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Review

Impact of COVID-19 on greenhouse gases emissions: A critical review

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HIGHLIGHTS
• Impact of COVID-19 on global greenhouse gas emission has been reviewed.
• Elevating CO2 emission levels is a major concern worldwide.
• Global energy consumption & relative emission level during pandemic are highlighted.
• Global economic shock during pandemic was observed due to lack of supply & demand.
• An overview to develop sustainable environmental policies is presented.

GRAPHICAL ABSTRACT
The COVID-19 pandemic has considerable impact on global greenhouse gas emissions and the short-term lessons can be significantly helpful to form effective policies for sustainable environmental and energy related issues.

ARTICLE INFO
Article history:
Received 14 August 2021
Received in revised form 10 September 2021
Accepted 11 September 2021
Available online 17 September 2021
Editor: Jianmin Chen

Keywords:
COVID-19
Greenhouse gas emission
CO2 emission
Climate change
Sustainable development

ABSTRACT
The global outburst of coronavirus 2019 (COVID-19) has posed severe challenges to human health, environment, energy and economy all over the world. The stringent measures to control the spread of COVID-19 results a significant slowdown in economic activities which in turn affected the environment by reducing the greenhouse gas (GHG) emissions, specifically lower atmospheric CO2 levels. Considering that, the present study intends to highlight the substantial impact of COVID-19 pandemic on GHG emissions, by systematically reviewing the available scientific literatures. The study further outlined the variation in GHG emissions by comparing the data focused on pre-pandemic, during pandemic, and post-pandemic (predictions) scenarios. Further, the assessment on elevating CO2 levels, global economic, and energy impacts of COVID-19 has also been reviewed. Also, the possible recovery plan for the framework of sustainable environmental and energy development is presented. Finally, the review concludes with an insightful summary involving the challenges and future outlook towards sustainable development goals in a hope that the present study can help the researchers to assess the global environmental and energy related consequences.
1. Introduction

With the global reliance of energy on fossil fuels, the environmental, social, and economic conditions worldwide are unstable. Burning of fossil fuels for the fulfillment of energy demands tend to release vast amounts of greenhouse gases (GHGs) like CO₂, CH₄, NOₓ etc. and causing egregious effects on climate. From observations, industrialization and use of fossil-fuel based automobiles are causing drastic upsurge in GHG emissions out of which transportations is responsible for one fifth of aggregate CO₂ emission with 75% contribution from the road transport (Siddique et al., 2021). However, with increasing population and energy demands all over the world, the chances of elevating CO₂ levels are most likely possible. Therefore, more stringent actions are required to control and limit the CO₂ emission into the atmosphere from transportations and other energy-related sectors. At the same time development of environmentally friendly and economic energy sources with the promise of cleaner environment in the future are highly desirable.

Notably, spread of the novel coronavirus (COVID-19) has created unprecedented influence on the global energy consumption and GHG emissions due to the government enforced lockdown and virtual halt of chief economic activities (Smith et al., 2021). During the initial shutdown period, the restrictions on international air transportations and industrializations substantially reduced the CO₂ emissions proved by various studies. Typically, after analyzing the emissions data for six economic regions across 69 countries, total 17% of reduction in daily CO₂ emissions was observed by April 2020 in contrast with the mean level in 2019. Additionally, Lie et al. reported a global 7.8% decline in CO₂ emissions owing to fossil fuels consumption during 2020Q1 compared to the 2019Q1 (Liu et al., 2020a).

Despite of such positive instantaneous influence, the longer term effects of COVID-19 on energy crisis and elevating atmospheric CO₂ levels are still not clear. It is worth noting that only after understanding the influence of COVID-19 on GDP along with the utilization of clean energy technologies for sustainable solutions of green economy has been presented. Finally, the review concludes with the important insights of the learning and proposes possible tactics as future recommendation for sustainable environment. We anticipate that this timely and up to date study with substantial information can be helpful to amend the environmental policies and develop more sustainable solutions to fight against upcoming pandemics in the future.

