COVID-19 pandemic: Sudden restoration in global environmental quality and its impact on climate change

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Abstract

As the pandemic COVID-19 spreads rapidly, governments around the globe have imposed strict restrictions to check it. Lockdowns in several countries have resulted in significant improvement in environmental quality. In this review we aimed to disseminate comprehensive knowledge regarding recent positive changes in air quality, plausible factors behind it and the impact of the novel coronavirus outbreak on the climate for a long run. Restoration in air quality and ecological rejuvenation has been observed as concentration of NO_x, CO_2, $PM_{2.5}$, PM_{10} and other pollutants have been reduced over several parts of the world which might be due to immense plunge in industrial activity, consumption of fossil fuels, electricity demand, road transport, aviation and even due to behavioral changes during lockdown period. Though shrinking emissions at the cost of human lives is not a desirable way, but the situation seems to be a turning point towards climate change. Economic burden of managing the SARS-CoV-2 outbreak coupled with the possibility of bouncing back of the emissions afterwards are posing questions on the persistence of this positive change, but efforts of governments and its citizens to tackle this catastrophic phase indicate that it is possible to sustain this climatic restoration, but only through wise policies as well as individual participation.

Keywords: COVID-19, Environmental quality, Air pollution, Climate change.

1. Introduction

Wuhan, the most populous and largest city of Hubei province of China [1] received global attention after becoming the ground zero of a cluster of pneumonia cases of unknown aetiology [2], later reported as COVID-19, caused by a novel coronavirus (SARS-CoV-2) [3]. The World Health Organization (WHO) regarded the outbreak as a Public Health Emergency of International Concern on 30 January 2020 and later declared as a global pandemic on 11 March 2020 [4,5]. More than 2,804,796 people have been reported to be infected while 193,710 have died with a fatality rate of 6.90 % over 178 countries and 33 territories [6] as of 26th April 2020. Several travel restrictions have been implemented around the globe to control the virus spread. China was the very first country to impose a strict lockdown in Wuhan on 23 January 2020 [7]. Other countries have followed the same in due course of time. A study shows that a strict lockdown has made the highest number of people (1380 million) to stay at home in India, followed by china and USA [8] (Extended Data Fig. 1).

When the whole world is busy in getting rid of current pandemic situation, people have forgotten about one of the gravest threats to mankind-the climate change. According to NOAA, the recent global CO_2 concentration has increased to 409.09 ppm from 408.52 ppm as in 2018 while in pre-industrial period, it was about 280 ppm [9]. The month, February 2020 has been registered as the second hottest February in 141 year global climate record, following 2016, the hottest February ever as reported by NOAA's National Centers for Environmental Information [10]. Global Alliance on Health and Pollution (GAHP) in their reports pointed pollution as the major culprit causing premature death of 8.3 million people which is about 15 % of all deaths. The number of casualties even exceeds due to Tobacco, HIV, Malaria, TB or war [11]. Ambient air pollution causes about 40 % of all pollution-related deaths, the value is about 4.2 million worldwide [12].

Though the global pandemic COVID-19 has shattered the world causing millions of positive cases and hundreds of thousands of deaths so far, widespread job losses and slumping economy - but the invigorating effect it is having on the environment is one glistening spot in the bosom of widespread calamity. From Satellite imagery certain improvement in air quality has been observed with significant reduction in NO_2, $PM_{2.5}$ and CO_2 all over the globe. The transport restriction possesses a huge impact to curb the emission as it contributes around 23 % of global carbon emissions [13]. Prolonged shutdowns in industrial sectors resulted in decrease in fossil fuel consumption as well as shrinking electricity demand, which left a positive impact on environment [14,15]. China being the largest consumer of coal, electricity and energy felt the most obvious changes [16]. Just within a span of 4 weeks china's carbon emission fell by a quarter [15]. But the sustainability of these positive changes is under question, as there is a possibility of "Revenge Pollution" during later part of the year. A similar phenomenon was observed during global recession period of 2008-2009 when dropped emissions reversed back to its previous as most of the stimulus was spent for the upliftment of staggered economy [14]. By keeping these aforesaid circumstances in mind, here, in this review we have discussed in detail about the a) recent restoration of environmental quality after the outbreak of novel coronavirus, b) credible reasons behind those and c) lastly we have presented an outlook regarding the sustainability of those positive changes and their future impacts.

2. Epidemiology and prevention of coronavirus disease 2019 (COVID-19)

Coronavirus disease 2019 (COVID-19), the new global pandemic is caused by the recently identified 7th member of coronavirus family. Initially the virus was named as Novel Coronavirus, later on 11th February, 2020 International Committee on Taxonomy of Viruses (ICTV) declared it as "severe acute respiratory syndrome coronavirus 2" (SARS-CoV-2) [17]. Taxonomically, SARS-CoV-2 belongs to the genus Betacoronavirus and the order Nidovirales,

consists of large, single stranded, positive sense RNA as its genetic material [18]. The very first cluster of infections had been reported from Wuhan, China at the end of December, 2019 with a common link to Huanan Seafood Wholesale Market, which might be the origin of the current viral outbreak [19]. Zhou et al. [20] reported *Rhinolophus affinis* bat as the natural host of SARS-CoV-2 while Pangolins could be considered as the intermediate host, which carries around 70 % strains of Coronavirus family [18]. Globally Mammals and birds are infected by different races of coronavirus which ultimately cause mild to moderate and sometimes severe illnesses related to lower-respiratory tract. Primary symptoms of COVID-19 are fever, sore throat, dry cough, breathing difficulty and pneumonia while secondary symptoms include diarrhea, headache and hemoptysis, though extent of different symptoms vary patient to patient depending upon immunity, age and other medical conditions [21]. According to WHO, 80 % patients could be recovered without any special treatment while 16 % patients exhibit the tendency to develop severe illness with difficulty in breathing, most of whom are either having other pre-existing medical conditions (such as asthma, diabetes, cardiovascular disease) or elderly people with weak immunity system. In spite of being symptomatically very similar, genetically SARS-CoV-2 is only 79 % and 50 % identical to SARS-CoV (Severe acute respiratory syndrome-related coronavirus) and MARS-CoV (Middle East respiratory syndrome coronavirus) respectively [22]. Human angiotensin converting enzyme 2 (ACE2) is the binding site of the SARS-CoV-2. Being rich in ACE2 receptor, the respiratory tract, salivary gland duct and epithelial layer of mouth of human act as the gateway of infection [20]. According to the earlier report of WHO, there was no evidence of transmission through animals such as dogs or cats but later in early March a pet dog was tested positive in Hong Kong infected from its owners [23]. A Malayan tiger along with six other big cats in the Bronx Zoo of New York City were also reported positive with symptoms of dry cough [24]. Exposure to an asymptomatic zoo keeper might be the reason behind it. As tigers and all other cats are under the same family

Felidae, this might be attributed to the pronounced susceptibility of cats towards the virus as compared to other tested animals and birds viz. dogs, pigs, ferrets, chickens and ducks [25].

COVID-19 has an incubation period of 2-14 days [26] in humans and reproduction number (R_0) is around 2-2.8 [27]. The virus directly spread human to human through droplet transmission during coughing, talking, sneezing and indirectly through contact and contaminated objects. Till now airborne spread has not been confirmed for COVID-19. Though the fatality rate of COVID-19 (6.90 %, calculated based on the data obtained from situation report of WHO published on 26th April, 2020) [6] is less than SARS (15 %) but it is more contagious. SARS had spread across 29 countries during period of 2 years (2002-2004) [28] while COVID-19 got spread to 178 countries within 3 months[6]**.** In spite of lower fatality rate, faster spreading and higher contagiousness made the situation difficult to handle and enforced WHO to declare COVID-19 as global pandemic on 11th of March through press briefing [5]. Till now highest number of people got the virus in USA (899281) along with maximum number of deaths (46204) [6] (Fig. 1a, b). International travel ban, quarantine, contact tracing, complete lockdown had been imposed in most of the countries to retard the spread. The epicentre of this pandemic was Wuhan but Italy, Spain and recently USA have emerged out as hotspots on later stages [6] (Fig. 1a). Daily increase in confirmed cases of infection as well as number of deaths proclaim the global emergency.

As of now no specified medication and vaccination is available for COVID-19, WHO published guidelines to check the spreading of SARS CoV-2 [21]. These includes frequent washing of hands with soaps or alcohol-based sanitizers, maintaining 1 metre distance from whoever is coughing or sneezing, avoiding touching eyes, mouth and nose and maintaining proper sanitation. Disposal of medicinal wastes, urine and faecal disposals should be managed properly as these have the potential to spread the disease. From the date of publishing of gene sequence of SARS CoV-2, various private and public sector companies like *Moderna*, *Johnson*

& Johnson are in the process of developing vaccine. Moderna company of USA was the earliest to start the first phase of trial on 17th March, 2020 [29] while Oxford University began the human trial of their developed vaccine claiming 80 % chance of success on 23rd April, 2020 [30]. From the medication point of view, few antiviral drugs like oseltamivir, ritonavir and lopinavir showed promising effect to some extent [31]. Broad-spectrum antiviral remdesivir, chloroquine and hydroxychloroquine are also found to be effective against SARS CoV-2 by group of scientists [32]. But Magagnoli et al. [33] found a contradictory impact as patients treated with hydroxychloroquine and an antibiotic combination received no benefit in rates of death or in use of a ventilator. Israel Institute for Biological Research (IIBR) successfully isolated an antibody which is believed to be an important key for development of medicine [34]. But specific medicines against SARS-CoV-2 are not available till the time of preparation of this manuscript. At this situation, physical distancing proved to be the best preventive measure that we can take to retard the spread [35]. The effect of physical distancing in terms of lockdown can be clearly observed in various countries. There is significant decline in number of new infections in mainland china after the Chinese authority had imposed quarantine especially at Wuhan [36]. Other countries like Italy, USA has already gone through nationwide lockdown before its current relaxations [37] while France extends the existing virus emergency until 24th July, 2020 [38]. India is going through the largest lockdown of the world since 24 March by keeping its 1.3 billion people inside their houses [39] to flatten the infection curve.

