Resource management: ways to sustain the environmental gains of COVID-19 lockdown

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Abstract
Natural resources are under constant exploitation due to industrialization and urbanization. Ecological disturbance caused by over exploitation of resources is one of the possible reasons for the outbreak of COVID-19 pandemic. Due to the highly infectious nature of this disease, countries across the world have taken self-imposed isolation measures such as lockdown, quarantine, curfew, etc., to limit human-to-human spread. Though this pandemic has shaken the world and left millions suffering, it has also caused surprising positive effects to environment. Due to reduced human pressure on ecosystems during the lockdown, betterment of air, water quality and biodiversity along with reduced consumption of natural resources have been reported. It is necessary to maintain this improvement in order to avoid the environmental benefits slipping away once the world limbs back to normalcy. The benefits acquired in terms of resource conservation prompt us to avoid unnecessary human interference and adopt sustainable life styles. Wide usage of information and communication technologies (viz. work from home, teleconferencing, e-learning and e-commerce) during the pandemic revealed their potential in meeting the needs of human livelihood and played a significant role in improvement in air quality and reduced resource consumption. Implementing them should be a policy measure during an environmental crisis. Active government involvement is necessary for coordinating institutional and policy aspects of resource conservation. Smooth transitioning to more sustainable post-COVID world thus requires coordinated action at individual, local, national and international levels. Restoring environmental resources is essential to prevent future pandemics.

Keywords COVID-19 · Resources conservation · Environmental quality · Lifestyle · Education · Technology

1 Introduction

Mother earth provides natural resources such as air, water, soil, minerals, fossil fuels forests, oceans, flora and fauna, which are vital for sustenance of life forms. These resources are under constant exploitation for meeting the ever-increasing demands of mankind.
Natural disasters and disease outbreaks frequently occur due to over exploitation of resources for industrialization, urbanization, etc. The recent pandemic caused by COVID-19 has shaken the earth leaving millions infected with deaths exceeding 760,000 within a few months of its outbreak. It also has the potential to infect million more. It has taken a toll on the global economy and livelihood. Nations all over the world are struggling to protect public health, economies, trade, etc., from this perilous pandemic.

Respiratory droplets of size greater than 5–10 μm in diameter from the infected person are the main cause of corona virus infection (WHO, 2020). It is reported to be transmitted by human-to-human contact and also by indirect contact with infected persons (Huang et al., 2020; Li et al., 2020; Liu et al., 2020). Social distancing and sanitation are the essential elements that control the infection rate of corona virus. So as to control the transmissivity of this infection, governments across the world have implemented containment measures such as total shut down, quarantine and curfews to ensure social distancing. By the end of April 2020, almost 90% of world’s population was under different forms of confinement.

Though COVID-19 pandemic has left millions suffering, it has caused surprising positive effects too. It seemed impossible to save our ailing oceans, suffocated atmosphere and scared animal resources from the shackles of human exploitation. Now there is a ray of hope to conserve our natural resources due to the pause caused by the pandemic. Environment is breathing a sigh of relief as industries and transportation sectors came to a complete halt due to the lock down and self-quarantine measures imposed by governments. Nature has gained in terms of reported improvement in quality of its various components. It is necessary to maintain this improvement in order to avoid the environmental benefits slipping away once the lock down is lifted.

In this article, we have given a comprehensive evaluation of the environmental gains acquired in conserving natural resources such as air, water and biodiversity during shutdown. Among the four major sub-systems of earth (air), hydrosphere (water), biosphere (living things) and lithosphere (land), the positive effect on environment during COVID-19 imposed lockdown was more evident on air, water and biocomponents (as endorsed by a majority of the publications), suggesting that these key environmental indicators have been exploited to a larger extent. Hence, these are chosen as an evaluation index. Scientific evidences on improvement in quality of air, water and biodiversity observed by various research groups have been compiled in this paper. Adopting eco-friendly measures, technological strategies, change in mindset, policy intervention, etc. are suggested as ways to sustain these vital resources. This review would help regulators, policy makers and the common man to reorient and march toward conserving the natural resources for achieving the sustainable development goals (SDGs) of the United Nations.

2 Environmental gains of COVID-19 lockdown

2.1 Air and atmosphere

Atmosphere, which consists of layers of gases, is vital for existence of life forms. Atmospheric gases surrounding the earth give protection from dangerous UV rays of the sun. Oxygen, nitrogen and carbon dioxide the major components of earth’s atmosphere are necessary for survival. Over the years, the air quality has been deteriorating due to over exploitation by mankind. Air pollution is one of the major causes of illness and death in
many countries. According to WHO data, 90% of world’s population breathes polluted air. Transport and industrial sectors and construction activities are the major contributors of air pollution.