2. Methodology

The present study was accomplished by collecting the short-time relevant published literature, case studies, and information from different countries begin to stabilize their economy, the situation might get worst. For instance, a report from ‘The United States Energy Information Administration’ has forecasted that the atmospheric CO₂ levels will upsurge by 6% in 2021 in order to recover the economy (IEA, 2011) by using excessive energy resources. So it is the high time for the governments to form strict policies and eliminate the use of fossil fuels and shift to a more sustainable and ecofriendly energy transition.

Till date, various review articles (Table 1) have critically investigated the impact of COVID-19 on various parameters involving environmental and energy concerns along with the global economy (Elavarasan and Pugazhendhi, 2020; Khan et al., 2021; Le et al., 2020; Sanjuan-Reyes et al., 2021; Shakil et al., 2020). However, an all-inclusive report which covers the latest information on impact of COVID-19 on greenhouse gas emission along with assessment on CO₂ emissions, global economy, energy influence, and sustainable policies for better future is still missing. In this context, the basic theme of this review is to outline the impact of COVID-19 pandemic on GHG emissions. The review critically highlights the energy consumption scenarios and the subsequent CO₂ emission levels pre-pandemic, during pandemic, and post-pandemic with special emphasis on assessment on elevating atmospheric CO₂ levels and global economic energy impact. The long term and short term impact of COVID-19 on environment and sustainability has also been comprehensively summarized. A critical discussion on the influence of COVID-19 on GDP along with the utilization of clean energy technologies for sustainable solutions of green economy has been presented.

Finally, the review concludes with the important insights of the learning and proposes possible tactics as future recommendation for sustainable environment. We anticipate that this timely and up to date study with substantial information can be helpful to amend the environmental policies and develop more sustainable solutions to fight against upcoming pandemics in the future.

### Table 1

| Title | Journal | Highlight of review | Reference |
|-------|---------|---------------------|-----------|
| COVID-19 and the environment: A critical review and research agenda | Science of The Total Environment | Bidirectional characteristics of COVID-19 on environmental quality and degradation | (Shakil et al., 2020) |
| Restructured society and environment: A review on potential technological strategies to control the COVID-19 pandemic | Science of The Total Environment | Technology-based strategies in controlling the pandemic and to support the society | (Elavarasan and Pugazhendhi, 2020) |
| COVID-19 in the environment | Chemosphere | Comprehensive study on impact of COVID-19 on human health, transmission factors, and environmental consequences involving air quality, wastewater, and climate changes | (Sanjuan-Reyes et al., 2021) |
| COVID-19 pandemic and its positive impacts on environment: an updated review | International Journal of Environmental Science and Technology | Positive impacts on COVID-19 on environment involving reduced pollution and declined GHG emission | (Khan et al., 2021) |
| A remarkable review of the effect of lockdowns during COVID-19 pandemic on global PM emissions | Energy Sources, Part A: Recovery, Utilization, and Environmental Effects | An overall picture of global PM pollution during the city-to-nation lockdowns in the COVID-19 period | (Le et al., 2020) |
different government and non-government organizations related to environmental and energy consequences of COVID-19 pandemic. Primary literatures from the major scientific flux were recorded using Scopus, Science Direct, and Google Scholar. It is worth mentioning that the abundance of data available in a particularly short time as can be seen in Fig. 1 which depicts the number of publications in the respective years using Scopus database search with keywords “COVID-19 + Greenhouse gas emissions” and “COVID-19 + energy consumptions”. After analyzing the available literatures, the present review article compiles and outlines the data and information with clear emphasis on impact of COVID-19 pandemic on environmental and energy issues, as argued in the forthcoming sections.