3. Improvement in air quality and ecological balance after SARS-CoV-2 outbreak

3.1 Sudden restorative alteration in air quality

In spite of having tremendous negative impact on human lives and economy, this pandemic has brought a huge improvement in terms of air quality, water quality and ecological balance. Copernicus Sentinel-5 of European Space Agency (ESA), dedicated for monitoring air quality

of earth revealed a report of nitrogen dioxide (NO_2) concentrations over China which indicates significant variation from December 2019 to March 2020 [40]. A dramatic reduction in NO_2 of around 40 % was observed which could be attributed to the nationwide shut-down of a large number of cities of China to prevent the spread of the disease. Coinciding with the period of quarantine and lockdown, the decrease in NO_2 levels was pronounced from late January to middle of the month of February, 2020 while gradual rise in concentration has been noticed from beginning of March as many provinces are downgrading the restrictions (Fig. 2a). The time of the study also coincided with Lunar or Chinese New Year and lowering of air pollution usually came into notice during this holiday period (last week of January to early February) and then increases after the festive week. On comparing with the reports of the previous year, the magnitude of the atmospheric NO_2 decreased around 10 to 30 % more and was found persistent even in late February [41] (Extended Data Fig. 2). The average values of NO_2 contents from 2005-2019 have been compared with the NO_2 values detected by Ozone Monitoring Instrument (OMI) on NASA's Aura satellite and a significant lower value were obtained nationwide. As NO_2 is the primary indicator of traffic and industrial activities such notable reduction in its concentration in air could be considered as the effect of enforced environmental regulations of China over the past few years coupled with the enforced lockdown during the present pandemic. Satellite image of Sentinel-5P depicted prominent reduction in air pollution, specifically NO_2 concentrations over the Po Valley in northern Italy in the first week of March which might be attributed to lockdown imposed in severely diseased Italy to restrict rapid transmission [42] (Fig. 2b). Mean atmospheric concentration of NO_2 was recorded about 65 μg m^{-3} in January, 50 μg m^{-3} in February and less than 40 μg m^{-3} during the first half of March, 2020 suggesting a rate of decrease of about 4 μg m^{-3} per week [43]. Along with Italy, lower NO_2 concentration in other parts of Europe was also observed [43,44] (Extended Data Fig. 3). According to Finland's Centre for Research on Energy and Clean Air

(CREA), an emission of 800 million tonnes of CO_2 from China in 2019 has been cut by 200 million tonnes up to March 1 which is half of the annual emission of Britain [45]. BBC [46] reported a drop of around 5-10 % in CO_2 during 2nd week of March over New York as compared to previous year, as a result of 35 % reduction in traffic while a 50 % drop was observed as in case of Carbon monoxide concentration.

Particulate matter having diameter 2.5 µ or less ($PM_{2.5}$) is another detrimental air pollutant [47] responsible for about 13–125 deaths per 100,000 people in the cities [48]. The Copernicus Atmosphere Monitoring Service (CAMS) compared the mean monthly values of $PM_{2.5}$ concentration in air of February 2020 with average of the mean monthly values of February 2017, 2018 and 2019 which indicated around 20-30 % decline over the large part of China [49] (Fig. 3a,b). This might be due to lower emission of NO_2 in China as $PM_{2.5}$ could also be formed in the form of secondary particles as an outcome of chemical reactions with NO_2 [50]. Studies of busiest areas of Hong Kong revealed around 32, 29 and 22 per cent reduction in $PM_{2.5}$, PM_{10} and NO_2 concentrations in air during February 2020 as compared to the previous month [51] (Extended Data Fig 4c). Significant reductions in NO_2 concentration have been reported in the big cities of US including Los Angeles, Washington DC, Seattle and New York [52]. In late March the average concentration of NO_2 and $PM_{2.5}$ has been recorded around 25 % lower in UK than the pre-outbreak period (before 10th February, 2020) while in some cities like London, Birmingham, Bristol and Cardiff the drops were recorded about 50 % or more [53].

Based on $PM_{2.5}$ concentration, according to World Air Quality Report of IQ Air, among the 30 worst polluted cities of the world, 21 are from India [54]. Ghaziabad ranked as the most polluted city of the world and Delhi ranked as the worst polluted capital of any country. Myllyvirta [55] reported lowest average value of NO_2 in air after only one-day lockdown imposed by Government of India on 22nd March, 2020 (Extended Data Fig. 4 a, b). The result

was based on the average values of studies performed in the notable cities including Delhi, Mumbai, Chennai, Kolkata, Bengaluru, Ghaziabad, Howrah, Hyderabad, Jaipur, Lucknow, Noida and Patna which also exhibited a Significant decrease in $PM_{2.5}$ and PM_{10}. System of Air Quality and Weather Forecasting and Research (SAFAR), India [56] reported a drastic reduction in NO_x, PM_{10} and $PM_{2.5}$ in air after complete lockdown compared to prior-lockdown period in four major cities in India (Table 1). The Times of India [57] revealed a statistic regarding the Air Quality of Prayagraj (Allahabad) depicting an AQI value of 24 on 23th March, 2020 which was about 206 on 18th March and was as high as 622, about six times higher than permissible limit on November 4th last year. After initiation of the 21 days of complete lockdown marked decrease in $PM_{2.5}$ concentration [56] (Fig. 3c) as well as AQI index [58] were recorded in New Delhi.

3.2 Is Coronavirus indirectly saving more lives by lowering pollution?

Air pollution is responsible for major environmental health problems and is liable for millions of premature deaths every year. But we always overlook and downgrade the effects of air pollution, which can appear as a future pandemic. As per State of Global Air 2019 report, global pollution is responsible for more deaths (15 % of all deaths) than other risk-factors like alcohol consumption, obesity or malnutrition [59]. Near about 91 % of the world population was recorded to live in places that do not meet the limits of air quality guidelines of WHO (WHO 2018a). Every year ambient (outdoor) air pollution causes about 4.2 million premature deaths worldwide considering both cities and rural areas [12] out of which around 1 million deaths are reported from china only [60]. The household air pollution is also responsible for loss of 3.8 million human lives [61]. Deaths of around 600000 children in each year were also reported by WHO due to acute lower respiratory infections caused by polluted air [62]. Such deaths due to air pollution mainly associated with NO_2 concentration and $PM_{2.5}$ in air, causing cardiovascular problems, respiratory disease and cancers [12,63]. Hence, drastic drop in NO_2,

$PM_{2.5}$ and other pollutants in air as an outcome of prolonged lockdowns in several countries might result in a promising reduction in the number of deaths due to air pollution. Professor Marshall Burke of Stanford University predicted that such restored air quality could save 4000 kids under 5 and 73000 adults over 70 years in China in two months while the more conservative calculation still indicated a saving of 1400 kids and 51700 elderly [64]. He used the average of the drop in pollution levels in terms of $PM_{2.5}$ and calculated the subsequent effect on mortality excluding other negative effects of the lockdown [64]. Professor Burke is hopeful that the lives saved due to the pollution reductions would be around 20 times more than the loss due to COVID-19 infection [65] which is in conformity with the views of François Gemenne, director of The Hugo Observatory [66]. Goodkind et al. [67] (2019) reported around 107000 premature deaths in United States and identified $PM_{2.5}$ as the prime causal agent behind that, while air quality report of European Environment Agency reported around 412000 premature deaths in Europe due to air pollution of which around 374000 were in the EU-28 in 2018 [68]. A toll of 76200 people due to air pollution was recorded against Italy alone [69] and majority of which due to exposure of $PM_{2.5}$ and NO_2. Therefore, significant reduction in NO_2 and $PM_{2.5}$ in the air of Italy as well as in the entire Europe [42] might appear as a positive phenomenon that would help to decline the loss of human lives due to air pollution. On the other hand, recent reports from Aarhus University revealed a direct link between air pollution levels and susceptibility towards COVID-19 outbreak [70]. Back in 2003, during SARS-CoV outbreak data in China, Cui and co-workers also reported that exposure to more polluted air increased the mortality twice than that of the people lived in places with less pollution [71]. Assessed on 21st March, 2020, severity of the disease was found as high as 12 % in Lombardy and Emilia Romagna, marked as the most polluted area in Italy [72] whereas it was about 4.5 % in rest of country [73]. This might be attributed to the fact that most of the fundamental health issues are associated with air pollution are generally related to respiratory infections

which make people more vulnerable to novel coronavirus and increase the risk of dying from COVID-19.

3.3 Ecological rejuvenation and animal encroachment in lockdown cities

Mother Earth has started to rejuvenate its degraded environmental condition to maintain an ecological harmony by hitting the reset button on anthropogenic creations. Due to the lockdown in numerous cities around the world, with each passing day, people are witnessing clean water to clearer sky and wild animals, roaming the cities freely. Since the beginning of Ganga Action Plan, 1986, the Government of India has funded about Rs 5000 crore to maintain the health of the river Ganga, but is of little impact. The monitoring stations of The Central Pollution Control Board (CPCB), at the upstream and downstream, after accessing various parameters noticed significant improvement in the health of river Ganges [74]. The monitored values along with their permissible limits are mentioned in Table 2. That indicates the improved water quality of the river Ganga during the recent enforced lockdown especially around the industrial clusters due to lesser effluent generation and discharge [74]. A similar story is found as in case of river Yamuna due to less industrial discharge and ammonia free water as blows from Haryana, Delhi Jal Board (DJB) reported [75]. Due to lack of nautical activities, the canals in Venice appears to be clearer with lesser turbidity than usual [76]. The view of Dhauladhar range of Himalaya, located in Himachal Pradesh was visible from Jalandhar (Punjab) which is about 200km away from Himachal after 30 years due to clearer sky and less pollution load [77].

Though temporarily, but the animals seem to get a free reign on the roads of bustling cities and metropolitan areas as most of the populace quarantined themselves. Reports showed that various animals like horse, sheep, wild boars have been found to roam in the streets of Italy [76]. In Lopburi city, Thailand, a swarm of monkeys also got viral on social media as they have been wandering in a city plaza [78]. Similar incident was found in Nara City, Japan as

local people reported that a herd of sika deer (*Cervus nippon*) wandered off of their territory and roamed in the city streets [79]. Coyote and wild Turkeys were seen to jog in vacated streets and playground of California, USA. Low pollutants load allured different fish species, swans, cormorants or even dolphins to the canals water of Venice [79]. Indians witnessed a heard of spotted dear in the roads of Tirupati, Andhra Pradesh, Olive Ridley Turtles on Odisha beach, a Nilgai (Blue bull) on main roads of Noida and Dolphins at Mumbai coast [80]. On the contrary, according to an article of National Geographic [81], some of these aspects are exaggerated as the swans, found in the canals of Venice, are regular of the canals of Burano island where the photos were actually captured, or the video of Venetian dolphin was also filmed previous year at a port in Sardinia. In spite of such exaggerated news, it is quite obvious that there are some positive changes that the nature is feeling.

4. Factors behind such restoration

4.1 Reduction in fossil fuel consumption

Being the epicentre of this pandemic China, the largest consumer of both coal and oil showed a drastic fall in fossil fuel consumption in the first quarter of 2020 which ultimately lead to a cut in greenhouse gas emissions and eventually air pollution. A 36 % reduction in coal consumption at power plants was recorded in China over previous years [15]. Every year a week long holidays during Chinese New Year shows a short-term declining impact on the industrial consumption of coal but this year the effect was prolonged with no sign of bouncing back upto first week of March due to lockdown and other strict policies of the government to restrict the spread of the disease (Fig. 4a). Other indicators of industrial capacity utilisation also exhibited declination in subsequent weeks after Lunar new year. Throughput at the main coal port, Qinhuangdao, was recorded least in four years comparing four weeks to 1st March. Similarly, capacity utilisation of China's main centre for oil refining in Shandong province

exhibited a dramatic fall to the lowest level since autumn 2015 indicating a sharp plunge in oil demand. Greater than 15 % reduction in operating rates for main steel products was observed while there was almost no change in crude steel production. On the other hand, 29, 23 and 34 % fall was recorded regarding coal throughput at the largest coal port fell, coking plant utilization and oil refinery utilization respectively. Combined cut in the coal and crude oil consumption indicate a drop of around 100 Mt CO_2 emission than that of 2019 which is about 6 % of global emissions over the same period.