Due to the shutdown, improvement in air quality, reduction in noise pollution, reduction in travel-related accidents, reduction in demand for coal and oil and reduction in global carbon emissions were observed. Blue skies with breathable air were reported in many nations which otherwise face severe air pollution problems. Short-term improvement in air quality with reduced emission of NO₂ was reported in China due to the decreased economic activities during the pandemic (Wang & Su, 2020). Reduction in levels of nitrogen dioxide and carbon monoxide to an extent of 0.00002 mol m⁻² and < 0.03 mol m⁻² in the pandemic affected hotspots was reported during Feb–Mar’ 2020 (Lal et al., 2020). Due to the imposed restrictions, 50% reduction in air pollution levels in New York and 40% reduction in consumption of coal by China’s thermal power plants have been reported (Saadat et al., 2020). Reduced NO₂ emission levels were observed in Europe (Ficetola & Rubolini, 2020). Among the south Asian countries, Delhi, the national capital of India, which is the most polluted city in the world (WHO 2016) with hazardous air quality has been reported to have 40 to 50% reduction in criteria air pollutants such as NO₂, CO, PM₁₀, PM₂.₅, SO₂, O₃ along with ammonia (Mahato et al., 2020). Ambient air quality analysis (Fig. 1) over a 04-year duration (2017 to 2020) revealed lowest levels of NO₂ (20 µg/m³) and PM₂.₅ (30 µg/m³) in air during 2020 as against the maximum levels of around 55 and 150 µg/m³ observed, respectively, during 2017 (Myllyvirta & Dahiya, 2020). During the lockdown, improvement in air quality has been reported across the world (Table 1). NASA satellite images showed 30% reduction in NO₂ levels in the pandemic-infected China (NASA, 2020).

Fossil fuels are major source of energy and an important component of global economy. Worldwide, the dependency on fossil fuel derived energy varied from 32.1 to 100% (BP

![Fig. 1 Year-wise comparisons of NO₂ and PM₂.₅ levels in Indian cities (Average) (Myllyvirta & Dahiya, 2020)](image-url)
| Sl. No | Name of the country and study details | Air pollution parameters studied | Reductions/ improvements achieved | Reference |
|-------|--------------------------------------|-------------------------------|----------------------------------|-----------|
| 1     | Italy—Milan city (air quality analyzed during partial and total lockdown conditions) | PM$_{10}$, PM$_{2.5}$, Black carbon, Benzene, CO, SO$_2$, NO$_x$ | PM$_{10}$ 48.3%, PM$_{2.5}$ 47.1%, Black carbon up to 71%, Benzene upto 69%, CO maximum 57.6%, SO$_2$ 25.4%, NO$_x$ 74.5% | Collivignarelli et al., (2020) |
| 2     | Spain (Barcelona) Air quality was analyzed traffic and urban background stations | PM$_{10}$, BC, NO$_x$, SO$_2$, O$_3$ | PM$_{10}$–27.8%, BC–45.4%, NO$_x$–47%, SO$_2$–19.4%, O$_3$–28.5% * | Tobías et al., (2020) |
| 3     | India (North, South, East, West and Central India) Air quality during lockdown period was compared to the previous years | PM$_{2.5}$, PM$_{10}$, NO$_x$, SO$_2$, CO, O$_3$, Air quality index (AQI) | 43, 31, 10, and 18% reduction in PM$_{2.5}$, PM$_{10}$, CO, and NO$_x$, respectively, were observed 17% increase in O$_3$ and negligible changes in SO$_2$ observed AQI reduced by 44, 33, 29, 15 and 32% in north, south, east, central and western India, respectively | Sharma et al., (2020) |
| 4     | Kazakhstan (Almaty) Air quality during 27 days lockdown was observed | PM$_{2.5}$, NO$_x$, SO$_2$, CO, O$_3$, BTEX (Benzene, toluene, ethylbenzene o-xylene) | PM$_{2.5}$–21%, CO–49%, NO$_x$–35%, SO$_2$–7%*, O$_3$–15% * Benzene and toluene concentrations were 2–3 times high Ethylbenzene and o-xylene concentrations were 4 and 2.7 times less | Kerimray et al., (2020) |
| Sl. No | Name of the country and study details | Air pollution parameters studied | Reductions/improvements achieved | Reference |
|-------|--------------------------------------|---------------------------------|---------------------------------|-----------|
| 5     | Malaysia | PM$_{2.5}$ | PM$_{2.5}$ showed a high reduction of 58.4% during the Malaysia Movement Control Order (MCO) Red zone areas showed 28.3% reduction in PM$_{2.5}$ concentrations The Northern Region of Peninsular Malaysia showed 23.7% reduction in PM$_{2.5}$ | Abdullah et al., (2020) |
| 6     | Northern China | PM$_{2.5}$ PM$_{10}$ NO$_2$ SO$_2$ CO | On average, the air quality index decreased by 7.80% PM$_{2.5}$–5.93% PM$_{10}$–13.66% NO$_2$–24.67% SO$_2$–6.76% CO–4.58% | Bao & Zhang, (2020) |
| 7     | Brazil (Rio de Janeiro) Impact of partial lockdown on air quality of the city was analyzed | PM$_{10}$ NO$_2$ O$_3$ CO | CO—48.5% PM$_{10}$–33.3% O$_3$ a NO$_2$ 32.1% | Dantas et al., (2020) |
| 8     | China and Wuhan | PM$_{2.5}$ NO$_2$ | NO$_2$ dropped by 22.8 μg/m$^3$ in Wuhan and 12.9 μg/m$^3$ in China PM$_{2.5}$ dropped by 1.4 μg/m$^3$ in Wuhan and 18.9 μg/m$^3$ in China | Chen et al., (2020) |
| 9     | India (Delhi) Air quality of city during 3 weeks of lockdown starting from 24th of March 2020 was analyzed | PM$_{2.5}$ PM$_{10}$ CO NO$_2$ SO$_2$ NH$_3$ | PM$_{2.5}$–53.11% PM$_{10}$–51.84% NO$_2$–52.68% CO–30.35% SO$_2$–17.97% NH$_3$–12.33% | Mahato et al., (2020) |
| 10    | Morocco (Sale city) | PM$_{10}$ NO$_2$ SO$_2$ | PM$_{10}$–75% NO$_2$–96% SO$_2$–9% | Otmani et al., (2020) |
| Sl. No | Name of the country and study details | Air pollution parameters studied | Reductions/ improvements achieved | Reference |
|-------|--------------------------------------|---------------------------------|----------------------------------|-----------|
| 11    | France NO\textsubscript{2} concentration was observed using Copernicus Sentinel-5P satellite | NO\textsubscript{2} | 20–30% | ESA (2020) |
| 12    | USA                                  | NO\textsubscript{2} | 30% reduction in NO\textsubscript{2} concentration was observed using Aura satellite | NASA, (2020) |