3. Global greenhouse gas emissions: observations and consequences

Emissions of CO₂ and other greenhouse gases worldwide are a primary driver of climate change and sharp incline in global temperatures creating serious threat for human life (Lacis et al., 2010). Notably, the elevation in global temperatures and greenhouse gas emissions, especially CO₂ concentration are interconnected as can be seen from Fig. 2a, depicting the average global temperature with respect to the average of the period in between 1961 and 1990. The red line in the graph represents the variation in average annual temperature with time and the greys line depicts the upper and lower confidence intervals. Clearly, over past few years the global temperatures are rising sharply with an increment of 0.7 °C from 1961 to 1990 baseline, which contributes to an average inclination of 1.1 °C. This small rise in temperature might seem insignificant but the rapid warming by 1 °C can substantially impact the climate change and can cause large variations in warming across the globe. For instance, a report from Berkeley Earth global temperature showed the variation in temperature in the year 2019 as compared to the 1950–1980 as shown in Fig. 2b (Rohde and Hausfather, 2020). The report presented following key observations (Ritchie and Roser, 2020):

• In contrast with ocean, the average temperatures over land have increased twice with an average increment by 1.32 ± 0.04 °C. While, the temperature of ocean surface across the world has increased by only 0.59 ± 0.06 °C.
• As can be seen from Fig. 2b, the temperature change is not uniform throughout the globe. Typically, the regions near the poles with high latitudes saw an upfiling in warming by 3–5 °C and are often the regions with high risks of permafrost, sea ice, and glacial melts.

A comprehensive report on global GHG and CO₂ emissions from PBL Netherlands Environmental Assessment Agency revealed that the year 2019 before the COVID-19 pandemic was the second warmest year with an average increase of +0.95 °C land and ocean surface temperatures in the 140 year record (Olivier and Peters, 2020). This global increase in temperature was ascribed to the augmented GHG emissions all over the world. From Fig. 3, the trends in GHG emissions by six major emitters namely, China, United States, European Union, India, the Russian Federation, and Japan which contributed 26%, 13%, 9%, 7%, 5% and 3% of total 62% of the collective GHG emission, respectively. Typically, European Union (~3.8%), United States (~2.8%), and Japan (~2.1%) showed a slight decrease in GHG emission and partially counterbalanced an increase in GHG emission mainly by China, India, and Russian Federation. The noteworthy increase in the emission rate was aided by the incremented combustion of fossil-fuels altogether by 0.9% in 2019 leading to the 12% enhancement in CO₂ and CH₄ emission along with 50% increased F-gas emission.

However, the global outbreak and spread of COVID-19 in 2019 not only drastically threatens human health, but also affected the global GHG emissions (Bai et al., 2020). During the pandemic most the countries implemented stringent measures like lockdowns in order to control its spread. Such measures have had substantial effects on global economy, and consequently on emissions throughout the world. Of note, it was very difficult to observe the real time change in energy consumption and subsequent emission of GHG so most of the studies have utilized the proxy data on mobility from Google, Apple, and TomTom to analyze the emission trends during 2020 along with some real-time data which depicts activity levels like electricity production and consumption. Moreover, some of the studies estimated the impact of COVID-19 during 2020 using emissions data for year to date while others evaluated for the full year (Le Quéré et al., 2020; Liu et al., 2020c; Olhoff and Christensen, 2020). The report further revealed that the GHG emissions were collectively declined by 7.1% till 1 November 2020 globally due to the restrictions and subsequent variations in energy consumption. Furthermore, maximum of 17% reduction in the emissions were recorded in April 2020 based on the emission data only which reduced to ~12% in the mid-June due to partial upliftment of the restrictions in some of the countries. However, as per the 2020 full-year estimation data for CO₂ emissions, a total 7% and 8% decline was observed in contrast with the estimated data in 2019 by IEA 2020 and Enerdata 2020 reports, respectively (Programme UNE, 2020). Thus, the restrictions in mobility to limit the transmission of COVID-19 substantially influence the emission levels globally.

