Valentina Olabi[1]
Tabbi Wilberforce[2]
Khaled Elsaid[3,*]
Enas Taha Sayed[4,5]
Mohammad Ali Abdelkareem[4,5,6,*]

Impact of COVID-19 on the Renewable Energy Sector and Mitigation Strategies

This review explores the impact of the COVID-19 pandemic on the renewable energy (RE) sector, especially in countries with the highest RE capacities, e.g., the USA, China, India, and the EU. It highlights stimulus packages put in place by governments worldwide and their sustainability to cushion the RE sector. Commissioning of RE projects has stalled due to lack of funding allocation and interruptions in the supply of equipment and components due to lockdown measures. Despite the need to fund COVID-19 vaccination programs and other related health services, the world must not neglect other sectors of the economy, creating more problems, such as worsening the climate change situation in the long run. This review aims to present the information needed to sustain future energy during the COVID-19 global pandemic.

Keywords: COVID-19, Energy resources, Mitigation strategies, Renewable energy

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1 Introduction

Rapid growth in world population and technological advances have resulted in a significant increase in fossil fuel consumption with severe environmental impacts [1, 2]. Such environmental impacts resulted in serious health problems and critical climate changes. Efforts have been devoted worldwide to reduce or eliminate the consumption of fossil fuel through improving the efficiency of the current energy conversion processes [3], developing efficient environmentally friendly energy conversion devices [4, 5], using environmentally friendly materials [6, 7], and developing renewable energy (RE) resources such as biomass [8], wind [9], geothermal [10], and solar [11]. Additionally, hybrid RE resources have been widely described for improved energy sustainability [12]. Among the different methods, utilizing RE not only has lower environmental impact, but is also a sustainable solution [13, 14].

The first case of coronavirus (COVID-19) disease can be traced to Wuhan, China in late 2019 [15]. The spread of the virus initially was not detected by scientists globally; hence, the disease became a global crisis causing the World Health Organization (WHO) to declare it as a pandemic on March 11, 2020 [16]. China was the first country to go on nationwide lockdown, and this was replicated in other countries across the globe in the quest to reduce the spread of the virus. Countries across the world going on lockdown reduced the spread of the virus, but as the majority started opening up again, the spread of the virus started to surge again, forcing them to consider another lockdown [17]. By mid-January 2022, the total number of confirmed cases recorded globally was greater than 325 million, and the total number of deaths was 5.6 million, according to the European Centre for Disease Prevention and Control [18] and the WHO [19]. Fig. 1 shows the spread of the COVID-19 pandemic across the globe in terms of confirmed cases per million of population. It shows the global expansion of the pandemic with high infection levels reaching up to 37 % in some countries [20, 21].

China managed the spread of the virus by implementation of drastic measures [22]. The COVID-19 pandemic is characterized by a high spread rate coupled with longer incubation time, severe impact on respiratory systems, and the many variants produced [23, 24]. The impact of the COVID-19 pandemic on the health care sector and lifestyle, which are directly impacted by such a pandemic, has been widely quantified. However, many other sectors, including the environmental and energy

[1]Dr. Valentina Olabi
College of Social Sciences, University of Glasgow, Glasgow, UK.
[2]Dr. Tabbi Wilberforce,
Mechanical Engineering and Design, School of Engineering and Applied Science, Aston University, Aston Triangle, Birmingham B4 7ET, UK.
[3]Dr. Khaled Elsaid
khaled.elsaid@qatar.tamu.edu
Chemical Engineering Program, Texas A&M University at Qatar, P.O. 23874, Doha, Qatar.
[4]Dr. Enas Taha Sayed, Prof. Mohammad Ali Abdelkareem
mabdulkareem@sharjah.ac.ae
Centre for Advanced Materials Research, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates.
[5]Dr. Enas Taha Sayed, Prof. Mohammad Ali Abdelkareem
Chemical Engineering Department, Faculty of Engineering, Minia University, Egypt.
[6]Prof. Mohammad Ali Abdelkareem
Department of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates.