* Increased in concentration
Statistical Review, 2017). Fossil fuels also have the dubious distinction of contributing to air pollution. Carbon dioxide, carbon monoxide, nitrogen oxides (NOx), sulfur oxides (SOx) and particulate matter are the primary pollutants emitted during fossil fuel burning. It also contributes to negative environmental impacts such as global warming, ozone layer depletion, acid rain, etc. Greenhouse gas emission from fossil fuel combustion has proven physical and psychological health impacts (Perera, 2017). Though the trends in consumption of fossil fuels have been ever increasing pre-COVID-19, decline in fossil fuel and oil consumption has been observed across the globe during the lockdown (Dutheil et al., 2020). As the demand for fossil fuel reduced, huge price cut down has been reported globally (Muhammad et al., 2020). Lowering trends in carbon emission was observed due to decline in world consumption of oil and oil-derived products (Duan et al., 2020).

2.2 Water

Water, one of the fundamental resources for sustaining life, has been subjected to continuous deterioration by human activities. As the borders of nations were closed and tourist’s numbers have got reduced drastically, and industries have come to a complete halt, water bodies have been reported to have lesser pollution load. Water canals of Venice in Italy had noticeable decrease in pollution levels with increased visibility of fishes (Saadat et al., 2020). Satellite remote sensing studies reported improved water quality in Vembanad lake, one of the longest fresh water lakes in India. The images gave evidence of reduction in suspended particulate matter in water to an extent of 34.6%. Time series analysis of data (2013 to 2020) revealed lowest SPM levels in 50% of the zones during the month of April’ 2020 (Yunus et al., 2020).

Lockdown imposed during COVID-19 could provide a unique opportunity to environmental scientist for collecting data on point source of pollution in rivers. As industrial operations have come to a complete halt, systematic testing and data collection on water quality could serve as baseline through which point source of pollution could be detected (Saraswat & Saraswat, 2020). Enhanced phytoplankton growth was reported in Hooghly estuary of the Ganges River in India due to decline in pollution load during lockdown (Mukherjee et al., 2020). Table 2 summarizes few reported studies on improvement in water quality observed across the world.

2.3 Biodiversity

Biodiversity and animal habitat have been diminishing drastically over the years due to the disturbance caused by anthropogenic activities. Ever-increasing global population, habitat conversion, deforestation and climate change due to pollution and invasion by exotic organisms and diseases are the major reasons, which put the biodiversity under constant threat. Tropical rainforest and marine ecosystems hold more than 90% of biodiversity. Noise from air, water and land transport causes tress to flora and fauna. Oil pollution in oceans and human coastal activities endanger the survivability of marine habitats.

Though there seems to be no hope for reviving the biodiversity, terrestrial and aquatic ecosystems have found a silver lining during the lockdown. Marine, land and wildlife species pushed their boundaries and started returning to their natural habitats due to the nil and minimum disturbance. As the transport and industrial activities near the beaches and on the sea have been halted, reduced levels of noise and reduction in ocean pollution loads have been reported by news agencies. Sighting of coyotes and foxes in the US cities,
## Table 2 Improvement in water quality observed across the world during COVID-19 lock down