For a fact, it is very difficult to predict the long-run effects of COVID-19 on GHG emissions throughout the world considering the rapid mutations in virus and how the extent of vaccination will bring the pandemic under control (Gautam and Hens, 2020). However, it is being estimated that in the short run (by 2025), the COVID-19 and response measures would cause regional decline in the GHG emissions in almost all the countries (OECD, 2021). More interestingly, the GHG emissions and material use in India will also face large reductions in India owing to the influence of energy systems. On the other hand, by the year 2040, both reduced GHG emissions and economic losses will be partly faded away globally with some significant lessons from the pandemic. Particularly, the regions with Organization for Economic Co-operation and Development (OECD) will continue to outstrip gross domestic product (GDP) impacts with reduced emissions level due to specialized economies with clean sectors ascribed to the COVID-19 pandemic and

![Fig. 1. Pie chart depicting the total available literature published with keywords “COVID-19 + Greenhouse gas emission”, “COVID-19 + Energy consumption”, and “COVID-19 + Global economy” in the year 2020–2022 till July by using SCOPUS Scientific database.](image-url)
response measures. To summarize, the real-time evaluation of the impacts of COVID-19 pandemic on GHG emissions is far from being possible with the current disaster of epic proportion and great complexity.

4. Assessment on CO2 emissions main concern

Of note, the large stationary sources such as combustion actions, industrial practices, and natural gas processing are the major CO2 emission areas (Rubin and De Coninck, 2005). However, the carbon oxidation resulting from fossil fuel combustion is the largest source of CO2 emission which is directly associated with various processes in power plants, oil refineries, and vast industrial conveniences. Besides, non-combustion emission of CO2 involves chemical, physical, or biological transformation of materials such as use of carbon fuels in petrochemical processes, carbon as reducing agent in metallurgical procedures, the fermentation of biomass, and thermal decomposition of dolomite and limestone in lime production or cement formation (Gale, 2004). As reviewed earlier, the crises of COVID-19 pandemic and its global spread depicts an epoch-defining event with clear impacts on human health, economy, and environmental consequences like CO2.
emission and climate change (Barouki et al., 2021; OECD, 2021). Notably, it was observed that in contrast with 2019, the initial months of 2020 were recorded to be warm across northern hemisphere, suggesting the significant role of COVID-19 restrictions posing disruption in economic activities and energy generation (Aletta et al., 2020; Hale and Leduc, 2020). For better understanding of the relationship between variation in CO2 emissions over the years by the changes in energy production, population, real GDP per capita, and carbon intensity Hale et al. utilized Kaya identity and the results obtained are depicted in Fig. 4 (Hale and Leduc, 2020). Clearly, CO2 emission level has increased over the past 20 years (panel A) with the increase in driving factors like population and GDP since 2000 (panel B). However, carbon intensity showed negligible impact on CO2 emissions. Interestingly, the world’s energy intensity has reduced over the past two decades, rendering significant decline in emissions as shown in panel A. What’s more, owing to the increased global attention on environmental sustainability and the focus on inventing and utilizing more lower-emission technologies, emission levels seems to be stabilized since 2013 despite of non-stop economic advancement.

Also, it was observed that the overall cost accompanied carbon emissions and the subsequent climate change results about 5% decline in GDP each year which can be increased up to 20% if the necessary actions are not taken immediately (Stern and Stern, 2007). Furthermore, to control CO2 emission levels, the energy demand needs to be reduced which will definitely influence the GDP. Hence, the substantial attempts to control energy consumption in order to influence the CO2 emissions will exert negative impact on economic growth as energy is the major constituent in the industrial processes (Acheampong, 2018). Consequently, these influential parameters and counter arguments result inconsistency in between energy, environmental conservation and economic policies.

With COVID-19 pandemic and the challenge to control the transmission, graphs of industrial production and energy consumption showed substantial decline (30%) in some countries owing to the strict lockdowns which partly affected the CO2 emission levels (Economics O, 2020; Liu et al., 2020b). Despite of seasonal variations, there has been a significant reduction in the daily CO2 levels as compared with 2019. From Fig. 5, an estimated trend depicting global decline of 7.8% in the CO2 emissions was observed during initial 4 months of 2020 (solid black line) in contrast with 2019Q1 represented via dashed black curves (Liu et al., 2020a). Interestingly, in the first quarter of 2020, China showed highest −9.3% decline in emissions with progressively smaller reduction of −8.4%, −4.7%, −3.6%, −2.5%, and −2.1% in Europe and United Kingdom, the United States, Japan, India, and Russia. However, the apparent reductions in CO2 emissions were not similar in most of the countries and the greater decline was observed in April and March as compared to February due to the stringent restrictions in movement as shown in Table 2. The data in Table 2 is obtained from a report published by Cornell University in General Economics (Liu et al., 2020a).