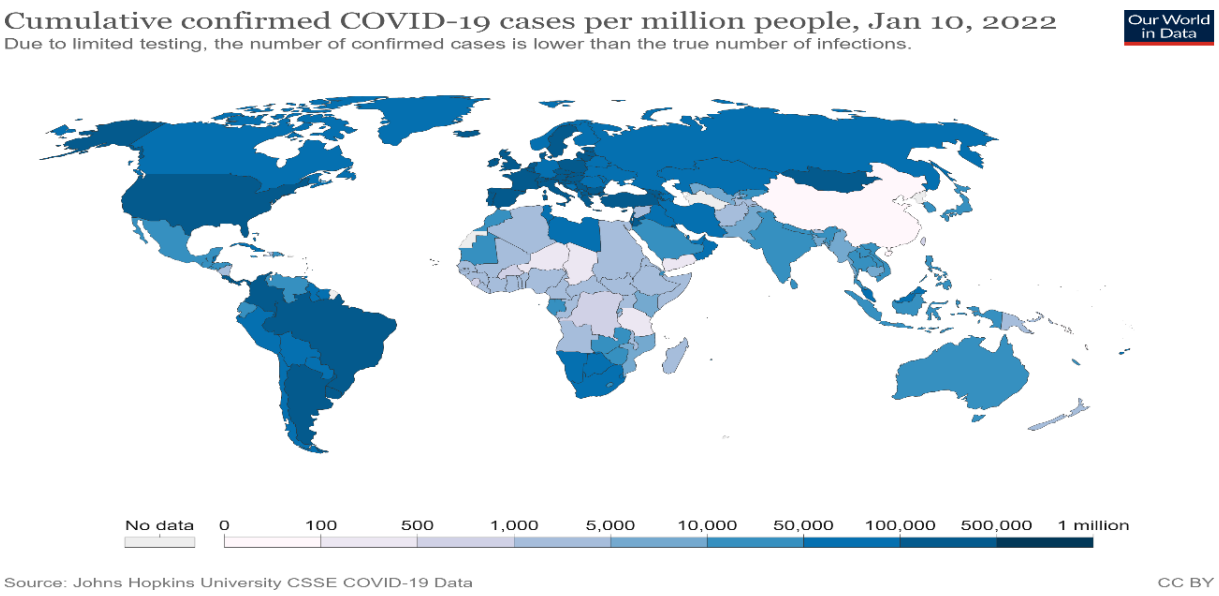

Figure 1. COVID-19 global distribution of cumulative confirmed cases (source: Our World in Data [81]).

sectors, have been strongly affected by the pandemic. This review sheds light on the global effect of the COVID-19 pandemic on the RE sector and the potential positive and negative impacts. It discusses the specific impacts of the pandemic on RE sectors with respect to RE resources, mainly solar and wind owing to their larger share in RE capacity worldwide. This is followed by a discussion of the progress in RE capacities and project execution in the countries with the largest share of RE capacities, such as the USA, EU, China, and India, which can be considered as models to predict the response globally. The discussion of these countries expands over developed and developing countries with different economic strengths and situations to better represent the different impact scenarios. The review starts with the economic impact, which consequently affects the energy sector in general and the RE sector in particular. It then briefly discusses the environmental impact of COVID-19. The specific impacts of the pandemic on the RE sector along with implemented and suggested mitigation strategies to be considered by governmental and international entities are discussed.

2 Impact of the COVID-19 Pandemic on the Economy

Due to the challenging issues pertaining to the spread of the COVID-19 virus, most countries have resorted to daytime curfews, total lockdowns, truncation of term time in academic institutions, closure of businesses that do not render essential public services, as well as a complete ban on social activities during the early stage of the pandemic expansion [25]. All these policies are geared towards ensuring the spread of the virus is kept to a minimum. China being one of the first countries to undergo lockdown had a huge impact on macroeconomic growth globally. Most countries in Europe also had to follow suit, and by march 2020 India also went into lockdown [26]. With the USA going into lockdown as well by April 2020, the world's macroeconomy by this time had started to fold [27]. Despite China lifting the ban and restarting its factories after being in lockdown after close to nine months, there were still government policies in place that impacted the service sector negatively, such as social distancing [28]. Furthermore, imposed travel restrictions due to lockdown led to a reduction in aviation and transportation activities. Fig. 2a shows the reduction in commercial flights in 2020 relative to 2019, showing also the slow recovery in 2021, which did not reach 2019 rates. It shows a drop in commercial flights by about 75 % in 2020 during the severe lockdown, and slow recovery, reaching only 65 % of that 2019 by the end of 2020. Fig. 2a shows also that the number of flights in 2021 is still below that of 2019 due to the continuity of partial lockdown and restrictions on travel. Fig. 2b shows similarly the drop in maritime trade as one of the major indicators for global trade activity, showing a steep decrease in 2020 close to that of the 2009 recession in terms of maritime trade, with a further drop in global gross domestic product (GDP) by –3.5 %, as opposed to only –1.2 % during the 2009 recession.