Extension of lunar new year holidays in China and South Korea resulted in halt of many businesses and industries during novel coronavirus outbreak. Along with this severe curtail in domestic travel and enhanced restrictions for visa, international policies including entry, departure or transit imparted a striking impact on economic growth as well as oil demand of China. Early estimation of a target of nearly 6 % growth in economy could be in between 4 and 5 % in this year according to experts [82]. An estimation of over 450,000 barrels per day (b d^{-1})cut in oil demand of China in first quartile (Q1) of 2020 was reported by Wood Mackenzie [83] which is a decline of around 3.5 % as compared to Q4 of 2019 (Fig. 4b). But if normalcy could be achieved by Q2 a positive recovery is expected like 2003 during post-SARS period. Regarding LNG demand of China, a 6.4 billion cubic metres (Bcm) cut has been predicted by IHS Markit [84] in base cases if the applied measures could check the disease transmission quickly otherwise in severe cases the drop down might be as high as 14.3 Bcm (Fig. 5c). International Energy Agency [85] reported a fall of 2.5 million barrels per day (mb d^{-1}) in global oil demand with a down of 1.8 mb d^{-1} in the China's oil demand. But a situation closes to normal could be expected in 2nd half of 2020. The crude oil demand of China is expected to drop down by 90 kb d^{-1} year-on-year which is for the first time since 2009. According to the prediction made by IEA the oil demand would be nearly 99.9 mb d^{-1} in 2020, around 90,000 b d^{-1} lesser than 2019 [86]. IEA has split their prediction in two scenarios in order to tackle

extreme uncertainties of energy market for COVID-19 affected 2020: a) low case, 730,000 b d^{-1} fall in global demand in a pessimistic situation where world fails to check the spread quickly and b) high case, a growth of 480,000 b d^{-1} in an optimistic situation if the globe could contain the virus within a short period of time. A reduction in total oil demand by 11 % was also reported from South Korea in February of 2020 where the fall in jet fuel demand (24 %) was most pronounced due to cancellation of significant number of flights to restrict the spread of the disease [87]. The U.S. Energy Information Administration (EIA) revised their forecast regarding global liquid fuel demand in February, 2020 which predicts a demand of 101.7 mb d^{-1} in 2020, 1 mb d^{-1} more as compared to 2019 but around 378,000 b d^{-1} less than the forecast made in EIA Short-Term Energy Outlook (EIA-STEO) during January 2020 [88] (Fig. 5a, b). The plausible reason behind this might be the allied effects of lower fuel consumption in Northern Hemisphere as winter was warmer than usual, expected sluggish economic growth and the economic effects of the COVID-19 [88]. In USA, around 2.7 million barrels cut in gasoline stockpiles was noted by the end of February, 2020. Along with the drop in refinery throughput distillate inventories fell by 2.1 million barrels compared to the previous year [89]. India imports around 4.7 mb d^{-1} of crude oil, processes 5.3 mb d^{-1} in its refineries and sells around 2.5 mb d^{-1} of transport fuels. Although the spread of the disease is not that much severe in India as compared to other large oil consuming countries at the time of the study but to check the increasing rate of the cases government imposed a 21 days lockdown from 24th March, 2020. This might result in a significant reduction in oil demand. A 15 % decline in oil demand has been noticed in the first half of March due to cut in transport whereas around 50 % decline in demand by the second half of March and in April has been estimated by the experts [90].

4.2 Fall in the demand of electricity

Electricity consumption of world's largest electricity consumer China fell 7.8 % year on year during January and February indicating a sharper descent than that of the period of recession

in 2008-09 [91] (Fig. 6a). IHS Markit [92] also predicted a cut of about 73 billion kilowatt hours (kWh) of industrial power in 2020 as output of many factories and industries has been stopped in wake of novel coronavirus (Fig. 6c). This cut represents about 1.5 % of industrial power consumption in China equivalent to 30 Mt of thermal coal or about 9 million tonnes of liquefied natural gas (LNG) which is almost equal to Finland's annual demand of power. As the industry accounts for around 70 % of total electricity demand of China this demand difference has become pronounced as a result of shut-down for a significant period of time. In Hubei province 22.5 GW fall in peak power load was recorded in February which was about 21 % lower than usual [83]. After 1 week of national lockdown another severely affected country Italy showed a 18 % fall in power demand as compared to demand just prior to the quarantine measures [93] (Fig. 6d). In Italy, after initiation of nationwide lockdown, 8.1 % decrease in energy demand was observed in week 11 of 2020 which was about 7.3 % less as compared to the same week in 2019 [94] (Fig. 6e). Such fall resulted in a 6.1 % drop in import in case of Italy, Europe's largest power importer. By the end of the 2nd week of March 2020, 5.6, 9.7, 1.5 and 4.7 % drops in power demand were noted in case of Spain, France, Germany and Great Britain respectively [94]. After March 25, the first day of the 21 days lockdown imposed by the government, a fall of 2.78 billion units in national electricity demand of India was reported by Reuters [95] indicating 20 % lower demand than the average of the first three weeks of March amounting 3.45 billion units per day. Hence, a lockdown in China for a significant period of time, the widespread lockdown in Europe and other countries, create a worldwide reduction in demand of energy and fossil fuels which brings a sudden purification of air quality of different parts of the world.

4.3 Cut in transport and air traffic

Contribution of transport is around 23 % towards global carbon emissions [13] of which road transport and aviation are the prime contributors accounting for nearly 72 and 11 % of the

global transport emissions respectively [96]. Contribution of South Asia and Sub-Saharan Africa are comparatively less than the rest of the world while countries with upper-middle and high-income levels act as notable sources in this regard. The top ten contributing countries including China, United States, India, Russia, Japan, Brazil, Indonesia, Germany, Iran and South Korea, together contribute 63 % of global transport emissions [97]. Considering transport emissions from European Union, major part was reported from road transport (71.7 %) followed by aviation (13.9 %), maritime (13.3 %), railways (0.5 %) and other transportation (0.5 %) [98]. United States ranked first by making up a quarter of global aviation emissions [99] while in the top five other four countries are China, United Kingdom, Japan and Germany. Though an efficiency improvement of 17.3 % since 2009 in aviation industry was reported by Air Transport Action Group [100], a 5.2 % increase in CO_2 emission in 2019 (862 million metric tons (MMT)) over 2017 (862 MMT) was also noted [101].

As travel restrictions and border control measures have been enforced by several countries to halt the breakneck spread of COVID-19 a drastic drop in air traffic is likely to be most common. In February 2020 suspension and reduction of flights of 59 airlines to Mainland China and other countries like USA, Russia, Australia, and Italy was observed [102-105]. The week starting from March 30, 2020, showed a 47.7 % reduction in scheduled flights worldwide as compared to the week of April 1, 2019 [106] (Fig. 7). On this concerned week the highest number of flights were cancelled in case of Singapore (89.3 %) while in Italy about 89.2 % reduction in flight numbers were observed. The impact of COVID-19 on the Chinese aviation was pronounced during the week starting from February 17, 2020 when it reached its peak with a reduction of 70.8 %. At European airports 88 % decrease in passenger traffic was recorded on 22nd March 2020 compared to the same day of the previous year [107] (Extended Data Fig. 5a). On 4th April, 2020, Transportation Security Administration (TSA) screened 118302 passengers at US airports, compared with over 2 million passengers screened on 4th April, 2019

[108] (Extended Data Fig. 5b). Based on this dramatic plunge in aviation industry Statista [109] has predicted a 90 percent loss in capacity in case of European airlines in the Q2 of 2020 (Extended Data Fig. 5c) if restrictions continue that would be the greatest among all (comparing with Asia Pacific, North America, Middle East, Africa and Latin America). The impact of SARS-CoV-2 outbreak was found significantly prominent on movement of vehicles also. The road traffic of Britain was recorded lowest since 1955 exhibiting a 73 % reduction than that of pre-outbreak period [110] (Extended Data Fig. 5d). On the other hand, researchers in New York reported a 35 % drop in road traffic during middle of March, 2020 compared to 2019 [46]. On an average around 30 % plummeting in road traffic was observed in United States which was about 51 % in case of San Francisco [111] while Los Angeles noted 53 % faster transits due to less traffic [52]. Such a shrink in the traffic around the globe could be considered as a plausible reason behind a cleaner air during this period, hopefully which might persist for some more days depending upon how fast the earth would able to contain the virus.

4.4 Cancellation of events around the globe

Cancellation and postponement of several international mega events in different sectors to manage the spread of the highly contagious virus, played a pivotal role in lowering the global emission in an indirect manner. The host country Switzerland cancelled Geneva Motor Show while CERAWeek gathering of oil and gas executives in Houston has been cancelled as well [112]. Restrictions and bans on public gathering lead to cancellation or rescheduling of global meet and conferences. Donald Trump, the US president has postponed the ASEAN (Association of Southeast Asian Nations) summit which was set for 14th March, 2020 [113]. The Mobile World Congress in Barcelona, the Game Developers Conference in San Francisco, Adobe's annual live summit, REV'd Up Media Summit, Facebook's annual conference for developers F8 and Global Marketing Summit in San Francisco, all have been called off and possibly would take place online to prevent the spread of the disease [114]. The spring meeting

between World Bank and IMF (International Monetary Fund) scheduled from 17 to 19th April, 2020 has been transformed to a virtual format [115]. The pandemic has disrupted much awaited the Olympic Games 2020 in Tokyo and UEFA Euro 2020 scheduled to be hosted by 12 countries in Europe. Both have been postponed to 20021 [116]. The French Open, set for late May, has been delayed until September 2020. Suspension of major leagues of soccer/football, NBA, hockey, cricket and several other sports were also reported [117]. Formula One grand prix in Shanghai has also been called off. The cultural world is also affected. Deferral of Art Dubai, the largest art Middle-East fair and the Cannes film festival are notable among those. London Book Fair and South, the mega annual film, music and media conference in Austin, Texas by Southwest have all been cancelled [118]. Concerts of several artists Mariah Carey, Stormzy, Slipknot and New Order have either cancelled or postponed. The Rolling Stone also has postponed their tour of North America. Although impact on climate would not be that much in this case as most of the audience were usually local and would not avail flights for attending the shows. The Louvre Museum in Paris, the Metropolitan Museum of Art and the Museum of Modern Art will remain closed until further notice [119]. All six Disneylands of Florida, California, Tokyo, Paris, Hong Kong and Shanghai are keeping their door shut for indefinite time and would open again by evaluating the complexity of situation. Prolonged closure of such places that usually attract millions of people every week would definitely indulge in a huge cut in power consumption, transport and air traffic. More number of virtual meetings and conferences instead of physical gathering could also be attributed as a key factor for cleaner air and nominal emissions during this period.