The global assessment of the impact of COVID-19 on longer-run is very limited and challenging. It is being observed that the data showing the real-time observations in late 2020 and the beginning of 2021 for evaluating the relationship between COVID-19 outbreak and CO2 emissions is also missing. Considerably less research work was available on the analysis of real-time variations in emission level and the subsequent impact on environment during and after the second wave of COVID-19. For instance Nguyen et al. examined the impact of COVID-19 on worldwide CO2 emissions in the last few months of 2020 and the report further suggested a considerable decline in the emissions along with a relevant concern about future climate change policies (Nguyen et al., 2021). Smith et al. utilized global vector autoregressive (GVAR) simulation model to evaluate the influence of COVID-19 on global fuel consumption and CO2 levels (Smith et al., 2021). The study presented global cross-sectional and time interdependencies of the effect of COVID-19 on energy consequences and global propagation. After analyzing the data for thirty two countries responsible for 81% of aggregate CO2 emissions owing to the use of fossil-fuels, significantly negative consequence of COVID-19 on fossil-fuels consumption was recorded with limited CO2 emissions from 2020Q1–2021Q4. However, in order to improve the economy due to the global pandemic, most of the countries may consume more energy than the pre-pandemic era and aid to the increased emission levels. Therefore, it can be anticipated that the pandemic and consequent shut-downs won’t impact the emissions over a two-year time zone and the need to develop stringent climate-control policies should be taken more seriously.

5. Assessment on global economic and energy impact

COVID-19 pandemic has caused considerable effects on the global economy and energy sector (Ergoalu, 2021; Gettelman et al., 2021). For a fact, COVID-19 has shocked our global economy and the damage is even worse than the World War II (Insights D, 2020; Watts, 2020). The safety measures involving travel restrictions, quarantine, and border shutdowns in order to flatten the pandemic curve have caused justified uncertainties about looming long-lasting economic crisis (Burkert and Loeb, 2020). The COVID-19 induced economic loss is primarily caused by a significant decline in demand for many goods and services.

![Fig. 4. Schematics depicting global variation in CO2 emissions from 2000 to 2017 with Panel A showing world CO2 emissions and Panel B depicting the major drivers of CO2 emission. Reprinted with permission from FRBSF Economic Letter (Hale and Leduc, 2020).](image-url)
As a result of global economic fallout, the fossil-fuel demand throughout the world will also be hindered drastically (Mohideen et al., 2021). The observations from IEA global energy review in the year 2020 has showed 3.8% reduction in the energy demand during January to March and predicted ~6% decline at the end of 2020 which is nearly correct. Moreover, the economy related to fossil-fuels like oil, coal, and gas has showed a significant decrease by 5%, 8%, and 2%, respectively (Review GE, 2020). Of note, the researchers predict the fallout in economy would be greatly large than the global energy financial crisis occurred in 2008 (Mohideen et al., 2021).

Economic crisis are usually resulted via a shock to demand or a shock to supply. But the pandemic disturbed both of the components all together leading to global economic crisis (Oncioiu et al., 2021). The government imposed safety measures restricted the mass access to their professional activities which altered the production and eventually the cumulative supply of the economy. Furthermore, restrictions in the free moment caused limited consumption of goods and services rendered decline in aggregate demand and directly affected the economy as can be seen from Fig. 6a. Also, the different set of variables affected by the global pandemic such as private consumption due to the household responses, government consumption owing to the safety measures to stabilize the economy, unemployment as a result of shut-downs and least possibilities of working from home, and the export as a result of movement restrictions are also summarized in Fig. 6a. Typically, the private and government consumption has critically influenced the aggregate demand on the other hand, unemployment along with decline in export has also hindered the aggregate supply resulting into significant impact on economy globally.