| Sl. No | Name of the country and study details | Water pollution parameters | Reductions/ Improvements achieved | Reference |
|--------|--------------------------------------|-----------------------------|----------------------------------|-----------|
| 1      | India, Ganges river                  | Dissolved oxygen            | 23%                              | Lokhandwala and Gautam 2020 |
|        |                                      | Biological oxygen demand (BOD) | 25%                             |           |
| 2      | Nepal (Bagmati river basin)          | Dissolved Oxygen            | DO increased by 1.5 times        | Pant et al. 2021 |
|        |                                      | BOD                          | BOD decreased by 1.5 times       |           |
|        |                                      | COD                          | COD decreased by 1.9 times       |           |
| 3      | Turkey (Meriç-Erngene river Basin, especially Ergene river and Çorlu stream) | Metals (Cr, Ni, Zn, Cu, As, Pb and Cd) | Metal concentrations decreased significantly | Tokatali and Varol 2021 |
|        |                                      | Total hazard index values for children and adults | Total hazard index values for children and adults reduced by 67 and 69% respectively |           |
|        |                                      | Total carcinogenic risk values for As | Total carcinogenic risk values for Cr |           |
| 4      | Malaysia (Putrajaya lake)            | BOD                          | Considerable decrease in BOD, COD TSS | Najah et al., (2021) |
|        |                                      | COD                          | WQI improved from class 2 to 1   |           |
|        |                                      | TSS                          |                                 |           |
| 5      | China (Min river)                    | TSS                          | TSS decreased by 48%             | Xu et al., (2021) |
| 6      | India, Subsurface water, Coastal city, Tuticorin (March’2020 to May’2020) | Arsenic                      | 51%                              | Selvam et al, (2020) |
|        |                                      | Cadmium                      | 50%                              |           |
|        |                                      | Selenium                     | 42%                              |           |
|        |                                      | Iron                         | 60%                              |           |
|        |                                      | Lead                         | 50%                              |           |
|        |                                      | Nitrate                       | 56%                              |           |
|        |                                      | Total and faecal coliform    | 52 & 48%                         |           |
| 7      | Morocco, Boukhalef river (April 2020 measurements compared with April, 2019) | Escherichia coli | Decreased | Cherif et al, (2020) |
| 8      | South Asian countries (Pakistan and India) | coastal water quality, phytoplankton densities and algal blooms investigated using changes in chlorophyll (Chl-a) and turbidity | 50% reduction in Coastal Chl-a and 29% reduction in turbidity was observed | Shafeeque et al., (2021) |
wild boars in Spain, deers in Japan’s subway have been reported (Nagendra, 2020). Due to reduced human mobility, wild life and sensitive animal species were seen freely moving in rural and urban areas (Corlett et al., 2020). Over 1.5 lakh migratory flamingo birds visited Mumbai wetlands during April 2020 breaking their earlier records. According to news reports, the endangered hawksbill sea turtle and Olive ridley sea turtles were seen hatching on deserted beaches of Brazilian and Indian coasts. Uninhibited animal behavior patterns have been reported from many places (Table 3).

3 Lessons learnt and ways to sustain the environmental benefits of COVID-19 lockdown

Findings on improved environmental quality during corona pandemic lockdown have made us think about how to sustain these gains from slipping away. Redefining the environment in post-COVID requires unified action at individual, local, national and global levels. Technological interventions, individual life style changes and institutional and policy approaches are key drivers in sustaining the environmental benefits acquired during the lockdown.

3.1 Technological interventions

Harnessing technological innovations for sustainable development leads to effective resource management with environmental and economic benefits. Societal changes were felt necessary to curtail the spread of virus, and hence, the world witnessed large-scale transition to information and communication technological (ICT) options such as work from home (WFH), E-learning, video conferencing and E-commerce for telecommuting. These technologies have never been used on a global scale before COVID pandemic. Apart from preventing the spread of virus, application of these technological interventions can greatly contribute to resource conservation (Fig. 2). Improved air quality and reduced fuel consumption and traffic congestion are the major benefits of telecommuting (Bentley et al., 2016). Fuhr and Pociask (2011) reported that telecommuting could reduce the greenhouse gas emissions in the USA to an extent of 588.2 tones by 2021 due to reduced patterns of energy consumption, construction and travel. Effect of WFH concept on urban traffic and air quality was studied in Switzerland. Analysis of data over duration of 10 years (2002 to 2013) revealed reduction in traffic congestion and air pollution to an extent of 2.7 and 4.1 percent, respectively (Giovanis, 2017). The advantages of digitization were more evident in the urban setting. Marginalized and disadvantaged lot of the global population was unable to make use of these e-platforms. Accessibility to mobile phones, electricity and internet connectivity have hampered the efficient utilization of digital technology in rural areas. Socio-economic status, resource availability, territorial difference and literacy level are some key factors, which amplified the existing inequalities during the pandemic. Disadvantages of vulnerable population to digital inequality lead to increase in unemployment, devoid of technology-oriented health care and quality education and poor accessibility to products and services. An intersectional approach is necessary to bridge the digital divide (Zheng & Walsham., 2021).

Evidence of increased usage of these scientific innovations for networking during the lockdown is presented in this section.
## Table 3  Improvements in biodiversity observed across the world during COVID-19 lock down

| Sl. No | Name of the country and study details | Biodiversity/bioindicators | Improvements achieved | Reference |
|--------|--------------------------------------|-----------------------------|-----------------------|-----------|
| 1      | India                                | Fish densities in the reef areas | Significantly increased from 406 no. 250/m² to 510 no. 250/m² | Edward et al. 2021 |
| 2      | Latin America (Beaches)              | Ghost crabs, Dune vegetation, viz, beach grass, vines and shrubs | Significant increase in densities | Soto et al. 2021 |
| 3      | Northern, Middle and Eastern Jordan Badia rangelands | Shrubs and grasses | Increase in area covered by vegetation | Sawalhah et al. 2021 |
| 4      | India (Sundarban)                    | Mangrove Fauna              | Increase in Mangrove faunal diversity | Chaudhuri & Bhattacharyya 2021 |
| 5      | Italy                                | Birds, amphibians, reptiles | Increase in species richness higher breeding success of an aerial insectivorous bird, and reduction in road-killing of both amphibians and reptiles | Manenti et al. 2020 |
| 6      | StoraKarlso island (Baltic Sea)      | Sea eagles                  | Sevenfold increase in presence of white-tailed eagles *Haliaeetus albicilla*, a sevenfold increase in their disturbance of breeding common murres *Uria* | Hentati-Sundberg et al. 2021 |
| 7      | Israel                               | Coral reef fish             | Elevated species richness at designated reef entrances, predominantly influenced by increased evenness | China et al. 2021 |
3.2 Work from home