4.5 Physical distancing

As physical distancing has been found to be the most effective measure [35] to halt the spread of the pandemic, millions of people are forced into lockdown imposed by governments across several countries. From the last week of March WHO has started using the term ‘Physical

Distancing' instead of widely used 'Social Distancing' as according to many experts including Professor Daniel Aldrich, of Northeastern University, the term was misleading and counterproductive [120]. In a report of WHO [121] on 20th March 2020, Maria Van Kerkhove, the WHO epidemiologist said that the purpose of the change is to instruct people to keep physical distance without being disconnected with our loved ones as nowadays people can remain connected socially through advanced technology in many ways without physically being there. Prolonged lockdown might be odd for making one social person uncomfortable to some extent but along with the reducing the rate of transmission it brings some changes in lifestyle of an individual that would be helpful to combat climate change also. The changes in our daily life due to outbreak of novel coronavirus could be helpful for betterment of environment particularly in terms of reduction of carbon footprints in the following ways:

i. People being enforced to be at home actually reduce the emission of GHGs by cutting down the road transport and flights. Contribution of transportation towards anthropogenic GHGs addition plays a significant role in climate change. Quarantine, closure of schools, shut-down of several industries and factories, suspension of several offices and even working from home or virtual meetings are something that reduced traffic during this period could be marked as a promising factor behind such change in air quality. But it is generally applicable for the people residing in urban, sub-urban or rural area who use personal vehicles to reach their work but would not count much for those who use mass transit [122]. Although it was a different scenario as many countries imposed complete lockdown including public transport and that is why the change was contrastingly prominent. According to Dr. Kimberly Nicholas, a researcher at the Lund University Center for Sustainability Studies, Sweden eight years of recycling would be required to offset the emissions of one round-trip flight from New York to London [123]. Hence cancelation of thousands of flights also imparted a significant effect.

ii. The changed behaviour of dining at home instead of dining out during this period resulted in cut down in carbon footprint coupled with health benefits. Financially secure people who consume more food than required and waste a significant quantity have checked themselves thinking of the availabilities of the commodities. On the other hand, making food in home instead of dining in restaurants cut the extra emission associated with the vehicle used for that. Limitations in storage of meat indulged in stockpiling of grains and vegetables which again facilitates in dipping of carbon footprint as consumption of eating a plant-based food over meat could save about 0.8 t CO_2-eq per person per year [124].

iii. Although closure of schools and workplaces might diminish the power consumption but one can increase his carbon footprint by staying home which depends on the location of his residence [123]. People living in cold climate could indulge in household emission by turning their thermostat on while places depend more on renewable sources of power (e.g., 31 percent of total electricity demand of California comes from renewable energy and only 3 percent from coal) found potent enough to offset carbon footprint.

5. Will the pandemic exhibit a lasting impact?

5.1 Sustainability of the positive change and "revenge pollution"

Prolonged shutdowns across several countries resulted in depression in CO_2 and other GHGs emissions, cut down in coal, oil and natural gas consumption as well as in electricity demand leaving a positive impact on environment [14,15]. Being a ground zero of the disease china is feeling most obvious changes. But it is difficult to conclude how persistent the dip in emission will be and whether carbon and pollutant emissions will "bounce back" as if this clear-skied interlude never happened [14]. The executive director of the International Energy Agency

(IEA) Fatih Birol is not hopeful about the sustainability of the decline in emissions, as it will not last long without right policies and structural measures. Other experts also possess same opinion [125]. This is not the first time when worldwide carbon pollution reduces, even before the industrial age- economic shocks, diseases, and wars caused such dip. Emissions are likely to rise again as the economy bounces back [126]. A study published in *Nature* showed a 10 % fall in emissions between 2007 and 2009 as a result of the financial crisis [127], while another publication in *Nature Geoscience* revealed falls caused by the two World Wars and the Great Depression [128]. The financial crash of 2008-09 caused an overall dip in emissions of 1.3 % which quickly rebounded and shot up to 5 % by 2010 as economy recovered, leading to an all-time high [15]. To combat the global final crisis, in 2009 Chinese government launched a stimulus of $586 billion most of which was expended in large scale infrastructure projects, caused this pollution explosion. The current scenario may face situations like revenge pollution, where the bounce back effect reverses overall drop in emission [51].

SARS in china depressed the economy hard in Q2 of 2003, but it bounced back with a vengeance as situation achieved normalcy. A similar trend in economy could be expected in the second half of this year if COVID-19's spread is brought under control. Though global oil demand has not contracted this year, but if COVID-19 affects the supply chain, international travel, and Chinese growth as well, then one could think of 2008—when oil demand did not recover until the next year. It is likely that COVID-19 will end up somewhere in between the two [129]. Though IHS Markit expects positive growth demand rest of the year, Chinese economy growth will drop from 5.4 % to 3.9 % if rest of the world head into recession. Economists predict a plunge in economic activity in the major economies during the first half of the year, with a sharp rebound in the second half if the situation could be brought under control [91]. Albeit the pandemic has made the global economy fall by half, the OCED predicts it to still grow in 2020 [130]. According to researchers like Glen Peters of Center for

International Climate and Environment Research in Oslo, 2020 may still witness an overall drop in global emission of 0.3 % which is less striking than the 2008-2009 crash, but with a possibility of less rebound if measures to recover the economy are focused towards clean energy sector [14]. The emissions have already started to rebound in China, the earliest epicenter of the pandemic as the country has restarted its factories [131]. Furthermore, one alarming issue is that the pandemic could complicate the present activities regarding clean energy scenario, making it vulnerable as companies fail to provide necessary finance in any pending solar, wind or battery projects. Besides being one of the largest producers of solar panels, wind turbines, and lithium-ion batteries that power electric vehicles and grid storage projects china is grappling with production, shipment and supply issues [132]. China being the main supplier of rare earth elements, needed for making solar panels, electric and hybrid vehicles further worsen the situation [133] while cheap oil and gas prices crashed the Tesla's electrical vehicle market stock to lowest in recent times on 9th march. Any Clampdown on trade with China will further disrupt these clean-energy supply chain and distribution networks. As in case of India, which imports 80 % of its solar panel from China, already facing serious trouble [132,133].

Apart from these there are a few potentially countervailing forces as well. A Eurasia Group analyst argued to Axios that a portion of stimulus to eradicate SARS-CoV-2 must be spent in the clean energy sector [134]. The difference in China's energy consumption is significant as renewable energy sector comprise around 20 % of installed capacity currently comparing to 2 % during the Great Recession in 2009. Renewables have a win-win situation during the first two months of national lockdown in China resulting 1 % and 12 % increase in wind and solar energy sector respectively while thermal power generation dropped 9 % year-on-year in January and February [91] (Fig. 6b). The change in carbon-intensive behaviour that the pandemic initiated due to our rapid responses to withstand the acute danger, remote working

and virtual conferences to avoid travelling etc., can long last if we take some societal changes as per climate change demand [132]. Reponses about current coronavirus outbreak have drawn mixed opinion among climate scientists and activists. A group of scientists speculate in the midst of an economic plunge and public health dilemma, people and policymakers would understandably become more concerned about health crisis and pocketbook affairs -i.e. their jobs, retirement savings, homes and slummed economy and as an outcome the longer-term dangers of climate change would take a back seat. But for others, the community action has ignited hope for the climate in the longer protracted term.

5.2 Persistent behavioural changes would impart a notable impact

As the COVID-19 pandemic continues to spread globally, governments of several countries are becoming stringent regarding the movements of citizens to arrest the transmission of this highly contagious disease. As a result of complete lockdowns in such countries billions of people around the world are being compelled to be under restrictions and during this phase changes in daily lifestyle of people are actually driving the climate change to an opposite direction. Such behavioural alterations would be a great help to combat climate change if those last for a long run. Negligence towards behavioural changes is a common practice among policymakers and researchers as they are mainly concerned with energy consumption and rely on technological measures [135,136]. As lifestyle plays a significant role in GHGs emission from household, behavioural interventions regarding driving personal vehicles, availing flights, diet, shopping and other household works should be taken into consideration to meet the international targets [135,136-139]. Changes in such activities in daily life could result in emissions of around 2.5 t CO_2eq per capita by 2030 and 0.7 t CO_2eq by 2050 which would help the planet to be in line with the goal Paris agreement of limiting the rise in global temperature to 1.5 °C compared to pre-industrial era without depending on negative emissions. Currently

emissions due to lifestyle are about 10.4, 4.2 and 2.0 t CO_2eq in case of Finland, China and India respectively [140].

A significant decrease in emission has been observed ranging from 54–1041 kg CO_2-eq per driver per year due to cut in use of personal vehicles[133]. The facilities like free transit passes or e-bike rentals was found effective to change the habit of driving cars [141,142]. Hence, by providing low-carbon infrastructure like bike lanes and public transit policymakers could encourage the people. Nowadays, as air travel is becoming cheap people tend to travel by air frequently which might be due to its association with social prestige and cultural incentives. As a result of it, current contribution of tourism towards global GHGs emissions is about 8 % which is more than the total contribution of India [143] and is projected to continue to grow [144]. Keeping this in mind people should continue to avail air travel to a lesser degree even after this pandemic to build a carbon neutral world. According to Charles Duhigg, the author of the book "The Power of Habit", an effective reward is required to adopt a new habit [123]. So, governments should step forward with better policies to sustain such behavioural changes as rewards/incentives, taxation, parking management and telecommuting has been found promising for lowering the road and air traffic [141]. On a psychological point of view, in future a group of people might love to spend time with family than opting a vacation trip which in turn would reduce the emissions from flight. The propensity of working from home through telecommuting and attending conferences in virtual platforms would also play a pivotal role for curbing carbon footprint. A transition towards plant-based diets has been found effective to reduce carbon footprint [145,146] especially in high or medium-income countries. On an average 0.8 t CO_2-eq reduction per person per year was observed by Wynes and Nicholas [124] due to having plant-based diets instead of eating meat. On the other hand, during COVID-19 pandemic people are instructed not to stock up food and commodities so that there would be sufficient supply for all. Such promising practice of buying even after the lockdown phase

would help us to develop a sustainable world as the world wastes about one third of the food [147]. Feedback based on normative comparisons to neighbours regarding the behavioural interventions in high-emitting domains of personal vehicle use, availing flights and meat consumption was found effective to reduce household emissions [148]. During the pandemic many people might order essential commodities through e-commerce and the practice would be helpful to develop a low-carbon economy in future [149] because of logistically organized, centralized delivery routes and driving less. Contrarily purchasing fast moving consumer goods (FMCGs) through pure players with parcel delivery tends to emit more GHGs than that of traditional retail while GHGs footprints are way more in case of bricks and mortar compared to pure players when vehicles are used for shopping but a significant reduction in GHGs footprints in daily life could be achieved by curtailing a separate trip for shopping by applying trip chaining [150] (shopping when returning home from work). Many consumers are highly willing to pay for same-day delivery which affects the routing efficiency and hence, it would be effective only if they order in a bulk and avoid fast delivery services [150-152].