In a fascinating study Smith et al. analyzed global fossil fuel consumption by using unique quarterly data of natural gas, coal, oil consumption, equity prices, exchange rates, and fossil-prices for 32 primary CO2 emitting countries (Smith et al., 2021). The report further estimated the forecast for coal, oil consumption, and natural gas with respect to three different scenarios by 8-quarter horizon variation in

Fig. 5. Schematic illustration of daily CO2 emissions from 2019Q1 (dotted lines) to 2020 (solid line) for the United States (US), Italy, China, Brazil, Spain, India, Germany, United Kingdom (UK), Japan, Russia, and France. Note: Different colors for countries depict distinct continents. Reprinted from (Liu et al., 2020a), licensed under CC BY 4.0.
GDP for the developing economies (Fig. 6b). Comparing Scenario 0 (GDP forecast published in January 2020 by IMF, pre-pandemic observations (IMF, 2020a)) with Scenario 1 (IMF forecast in April 2020, IMF, 2020b), the negative impact of COVID-19 on GDP due to economic shock in Asia (January-February) along with Europe and US (March-April) can be clearly seen. The results further estimated that the global economy might return to the difficult and long-run growth path around 2020Q4 without much hindrance from the second outbreak. Scenario 2 predicts the impact of second wave of COVID-19 on GDP growth rate around 2021Q1 and Q2 which showed a significant decline, slightly lower in magnitude than the one observed during first wave.

To sum-up, the economies of developing countries are highly energy-intensive and in order to improve the current scenario, more efficient and ecofriendly energy sources are highly desirable. The developed countries with stable economies should collaborate with developing countries having lower economy by enabling technical assistance along with planned investments to support market-based energy policy agenda. Also, the designed policy should be focus on investors and industrial organizations with a security of investment under difficult situations like pandemic.

6. Recovery plan and sustainability

The COVID-19 pandemic has caused unprecedented crisis all over the world and governments in different countries are strategizing stimulus plans for damage control and sustainable recovery. The task to ensure public health, economy, and climate change all together is challenging yet highly desirable. Sustainable speculation in public health is of highest concern along with a synergistic balance between economic recovery and climate issues (Gillingham et al., 2020; Siddique et al., 2021). Notably, development of efficient energy resources can benefit remarkably by providing job opportunities, lowering the electricity bills and support economy, and enhance the energy use efficacy (Apostolos et al., 2013; Kumar and Zare, 2019). Typically, projects to run efficient energy sources should involve replacement of inefficient electrical appliances throughout and upgrade the current electrical system with advanced ones to achieve maximum efficacy. The best example in this regard is the up-gradation of streetlights in

| Months | Countries                  | % decrease |
|--------|----------------------------|------------|
| February | United States              | −1.9%  |
|         | EU27 and United Kingdom    | −8.4%  |
|         | India                      | −6.2%  |
|         | Brazil                     | −1.6%  |
|         | Japan                      | −1.1%  |
| March   | United States              | −13.8% |
|         | EU27 and United Kingdom    | −8.1%  |
|         | India                      | −16.4% |
|         | Brazil                     | −11.0% |
|         | Japan                      | −4.1%  |
| April   | United States              | −25.6% |
|         | EU27 and United Kingdom    | −25.0% |
|         | India                      | −27.9% |
|         | Brazil                     | −26.6% |
|         | Japan                      | −6.7%  |