To stop the spread of virus and to ensure social distancing, companies/organizations get their job accomplished by asking their employees to work from home. WFH has both environmental and economic benefits. It is efficient in making people cope-up with their work-related responsibilities while staying at home (Elavarasan and Pughazendi, 2020). Multi-national companies such as Google, Amazon, Microsoft, etc., have rolled out WFH policy to curtail the spread of virus. As per government’s order, during the lockdown, Indian information technology (IT) industries started implementing WFH model, and 90% of employees successfully worked from home out of which 65% worked from homes in metros and the remaining from homes in small towns strictly adhering to quality output (The economic times, 2020). This transition on WFH should be encouraged post-COVID-19, which could contribute to reduction in travel-related emissions and also is economic as there will be a considerable reduction in travel and infrastructure-related expenditure.

3.3 E-education and video conferencing

Across the globe educational institutions were forced to close down to prevent the spread of COVID-19. During this time of crisis, virtual learning platforms came to the rescue and ensured continuation of learning process. Academic institutions have started switching over to on-line platforms such as ‘Zoom’/‘Google Meet’/‘Teams’/‘Webex’ for inter-active sessions, ‘Voxvote’ for quizzes, ‘Testmoz’ for tests, ‘Canvas’ and Google Classroom for academically engaging students during the lockdown (Zayapragassarazan, 2020). Apart from virtual meeting platforms, there was a marked surge in usage of other Internet platforms such as WhatsApp and Skype for enabling smooth learning.
during the lockdown. A customized e-learning framework implemented at Polito University in Italy during February to April 2020 revealed enhancement in learning patterns and online collaborations through internet. An increase in ingoing (10 times) and outgoing (2.5 times) Internet traffic was observed with a marked surge in remote classes being attended even during weekends.

COVID outbreak lockdown has made institutions and companies to organize conferences and meetings on virtual mode. Many planned conferences have got cancelled or held through video conferencing, which is a catalyst for reducing the carbon footprint. It will become a new normal for business and scientific communities as it covers wider audience and discussion prospects are better through video conferencing. Resources consumption in terms of making logical arrangements for meetings and providing infrastructure can be minimized by virtual conferencing, as it may lead to less waste generation. McConnell, 2013 compared the efficiency of face-to-face meetings with collaborative professional learning through video conferencing. Findings revealed that though teachers prefer face-to-face interactions, video conferencing could be an effective tool when time and distance factors become barriers.

Video call services also helped to maintain emotional and mental health of societies, as it enabled families, friends and relatives to work closely in a virtual mode during the lockdown. Network and mobile data traffic have increased manifolds across nations. A 70% increase in usage of video calls, voice calls and messaging app was reported in Italy during the lockdown. Spanish telecommunications company Telefonica has reported increase in mobile data traffic up to 50%. Video conferencing also played a major role in telemedicine, exchange of medical diagnostics and treatment related discussions during the viral outbreak. In Singapore hospitals, coordination and interaction of radiological experts between inter- and intradepartments to manage the COVID infection were promoted through video conferencing (Tsou et al, 2020).

3.4 E-commerce

Executing business through digital means, referred as E-commerce, is reported to reduce carbon emissions to an extent of 209 mt of CO₂ and online procurement of standard electronic goods was found to reduce carbon footprint to an extent of 84% in comparison with purchase through conventional e-retailing (Carling et al., 2015). A study conducted to comparatively evaluate the CO₂ emission from conventional retail mode of business and e-commerce in Shenzhen, China, revealed that environmental cost implications were less in E-commerce and the total CO₂ emission difference between the two modes was estimated to be 124 million tonnes in 2016. Infrastructure and travel were the source of CO₂ emission in retail mode, and packaging was responsible for CO₂ emission from E-commerce (Zhao et al., 2019).

E-commerce could play a significant role during COVID-crisis. As visiting malls and big shopping complexes are discouraged as a precautionary measure, e-commerce platforms take a lead in meeting the needs of resource supply and demand. These online shopping strategies have marked environmental contributions in terms of reduced emissions and resource consumption. E-commerce was described as a sustainable and safe business option for vulnerable people and health workers during COVID emergency situation, and food orders were executed mostly through online in Italy and Spain during the pandemic (Pantano et al., 2020).
3.5 Life style changes and society–responsible consumption and production

The ever-increasing global population, which is expected to reach 9.6 billion by 2050, would require 3 more earth planets to meet the demands of human needs. The lockdown served as a catalyst for coming up with plans and recovery policies for transforming a human society that adopts a need-based consumption pattern. A human society which instills reduce, recycle, reuse and recovery policies as its voluntary life style option could leave the environment to future generations in a better form. Sustainable resource production and consumption are one of the central themes of united nation’s sustainable development goals, which discourage resource-intensive lifestyle patterns (Akenji & Bengtsson, 2014). Understanding how to co-exist with other components of nature will enable human civilization to move in a matured and positive manner. Environmental impacts of European lifestyle aspects were assessed using an environmentally extended input–output simulation model framework wherein the carbon foot print of sustainable life style models was compared with the already existing scenarios. Land and water usage patterns, greenhouse gas emissions and toxicity potential were the environmental factors assessed. Adopting vegan lifestyles, durable clothing, reduced transport and sharing mentality in humans could contribute to reduction in carbon footprints to an extent of 14, 3, 26 and 18%, respectively (Vita et al., 2019). Thus, human lifestyle patterns have significant environmental effects.