5.3 Retardation of progress in the climate crisis

Despite of a positive changes in environment in various part of the globe this pandemic is becoming a turning point towards the progress in mitigating climate change. The slow progress in climate actions that has been revealed after this sudden environmental restoration during the pandemic would lead a group of people to be more conscious regarding the future activities. On the other hand, diversion of people's minds from the climate crisis would be another outcome as saving lives is of utmost concern in this global medical emergency. Again, according to Professor Martin Siegert, co-director of the Grantham Institute for Climate Change at Imperial College London, shifting towards a low-carbon economy requires a bulk of investments and burden of managing the coronavirus outbreak might be responsible for a serious hindrance in transition towards clean energy [153]. According to U.N. Secretary-

General Antonio Guterres, fighting climate change along with a virus is not a desirable way but one has to also consider the loss of human and animal lives due to droughts, wildfires, floods and other extreme disasters indulged by climate change [154]. In a report of World Meteorological Organization, Guterres said that the planet is way off track to achieve the 1.5 °C or 2 °C targets of the Paris Agreement which should be kept in mind as the pandemic is expected to be temporary but climate change will remain as a serious problem which requires continuous effort [155]. Cancellation and postponement of notable mass events due to COVID-19 pandemic has made the situation even more difficult to make discussions or to develop strategies regarding climate. The biggest climate event of the year, 26th Conference of the Parties (COP26) set to take place in Glasgow in November has been shelved till 2021 by the United Nations Framework Convention on Climate Change (UNFCCC) [156]. The COP26 supposed to come up with more rigid plans and climate agenda to curb GHGs emissions after the failure of COP25 held in Madrid. All the meetings scheduled for April both in Bonn, Germany, the headquarters of UNFCC as well as around the globe have been cancelled or postponed. African Climate Week, was set to take place from 20 to 24 April in Uganda and London Climate Week, that was scheduled from June 27 to July 5 were also postponed [157,158]. The 15th conference of the parties (COP15) to the Convention on Biological Diversity (CBD), the most vital biodiversity conference has been postponed for indefinite time, earlier which was scheduled for October, 2020 in Kunming of south-western China [159]. The Ocean Conference 2020, UN conference on protecting marine biodiversity and all meetings of the International Maritime Organization (IMO) have been deferred for uncertain period of time [158]. Three days of nationwide protests of Greenpeace, Sunrise Movement, Sierra Club and other climate activist groups in April coinciding with the 50th anniversary of Earth Day have been called off in United States. After suspension of ‘Friday school strikes’, Swedish teenage

activist Greta Thunberg has urged for digital activism instead of physical protests amidst the pandemic [160].

Disruption in regular meteorological monitoring and researches regarding climate science has been appeared as a troublesome issue due to the current response of the world towards coronavirus pandemic. The World Meteorological Organization (WMO) has expressed its concern regarding quantity and quality atmospheric and climate monitoring as air traffic has been greatly affected by coronavirus outbreak [161]. Due to restrictions and bans on aviation during this pandemic in several parts of the world, particularly over Europe, the meteorological measurements has been disrupted strikingly during March, 2020 as Aircraft Meteorological Data Relay programme (AMDAR) is associated with several commercial airlines which use on board sensors and communication systems to monitor meteorological parameters (Fig. 8). Though most of the satellite components and ground observing networks are automated but in many developing regions, the shifting towards automated systems is still in progress. As a result of reduced man power, WMO is facing difficulties to achieve accuracy in forecasting due to lack of maintenance and data supply from such manual observation systems. Leaders of Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) were forced to cancel research flights in support of the *Polarstern*, the German ship deployed to investigate the impact of climate change on the Arctic [162,163]. The EastGRIP 2020 field season, the annual mission for monitoring glacier movements in East Greenland has also been called off for the entire year due to outbreak of SARS-CoV-2 [164]. Such disruptions in the field researches associated with Greenland and the Arctic could largely hinder the researches on climate science and its funding in a long run.

5.4 Government policies and public response

Under current chaotic scenario people as well as policymakers are fighting hard to get rid of this situation but when the issue of climate change comes in front row, we are too slugger to deal with it and often tangled with national and global policy issues. Countries around the globe are facing difficulties to handle two major catastrophes at once and prioritizing pandemic situation over climate issues, unable to understand how devastating those would be than, what people are experiencing today [165]. Nations are announcing stimulus packages to boost up health, economic wellbeing as well as job creation but must not forget the climate - the basis of our existence for building a more resilient and sustainable society. Before providing any economic stimulus and incentives those should be screened through the lens on the basis of sustainable climate and zero carbon technologies [166] This can be achieved by setting a science-based strategy for the companies by integrating decision making with science, prioritizing clean technologies, more investment in renewables and grid technologies. These will help in reducing emissions while providing job opportunity as well as safeguarding economic growth, without disrupting the agenda of Paris agreement [165]. Sufficient investment in renewable energy sectors would help the economic recovery from COVID-19 by spurring global GDP gains of almost $100tn (£80tn) between now and 2050 as well as the rise in global temperature will get curbed as using renewables in place of fossil fuels will reduce the CO2 emission by 70% by 2050 [167]. National government can also play a role for positive behavioural changes by encouraging regional governments, through impetus to take suitable steps, building database and policies to reduce emission or systematize information sharing on best practices as well. A Swedish policy, Klimatklivet, designed by national government finances regional, local and business programs to curb the emissions, has promoted over 3200 projects till date, reducing 1.57 million tons of CO_2 yearly at an average price of €38 ton^{-1} [168].

As the pandemic is likely to halt the growth of the clean energy sectors, Government can use their policy to boost up the condition of renewable sectors by either providing substantial stimulus or reducing the subsidies of non-renewable sectors [153] or by providing handsome incentives, rewards to ensure job security after post COVID-19 period [169]. In this regard Indian government rejected power distributors unwillingness to buy electricity from renewable sector citing a 'force majeure' [170], while funding $100 million in green bonds by State Bank of India will further support non-conventional energy sector for a sustainable future after this catastrophe [171]. New Climate Economy in its report shows, a shift to renewable or low-carbon economy have the potential of making $26 trillion of economic growth and 65 million of new jobs by 2030 [172]. Governments can also implement bans or restrictions on high-emitting transits (e.g., air travel). With this very concern US democrats urged President Donald Trump to put restrictions on greenhouse gas emission and ocean dumping before providing any financial help to US airlines and cruise industries [173]. Hong Kong's government in their recent budget include a series of green policies along with a roadmap for clean public transport system [48]. Countries should provide more finance in the underfunded schemes of health sector like Green climate fund, Climate investment fund and Adaptation fund to fight with climate issues along with the pandemic [174]. Personal protective equipment (PPE) and ventilators should also be in sufficient quantity in order to fight not only against Coronavirus but with other climatic hazards in near future [175]. Besides, it needs better policies to resolve the issues of plastic waste disposal in downstream, as generated from the PPE, Masks and Gloves in post pandemic period [176].

Public polling reflects the fact that people, concerned about the climate issues, are more likely to follow policies of less air travelling [177], or eating less meat which shows concerned mind set for climate mitigation as demanded by climate issues [178]. These kinds of behavioural changes due to COVID-19 surely have long term implications in curbing carbon

footprint and climate change issues [179]. Smart technologies have a great contribution to the climate change activities, for example, smart systems with the help of machine learning and cloud computation, allow using energy more efficiently or providing climate services; satellites make us informed about activities all over the world like deforestation; the composite view of virtual and augmented reality shows how a location will look like under different changes of climate, last but not the least, social media make the link between activists and young people to generate awareness and to collaborate in new ways [180]. Undoubtedly climate change possesses a serious threat to health, economy and mankind. At this crucial juncture integrating revival of health and economy coupled with climate activity will surely blow up the economy like never before while reducing emissions at the same time. At the face of gravest danger, COVID-19 has made us realise that governments can act promptly and decisively, and people can change their behaviour for the sake of mankind. The approach should also be adopted by the whole world to confront the challenge of climate change.

6. Conclusion

As saving lives in an unprecedented challenge is of paramount interest, governments around the world have imposed stringent restrictions to contain the rapid spread of novel coronavirus (SARS-CoV-2). As a result of it, significant restoration in air quality and ecology has been observed. Satellite images of European Space Agency (ESA) and NASA have indicated an appreciable decline in air pollution over several parts of the world, that are regarded as major hotspots of pollutants such as NO_x, CO_2 and $PM_{2.5}$. Prolonged lockdowns resulted in drastic reduction in anthropogenic activities responsible for GHGs emissions. The shrinkage in emissions could be attributed to reduced industrial activity, consumption of fossil fuels, electricity demand, road transport, aviation and even due to behavioral changes achieved at the time of physical distancing. A pandemic that is claiming people's lives certainly should not be the way of bringing about environmental improvement, but the situation seems to be a turning

point towards climate change. Burden of managing the SARS-CoV-2 outbreak, could emerge serious drawbacks toward a cleaner economy and scientific advancement to mitigate climate change. Again, possibility of bouncing back of emissions in future is posing questions on the persistence of this current environmental restoration. Contrarily, a wiser part of the world would be more conscious regarding the future activities after revelation of the slow progress in climate actions during this pandemic. By observing the optimistic response of governments and people in tackling this catastrophe, it does seem possible to sustain this climatic restoration for a long term, but only through committed and resilient coordinated policies as well as active individual participation.

Author contributions

A. Mandal conceptualized the article structure, content and figures. A. Mandal, R.R. and D.G. wrote the entire manuscript and compiled data with significant contribution from S.M. and A. Majumder. S.S.D. and A.S.T. provided substantial suggestions and edits. All authors edited and approved the final manuscript.

Conflicts of interests

The authors declare no competing interests.

Additional information

Extended data figures are available

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Tables

Table 1. Percent reduction in major pollutants (NO_x, PM_{10} and $PM_{2.5}$) in air after complete lockdown (average of 1-6 April, 2020) as compared to prior-lockdown period (average of 1-6 March, 2020). (Data Source: SAFAR-India [56])

Cities	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
	(% reduction)		
New Delhi	60	51	49
Mumbai	60	49	45
Pune	62	32	31
Ahmedabad	32	47	52

Table 2. Quality parameters of River Ganges (Ganga) observed 2 weeks after initiation of complete lockdown in India (Data Source: Central Pollution Control Board of India, Reported by: Hindustan Times [74]). Observed data for both upstream and downstream flow indicate average of the readings recorded by a number of monitoring stations.