Fig. 6. (a) Schematics representing the effect of COVID-19 pandemic on global economy. Adapted from (Oncioiu et al., 2021) licensed under CC BY 4.0. (b) Diagrammatic representation of three different GDP scenarios with and without global economic shock from COVID-19. Reproduced with permission from Elsevier under license no. 5124620751899 (Smith et al., 2021).
India with LEDs rendering 5 million tons decline in GHG emissions in 9 years along with the creation of 13,000 jobs (Siddique et al., 2021). A smooth transition to renewable energy technologies via bioenergy with carbon capture and storage along with atmospheric carbon capture can also be a fascinating strategy for moving towards energy efficiency (Budinis, 2020; Ope Olabiwonnu et al., 2021). Other than this, hydrogen economy is another promising approach for low carbon energy system since hydrogen is a versatile carbon-free energy carrier and can support energy service across various energy sectors (Grigoriev et al., 2020; Thomas et al., 2020). Considering this, so many developed countries have formed a policy framework along with certain national strategies to deploy hydrogen and fuel cell technologies as shown in Table 3 reprinted from Mohideen et al. (Mohideen et al., 2021).

Table 3
Summary of policy overview of major countries like China, US, Japan, and Europe (Mohideen et al., 2021).

| National strategies | Fuel cell vehicles | Hydrogen production & infrastructure |
|---------------------|--------------------|--------------------------------------|
| China              | US                 | Japan                                | Europe                        |
| - China has world’s largest new electric vehicle (NEV) market. Development of hydrogen fuel cell vehicle is quite late compared to other developed countries. | - US have become a leader to hydrogen economy among other countries by creating billions in revenue and jobs in hydrogen energy. | - In 2018, Japan launched fifth strategic energy plan on basis of Japan’s new energy policy and strategic road map for hydrogen production, infrastructure and fuel cell vehicles towards 2030 and 2050. | - In 2007, European strategic energy technology plan (SET-plan) launched Hydrogen fuel cell technology as ‘Key challenge for next ten years. |
| - Fiscal incentive policies for NEVs have been changed to endorse fuel cell vehicles. China has several national level policies for hydrogen and fuel cell commercialization. Based on the plan, several regions and provinces developed the local policies. | - Road map to a US hydrogen economy: By 2030, US hydrogen economy would reach revenue of $ 510 billion per year and create 700,000 jobs across hydrogen value chain. | - In 2019, Japan Ministry of Economy, Trade and Industry funded $560 million for hydrogen economy. | - In 2016, European policy highlighted green hydrogen from renewable energy source as future clean energy. |
| - China invested more than $17 billion funding for hydrogen transport industry through 2030 to develop their hydrogen economy. | - By 2050, it would reach $750 billion per year and 3.4 million jobs. | - European Union’s environmental policies indirectly supported hydrogen and fuel cell technology. | - Fuel cell and Hydrogen Joint Undertaking (FCH JU) hydrogen road map Europe: targeted 3.7 million fuel cell passenger cars. |
| | | | - FCH JU provided € 200,000 subsidies per bus. |
| National subsidy on fuel cell vehicles unchanged up to 2025. | - Road map to a US hydrogen economy: Classified its hydrogen road map into three steps. | - Targeted 100 buses by 2020 and 1200 by 2030. | - Targeted 45,000 fuel cell buses and trucks. |
| - New energy vehicle Technological road map: above 1 million fuel cell vehicles in service at 2030. | - 2020-2022: targeted 50,000 passenger cars and 50,000 materials handling fuel cell vehicles. | Fifth strategic energy plan: In 2025, 20000 passenger cars and 800000 by 2030. | - In 2016, FCH JU launched H2 Future and DEMOGRID projects to produce CO2 free hydrogen from renewable energy sources. |
| | - 2023 to 2025: 200,000 passenger fuel cell cars and 125000 material handling fuel cell vehicles. | - Targeted 100 buses by 2020 and 1200 by 2030. | - Targeted 3,700 HRS by 2030. |
| | - 2026 to 2030: 5,300,000 passenger fuel cell vehicles and 3,600,000 materials handling fuel cell vehicles. | - Fifth strategic energy plan: In 2025, 20000 passenger cars and 800000 by 2030. | |
Addressing environmental and climate related crisis necessitates integrated scientific knowledge and engineering expertise to eliminate the negative impacts with sustainable technical solutions. However, chasing sustainable technological aspect involves societal, political, organizational, and economic endeavors with certain non-technical challenges (Geels, 2004). The vision of ‘green economy’ started in 2015 when various countries adopted a 2030 agenda for sustainable development with the goals of tackling rising poverty and providing basic social needs along with improvement in environmental and climate change conditions (Söderholm, 2020). Hence, the sustainable development objective also addresses the worldwide concerns related to environmental pollution and energy crisis by forming a synergistic relationship between ecological system and economy. In this regard, cleaner technological innovation is a promising means of reducing environmental pollution and climate change crisis by promoting the green growth (Popp, 2012). For instance, various upper-middle and high income countries utilized advanced pollution reduction techniques to help improve the local air quality by decontamination of some pollutants (Dasgupta et al., 2002). However, to employ such technologies often entails a considerable starting cost which makes the process a lot difficult. Therefore, the development of energy efficient technologies such as appliances, vehicles, and industrial tools promotes less environmental pollution. Additionally, the implementation of stringent policies to flourish green technologies in the market should be a prior initiative towards sustainable development.