Corona lockdown has paved way for net-zero emission concept prompting humans to change their life style in a positive way. Forced home containment has enabled many humans to opt for healthy lifestyle changes such as improved physical activity, eating healthy home cooked food, spending quality family time, etc. that indirectly contributes to environmental conservation. Healthy life is an important component for a country’s economy as poor health leads to spending more for maintaining health care. Disrupted supply chains and the resultant economic crisis created by the pandemic have prompted societies to make efficient use of local resources for maintaining industrial production and adopt need-based consumption patterns (Cohen, 2020).

The pandemic has made us change our life styles in a positive way. Humans have learnt to adapt to optimum resource consumption, resource substitution, reduced waste generation, reduced travel and recycle as much as possible. Governments and businesses should take lead in advocating economic, health and environmental benefits obtained from adopting a low-carbon lifestyle. These behavioral and institutional changes if carried over post-COVID could contribute in minimizing the carbon footprint. The lockdown can accelerate transition toward need-based consumption with a sense of unity and purpose (Cloete, 2020).

3.6 Institutional and policy aspects

Natural resource management is intertwined with environmental protection. Institutional and policy aspects play a key role in management of natural resources. They are instrumental in conceptualization and implementation of environmentally conscious decisions, balancing traditional versus alternative approaches of resource consumption and mitigating natural hazards. Decisions on resource management could be at local, national or international level. Temporary benefits obtained on conservation of natural resources due to COVID-19 lockdown can be leveraged to long-term gains by coordinated actions at individual, local, national and international levels.
3.7 Promoting affordable and clean energy

Significant reduction in climate change impacts could be accomplished by switching over to renewable energy options. Renewable energy resources have environmental benefits in terms of reduced emissions of particulate matter and greenhouse gases. Policy proposals should encourage production of energy efficient fuels from waste biomass, provide incentives for low-carbon transport strategies and promote eco-friendly electric power, bioethanol, compressed natural gas and other renewable energy options, as global trends in consumption of renewable energy (Fig. 3) are low presently (IRENA, 2019). Hydro-power occupies the major share (44.7%) of renewable energy consumption followed by equal shares contributed by solar photovoltaic (22.9%) and onshore wind energy (23.4%). Other renewable options such as biogas, geothermal energy, liquid biofuels, municipal waste, solar thermal energy, etc. contribute the remaining 10% share. Policy interventions are essential for enhancing the pace of renewable energy transition. Policies should adopt a system-based approach and evaluate the renewable energy options based on their cost effectiveness and environmental benefits. Integrated planning that defines roles and responsibilities for every stakeholder in the energy sector is necessary for effective transition to renewable energy options. Regulators should encourage innovative approaches, which phase out fossil fuel-based energy systems. Hydrogen Breakthrough Steel Making (HYBRIT) project undertaken by Sweden is an example of government supported project that aims to replace fossil fuels by hydrogen-based energy for steel production (Karakaya et al., 2018).

Reduction in greenhouse gas emissions (up to 80% by 2050) is forecasted as one of the necessary steps to be taken for achieving the sustainable development goal on climate action (Griggs et al., 2013). Transitioning to clean energy alternatives and phasing out fossil fuels are vital for obtaining climate and air quality gains (Hanif et al., 2019; Shindell & Smith, 2019). Electric vehicles (EVs) are emerging as one of the most sustainable transport modes. Potential of E-bike in reducing the greenhouse gas emission was assessed under varying temperature, distance and rainfall conditions in Switzerland, and the energy demand was modeled accordingly. Findings showed that savings in energy and GHG emission to an extent of 17.5 and 10% could be achieved by e-bike deployment (Bucher et al.,

![Fig. 3 Global trends in renewable energy consumption by International renewable energy agency, 2019](image)
though disposal of the batteries is a concern. Effective deployment of EVs by smart grid control and opting for electricity generation by renewable sources are the major factors, which need to be considered for optimal utilization (Foley and Gallachoir, 2015) of electric powered vehicles.

Discouraging the use of motorcar and transition to walking or cycling mode for short distance travel causes improved health and environmental gains. Bicycles are referred as the most economic and sustainable zero carbon emission transport mode (Gatersleben & Appleton, 2007) which has many economic and health benefits. In many developing countries, the roads are hostile for cyclists. Dedicating separate lanes for cyclists will ensure safety and encourage more utilization of this most ecofriendly transport mode.