Parameter	**Permissible range**	**Observed Avg. Readings**	
		Upstream	**Downstream**
Dissolved oxygen (mg/litre)	> 5	8.70	8.31
Biochemical oxygen Demand (BOD) (mg/litre)	< 3	2.10	1.66
pH	6.5 – 8.5	7.90	7.80
Ammonia (mg/litre)	< 1.2	0.49	0.95
Chemical oxygen demand (COD) (mg/litre)	< 10	< 9	< 9

Figures

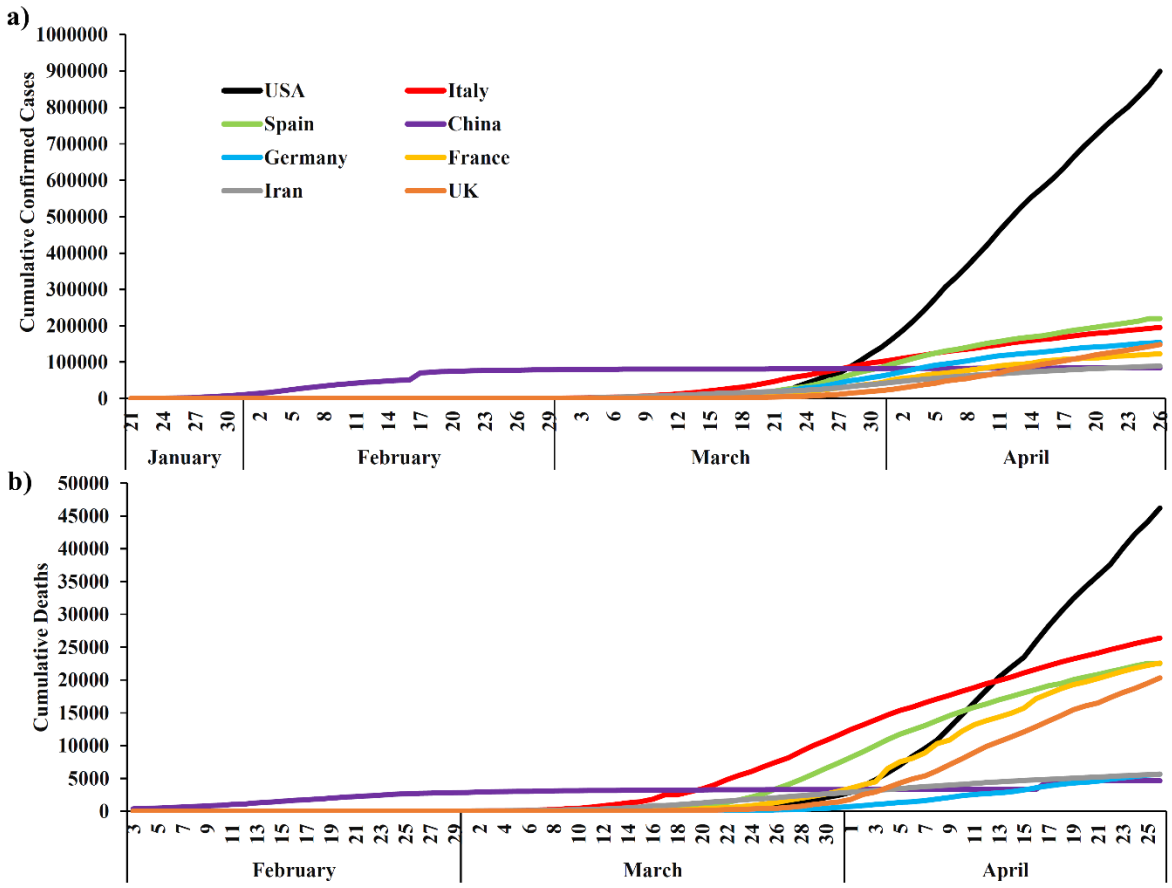

Fig. 1 Temporal changes in **a)** cumulative daily laboratory-confirmed cases of coronavirus disease 2019 (COVID-19) and **b)** daily numbers of deaths from different countries. Line diagrams are prepared by the Debrup Ghosh and Agniva Mandal using situation reports published by WHO till 26th April, 2020.

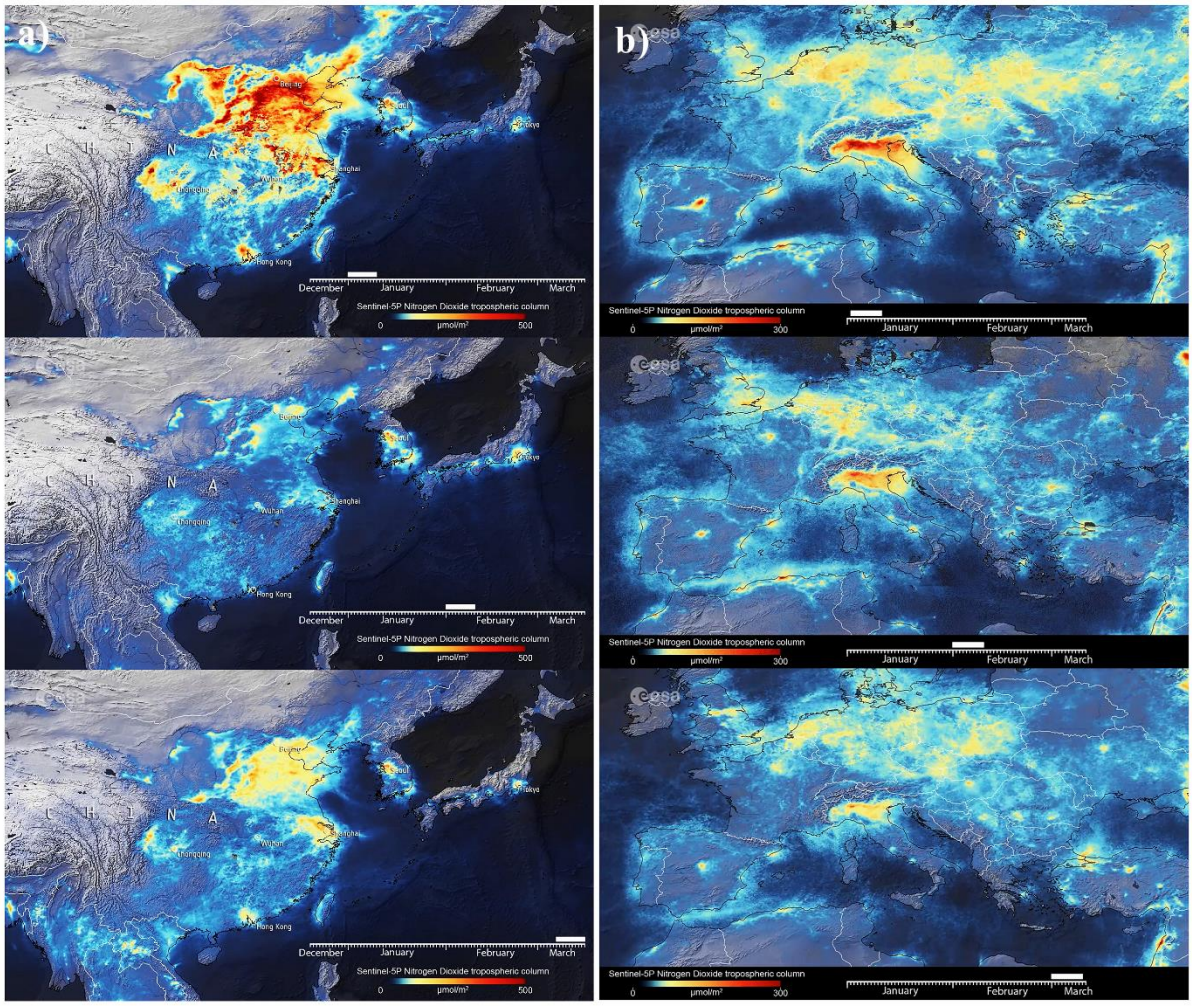

Fig. 2 Satellite images of Copernicus Sentinel-5P depicting alterations in NO_2 concentrations in air over a) China [40] and b) Europe [42]. NO_2 concentrations in the air during January, February and March, 2020 are presented in descending order. Moving average data of 10 days were used to prepare the satellite images for each months.