For a fact, extensive debate exists to operationalize sustainability across distinct contexts, however, strong sustainability refers to the ideal prescription for sustainability and human life and the exact meaning is still not clear (de Oliveira Neto et al., 2018). COVID-19 pandemic has elicited global response by exposing so many flaws in the present policies and stimulated the governments to construct stronger sustainability agenda by focusing on the following points (Rume and Islam, 2020):

1. For sustainable industrialization, it is important to maintain an energy efficient environment by using cleaner fuels and technologies. Also, industrial waste management and emissions control policies should be strictly designed to avoid environmental hazards (Pan, 2016).
2. To reduce the transport induced emission, it is highly desirable to encourage people about the use of public transport and switch to a vehicle sharing system for better environment (Rume and Islam, 2020).
3. Cleaner and greener energy sources like solar, wind, hydropower, biomass, and geothermal heat can reduce the global reliance on fossil-fuels and help to decline the GHG emissions all over the world by simultaneously meeting the worldwide energy demands (Ellabban et al., 2014).
4. The three R’s (Reduce, Reuse, and Recycle) approach can be substantially important to lessen the burden of wastes and environmental pollution. Therefore, it is of great interest to reduce the use of raw materials and waste production along with the proper management of waste segregation and disposal issues (Hysa et al., 2020).
5. Lastly, for a better and sustainable global environmental protection collective efforts are required with stringent policies and their proper implementation all over the world (Rume and Islam, 2020).

7. Conclusions

The outbreak of COVID-19 pandemic has joined the world ecosystem and discloses various bottlenecks associated with the current policies to tackle such global crisis. The inability to safeguard human health, economy, and climate crisis all over the world created a serious awareness that it is the high time to amend policies and implement them strictly to recover the ecosystem and global economy synergistically. Thus, based on the availability of scientific data, efforts have been made to present an in-depth overview on impacts of COVID-19 on GHG emissions globally. It is highly anticipated that by assessing the emission levels pre-pandemic, during pandemic and post-pandemic predictions, an insight into the relationship between climate changes with COVID-19 spread can be offered. However, the real-time monitoring of climate change with the pandemic is still challenging owing to the lack of data for operational forecasting of weather, ecological, and hydrological system.

For a fact, COVID-19 pandemic holds key insights for global climate change. Typically, the shutdowns during the pandemic even for a limited period of time caused considerable decline in GHG emissions all over the world, suggesting the significance of reducing fossil-fuel consumption and decreased emission from industries. However, this decline is obviously temporary and the urge of getting back to normal and stabilize economy would render rapid increase in the emissions as is the case with China and several other countries. The short-term relaxation in environmental standards by avoiding the commitments towards utilization of cleaner energy sources can substantially jeopardize the past efforts of transitioning to a cleaner, greener, and sustainable environment all over the world. Therefore, even with the pandemic induced strongest economic shock, there is still an opportunity to redesign vital policies towards greener economy that reduces the risks of crisis associated with climate-change in the near future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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