Waste to energy (WtE) is yet another sustainable option that conserves fossil fuels, generates electricity and also disposes off waste. Agricultural waste, municipal waste, liquid and solid waste from industries and energy crops are the major sources of biomass-derived energy. Waste to energy routes (WtER) have the potential for distributed energy supply (Kothari et al., 2010). At present, incineration is the most adopted technology for generating energy from waste. Switching over to technologically advanced anaerobic digestion/composting process for energy generation from waste could prove to be an eco-friendly option. Efficient energy recovery is a challenge when opting for WtE, and the economic viability of energy recovery from MSW is highly dependent on the availability and characteristics of the waste feedstock (Bisinella et al., 2017). Policies should strengthen research and development for improved energy recovery and provide subsidies for their industrial level production.

3.8 Clean water and sanitation

Access to good quality water, sanitation and hygiene are fundamental necessities in the fight against any disease outbreak. Urban slums have become the potential hotspots of rapid spread of COVID-19 infection. Water hygiene in urban slums can be regulated by providing improved water supply infrastructure and funding support. Sustenance of improved quality of water resources can be accomplished by establishing more real-time water quality monitoring network (Dawood et al., 2020), improved technology and infrastructure for water treatment and pollution abatement, adopting ecologically focused low energy-intensive treatment, engineered natural systems for water pollutant removal and ecosystem-based approaches (EbA) such as eco-bioremediation that utilizes the natural degradation abilities of both plants and microorganisms with civil engineering and biological interventions for optimal performance. Adopting internationally agreed water quality standards and guidelines will ensure safe water for all (Ahmed et al., 2021).

3.9 Biodiversity conservation (life below water and life on land)

Biodiversity conservation could be managed by imposing /strengthening policies that regulates infringement of protected animal habitats, exploitation of animal species for human consumption, invasion of exotic organisms and diseases, resource allocation, and restoration of species habitat. Environmental impact assessment a tool that integrates environmental and social aspects in decision-making should have biodiversity conservation as one of its essential components. Establishing ways for co-existence and cohabitation with natural species is the most sustainable approach for biodiversity conservation. Marine biodiversity conservation is essential for protecting the health of ecosystem. Policies should
regulate over exploitation of marine resources and marine pollution. The COVID-19 lockdown gave an opportunity for the revival of marine resources. Governments should come up with a road map for retaining these temporary benefits and focus toward rebuilding a sustainable ocean economy.

As per the Global Assessment Report on Biodiversity and Ecosystem Service (2019), around a million living species face the threat of extinction. Conservation of forest resources will reduce the climate change impacts and ensure a healthy ecosystem. United Nations Environment Programme (UNEP) in 2016 warned an increase in incidence of zoonotic diseases, which is possibly due to the over exploitation of natural habitats. Government policies should come up with an action plan to restore land resources in a scientific manner.

3.10 Climate action–sustaining the improved air quality

Implementing short-term shut down measures after taking in to consideration of the aspects of economy could be an effective solution for controlling emergency environmental pollution scenarios. As the air quality levels became hazardous in Delhi, the Indian capital city, community health emergency was declared in the year 2017 (Chowdhury et al., 2019). Temporary shutdown thus could be a viable step during emergency situations. Governments should implement realistic decarbonization strategies to reduce global GHG emissions. Observing no vehicle day, encouraging people to use cycle, phasing out polluting vehicles and old power plants, strict enforcement of polluter pays principle, capacity building, strengthening research and development are other policy interventions which if implemented can bring immediate benefits for the climate as well as the health and livelihoods of millions (Fig. 4).

Governments should mandate adoption of austerity measures in the tourism system by way of cutting down on unplanned travel, extravagant logistical expenses and encouraging virtual conferences. The learning from the pandemic should lead the global tourism industry to reorient toward achieving SDGs which can play a major role in reducing GHG emissions and climate change impacts (Gössling et al, 2020).

3.11 Sustainable cities and communities and sustainable economic growth

Small actions can lead to big changes. Individuals have a major role to play in resource conservation. Encouraging optimum utilization of resources and avoiding wasteful consumption should be the way of life. During lockdown, humans have learnt to learn with the available resources. These habits need to become new normal in the post-COVID world.

Technological innovations widely used during lockdown can be translated to long-term approaches. E-education can be made as an integral component of academic curriculum. Telecommuting using ICT is an effective resource management strategy. This strategy should be incorporated as a viable solution in environmental policies, which can be implemented as a response to emergency situations wherein environmental pollution has caused public health crisis. These web-based technological strategies technologies have advantages, but also the dubious distinction of having negative impacts such as poor social interaction and reduced physical activity, etc. (Table 4). Therefore, utilizing them in an optimized manner would make a balance of its positive and negative impacts.