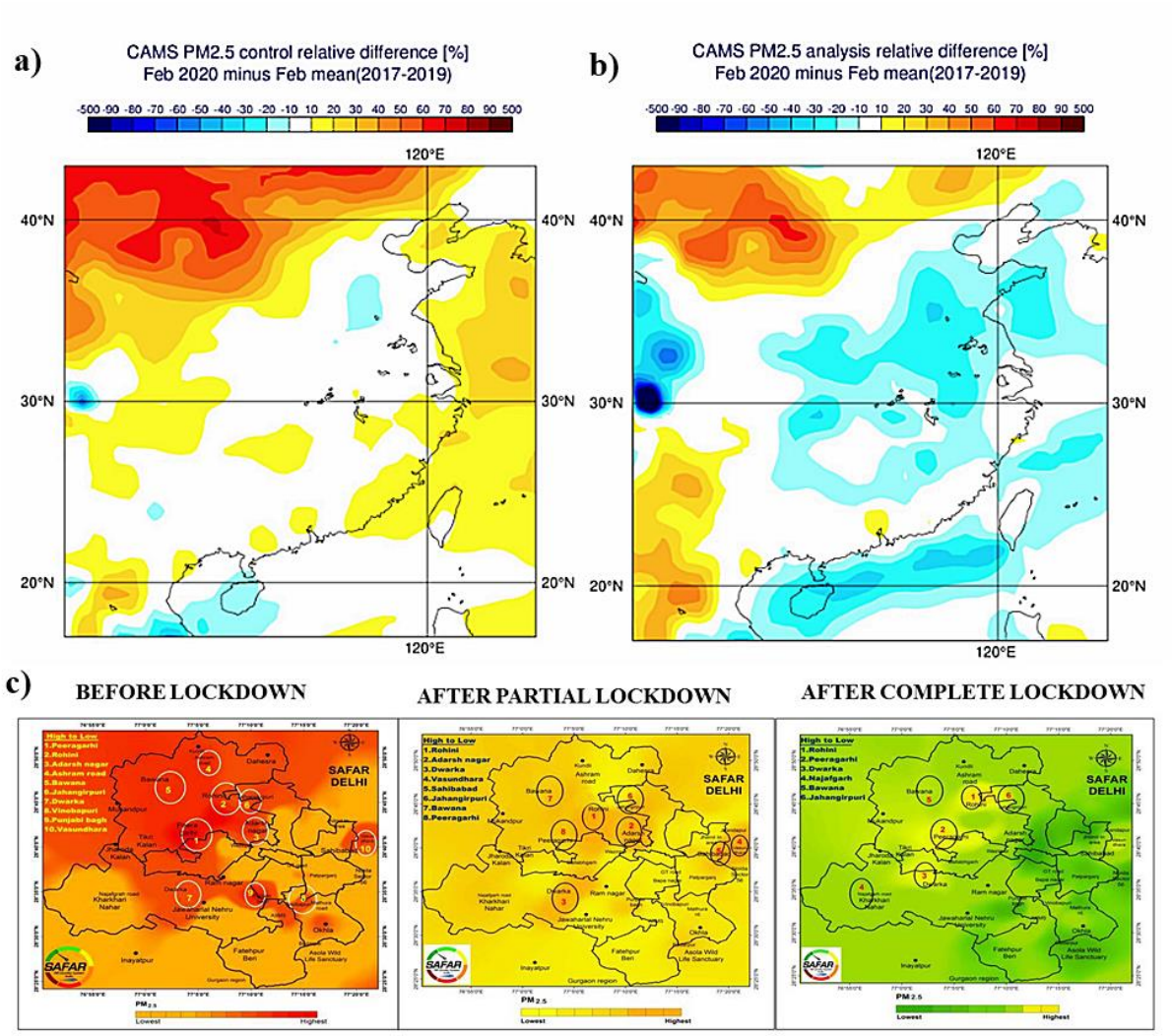

Fig. 3 Percentile **a)** control relative difference (satellite observations of aerosol are not included) and **b)** analysed relative difference of fine particulate matter ($PM_{2.5}$) levels for February 2020 compared to the February mean over the years 2017-2019 over China [49]. **c)** Status of $PM_{2.5}$ concentration in air of New Delhi before lockdown, after partial lockdown and during complete lockdown period [56].

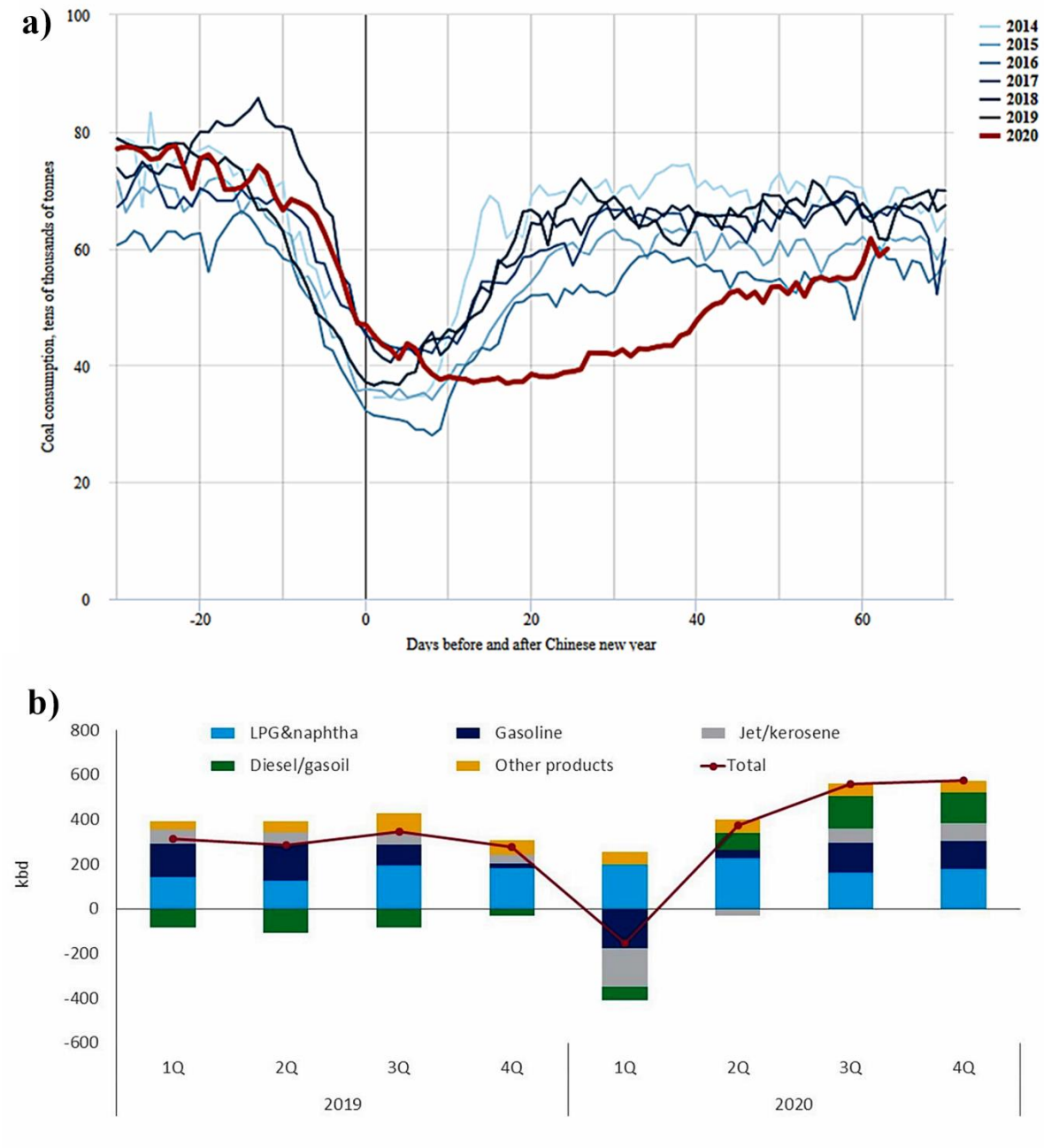

Fig. 4 a) Daily coal consumption (in 10000 t d^{-1}) in 2020 as compared to previous six years around the Chinese new-year period at six major Power firms of China [15]. **b)** Year-on year comparison between China's oil demand in 2019 and the demand predicted for 2020 after novel coronavirus outbreak [83].

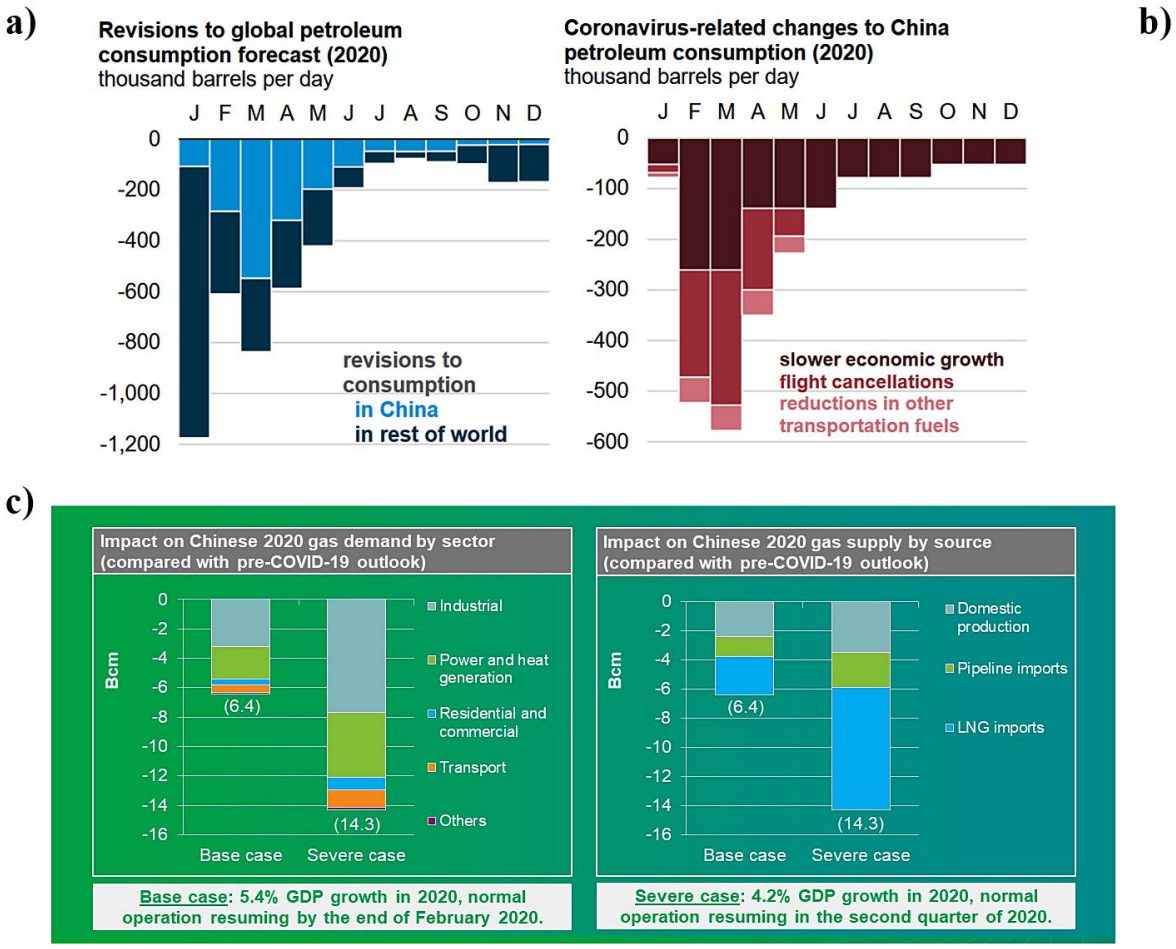

Fig. 5. Revised petroleum consumption (thousand barrels per day) forecast of U.S. Energy Information Administration (EIA) based on changes in **a)** global and **b)** Chinese demands after novel coronavirus outbreak [88]. **c)** Changes in gas (LNG) demand growth and supply sources in China due to COVID 19 pandemic [84].

