of environmental sustainability.* Environmental Sustainability, 2020. **3**(2): p. 117-119.
91. Afelt, A., R. Frutos, and C. Devaux, *Bats, Coronaviruses, and Deforestation: Toward the Emergence of Novel Infectious Diseases?* Frontiers in Microbiology, 2018. **9**: p. 702-702.