Policy differences before and after the pandemic have both positive and negative environmental impacts. During the pandemic policy measures, viz. lock downs, travel
restrictions, curfews, quarantine measures, closures of academic institutions and social distancing have been enforced to minimize the viral spread. Though effective in confining the spread, these policy interventions have put financial burden on every sector of the economy. Governments across the world have come up with recovery policies and packages to minimize the socio-economic impact. Measures related to work-from home, teaching by on-line platforms and procurement of goods and services through e-platforms have been rampantly implemented to reduce human-to-human contact. It is necessary to analyze the economic and institutional challenges and the magnitude of changes that these transitions would bring when implemented on a large scale. For smooth functioning of these e-platforms, it is necessary to ensure secured and robust network communication system, which is a major challenge in many developing countries. There is also a need for establishing low carbon enabling green ICT network strategies such as cloud computing, green metrics, etc. for sustainable use of these e-platforms (Uddin & Rahman, 2012) and international guidelines to improve the quality of services with respect to cross-border movement of goods and services through e-commerce. Utilizing them in an optimized manner would make a balance of its positive and negative impacts. With governments all over the world mandating the use of personal protective accessories such as masks gloves, etc. for preventing the spread of the disease, roll back/lenience of policies related to single-use plastics has been evidenced during the pandemic, posing waste management challenges. Green transport, control of invasive species, forest conservation and promoting nature-based solutions for waste management should be the critical components of policy measures.

Fig. 4 Institutional and policy aspects for resource conservation in post-COVID world
Table 4  Sociocultural and environmental advantages and disadvantages of web-based technologies

| Sl. No | Technology               | Advantages                                                                 | Disadvantages                                                                 | References                      |
|--------|--------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------|
| 1      | E-learning and video conferencing | a. Saving and documenting of lectures is possible which provides repeated access to students  
b. Provides support study materials viz., FAQs, tutorials, online feedback, etc.  
c. Enables online collaboration  
d. Infrastructure and energy saving  
e. Reduced traffic  
f. Savings in expenditure  
g. Lesser use of paper, as materials are delivered electronically | a. Growing anxiety around the pandemic leading to poor mental health and creating attention deficit in children  
b. Lack of self-discipline due to over-availability of resource  
c. Unfair burden for students in developing countries due to slow bandwidth and low internet connectivity  
d. Expensive tools for conduction of lectures/meetings  
e. Isolation and lack of social contact and lack of co-curricular activities | Itzhak, (2002); |
| 2      | Work from home           | a. Flexible working hours  
b. Increase in productivity and job satisfaction  
c. Less distraction  
d. Employees spend less on traveling which can save their money  
e. Recruit larger pool of potential employees, which decreases the need for managing visas and work permits, and paying relocation expenses for overseas hires | a. Remote working causes security issues which left users vulnerable to having their webcams and microphones hijacked  
b. Social and professional isolation overtime  
c. Disturbance in work-life and home-life balance  
d. Difficulty in monitoring performance and maintaining professional development and upgrading skills | Fuhr and Pociask, 2011; Hook et al., 2020 |
| 3      | E commerce               | a. E-commerce features low barriers of entry in terms of initial capital requirements  
b. Online vendors can get a wide audience through presence and ads on search engines and social networks  
c. Saves travel and time  
d. Effective comparison of models, prices and discounts  
e. Easy handling of return and reimbursement | a. Need for more energy intensive computers  
b. Faster delivery options can lead to increased fuel consumption  
c. Waste generation (packing material) | Tiwari & Singh, 2011; Moriset, (2020)  
Harpaz, (2002) |
4 Discussions and conclusion

Human well-being is always interlinked with a healthy and resilient ecosystem as over exploitation of natural resources leads to ecological destruction, habitat disturbance and spill-over of disease from wildlife to humans (Corlett et al., 2020). Corona pandemic has left millions dying and suffering. Saving human lives and controlling the pandemic should be the foremost aim of our society. Containment measures introduced during COVID outbreak have made us realize that reduced human pressure on ecosystems leads to revival of natural resources. Sustainable resource consumption and self-resilient behavior had a positive effect on the environment. From previous research, it is evident that the COVID pandemic served as a catalyst for positive changes in food, travel and working habits and enabled shift to less energy-intensive platforms and resource consumption patterns. Resilience and coping strategies during the pandemic were found to have a positive effect on the environment, whereas human centric beliefs had a negative effect (Sarkis et al., 2020; Tchetetchik et al., 2021). Encouraging eco-sensitive actions, enhancing public awareness about the linkage between public behavioral patterns and climate change can sustain the environmental gains in the post-pandemic era.

Despite the positive environmental effects, COVID pandemic has also exposed the existing physical, economic and social inequalities in the world that limit the vulnerable population of the society to take advantage of advanced technologies. These inequalities have exacerbated the issues of unemployment, gender and digital divide, etc. Brave steps within and between countries are necessary to address these inequalities.

The insights obtained from the reported scientific evidences on the short-term environmental gains during the lock down prompt us to establish newer ways of conserving natural resources in the post-COVID world and work toward achieving the sustainable development goals. The following recommendations are proposed for sustaining the environmental gains:

- Capacity building and effective communication of environmental perils of climate change and pollution
- Optimum utilization of environmental resources
- Investing on renewable energy future
- Encouraging behavioral change in day-to-day life
- Personal and political commitment and international cooperation for alleviating inequalities
- Prioritizing digitalization and developing techno-centric smart cities
- Effective implementation and enforcement of industry, travel and environment-related regulations
- The policy interventions to have a strong research base, with clear targets and timelines for effective implementation

Environmental issues are directly linked with sustainable global development. The pandemic provided a wake-up call for scientists, government and policymakers to ensure judicious utilization of natural resources. Coordinated efforts at various levels with a long-term strategy are the need of the hour.

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Declarations

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