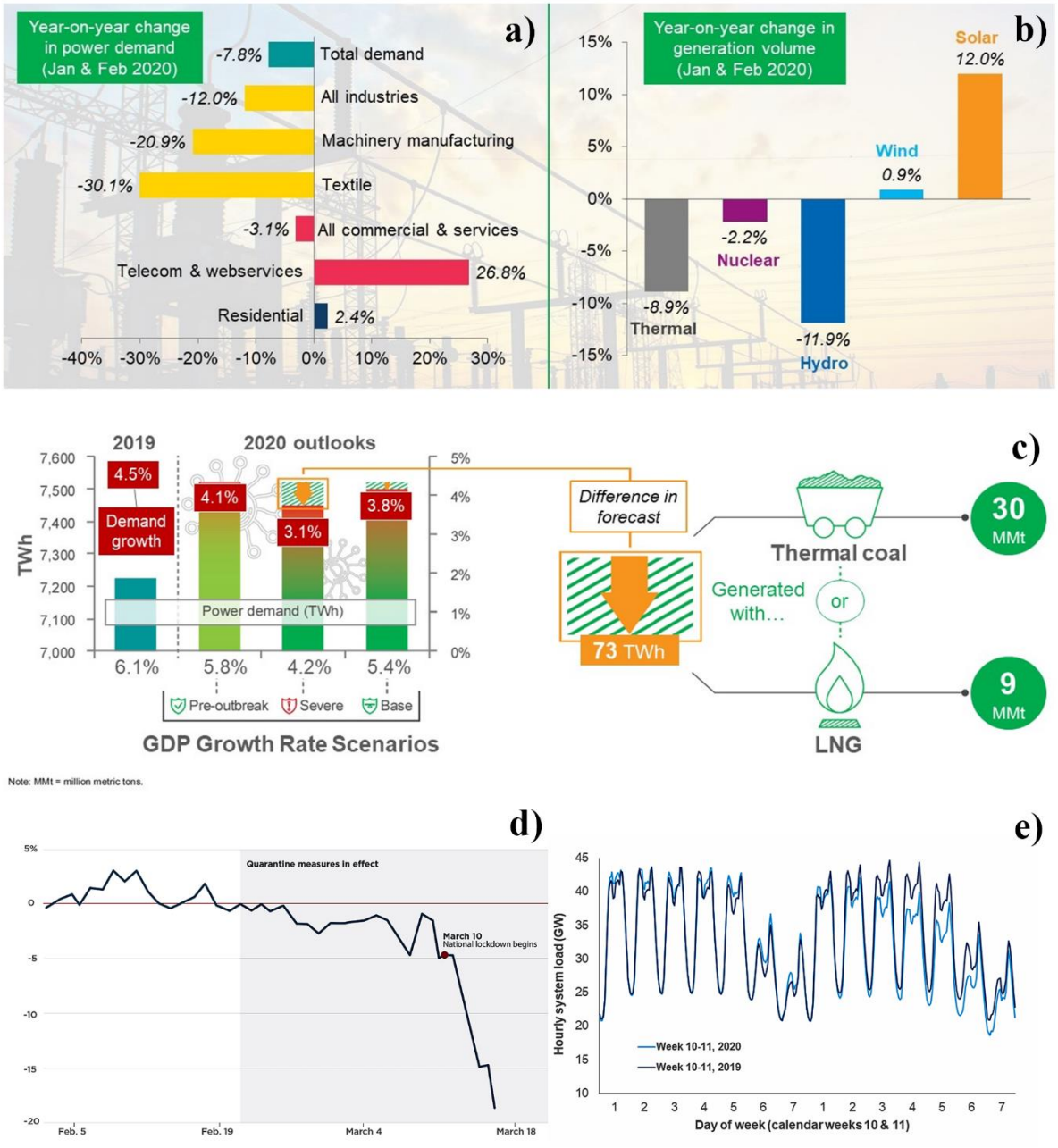

Fig. 6. Year-on-year (2020 vs 2019) changes in **a)** power demands in different sectors and **b)** power generation volume of different sources in China. Only data of January and February were considered for both 2019 and 2020 [91]. **c)** Impact of COVID-19 on the predicted power demand of China. Pre-outbreak outlook predicted a 4.1 % growth in electricity demand for a 5.8 % GDP growth. Revised outlook indicated about 3.8 and 3.1 % growth in power demand for base (5.4 % projected GDP growth) and severe (4.2 % projected GDP growth) case respectively [92]. **d)** Per cent changes in electricity

demand after imposition of lockdown (10^{th} March, 2020) as compared to previous month (February, 2020) [93]. **e)** Year-on-year (2020 vs 2019) comparison of changes in power demand during week 10-11 in Italy [94].

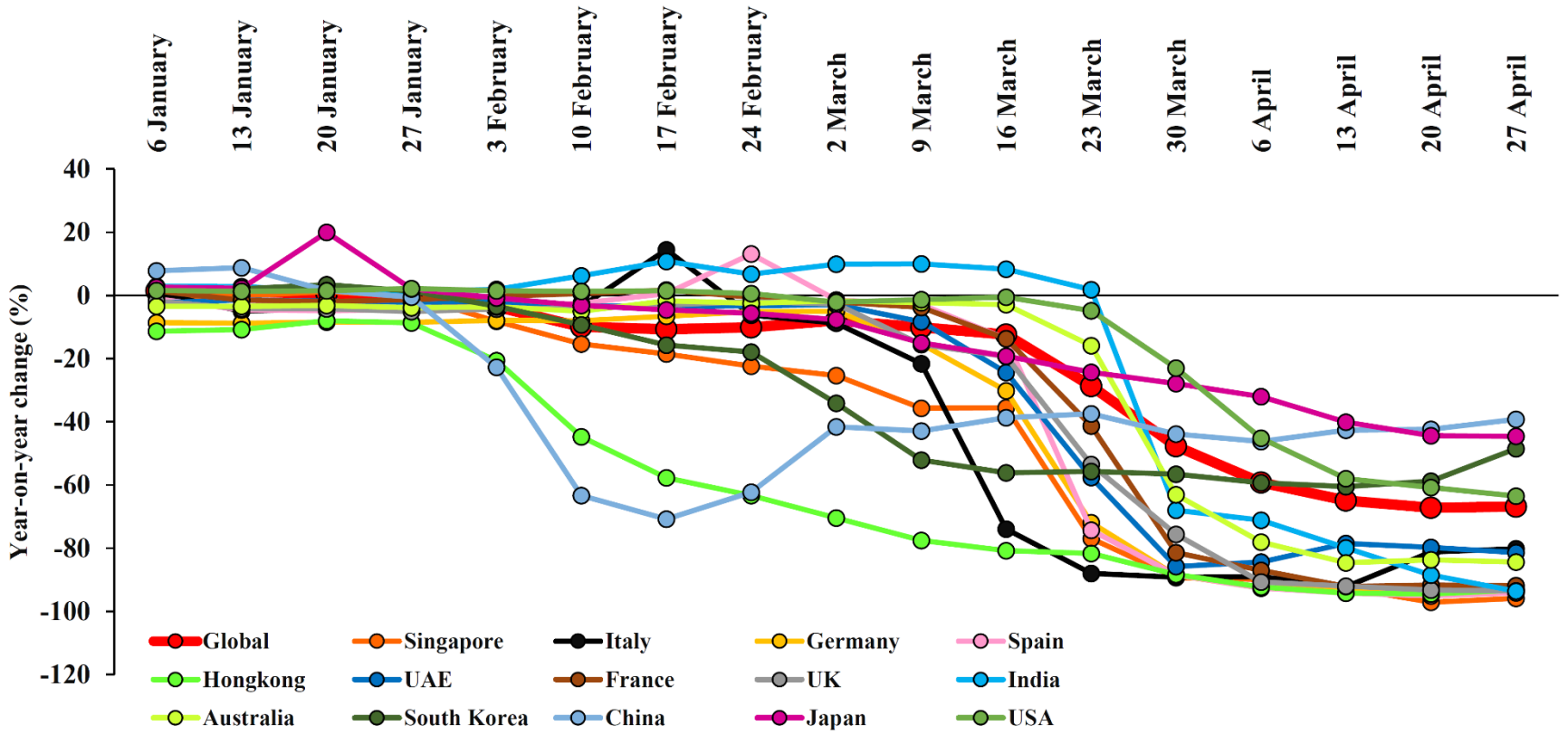

Fig. 7. Year-on-year change (6th January to 30th March, 2020) of weekly flight frequency around the globe (Prepared by Agniva Mandal, Data Source: OAG [106]).

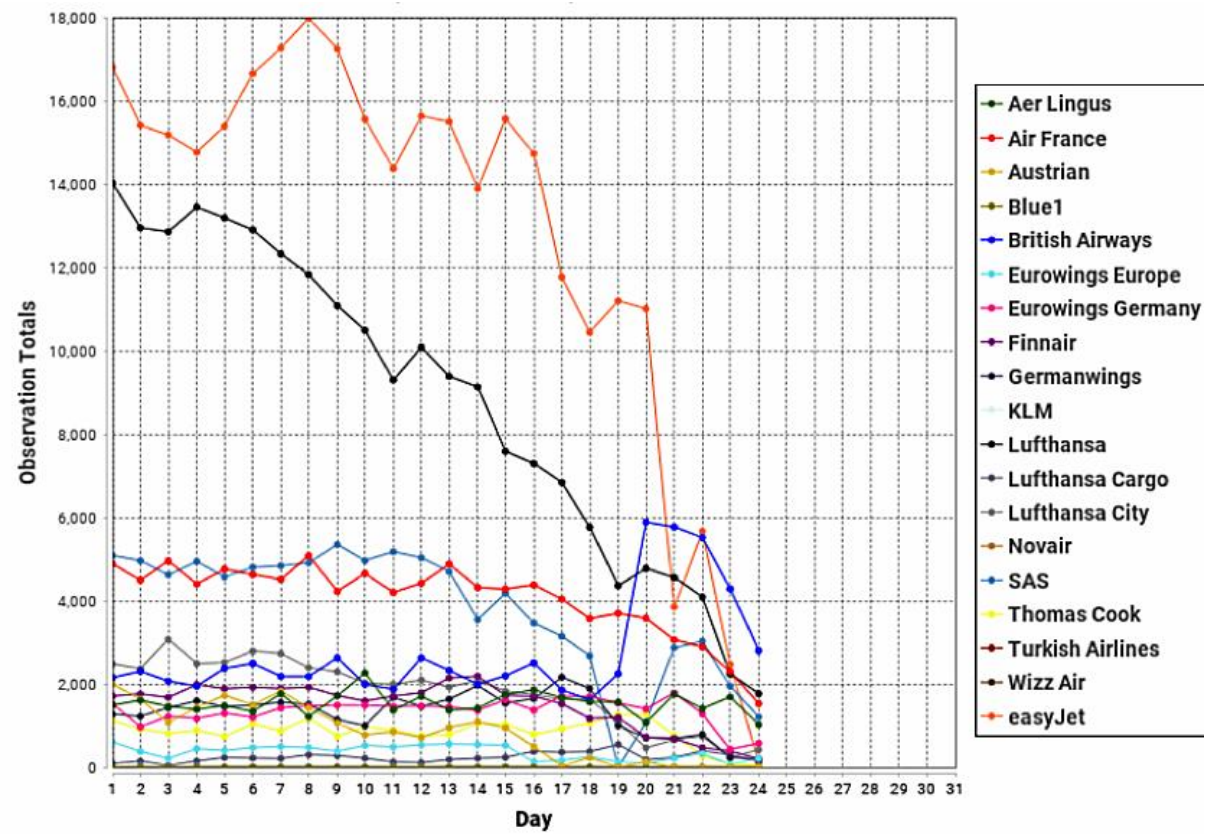

Fig. 8. Reduction in AMDR (Aircraft Meteorological Data Relay programme) observations due to disruption in airlines of different regions due to novel coronavirus outbreak [161].