The restrictions had a high impact on the supply and demand chain, causing a shock, as seen from the drop in maritime trade in Fig. 2b. The supply shock can be attributed to the pressure exerted on economic activities with the closure of manufacturing industries to prevent the spread of the virus. Accordingly, in the USA about 26 million of the labor force lost their jobs due to the COVID-19 pandemic, which is almost ten times higher as compared to other global economies [29]. The UK saw more than 1.4 million people register for unemployment benefits by March 2020 [30].

The duration of the lockdown greatly determines the impact of the pandemic on GDP and the energy sector, e.g., the oil and gas trade [33]. The shape of the recovery of the economy will

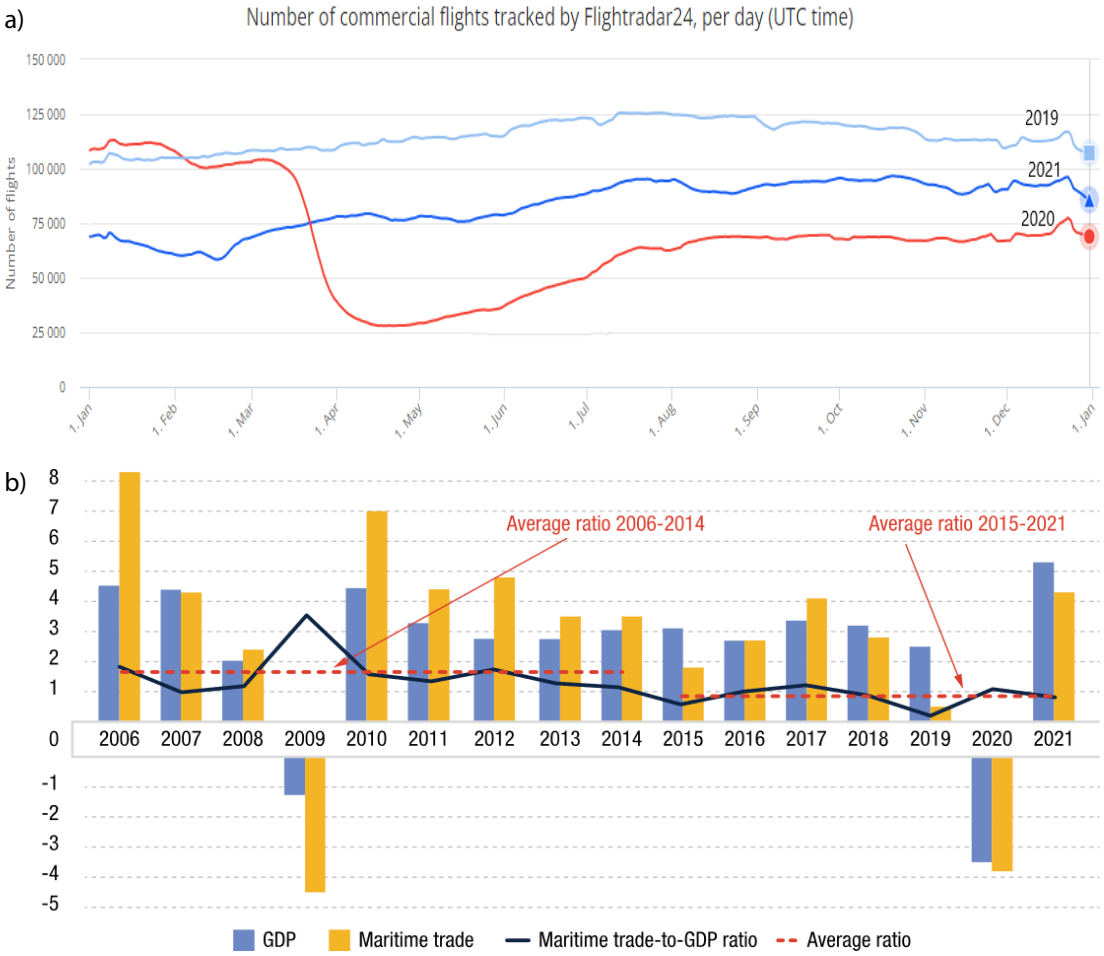

Figure 2. (a) Number of commercial flights from 2019–2021 [31], (b) annual growth rate of global domestic product GDP and maritime trade [32].

also dwell on the indirect impact of the pandemic. In certain sectors such as tourism, the global crisis will have a long-term effect on the sector. Some activities may eventually not even go back to the pre-crisis growth path. With lockdown lifted in late 2020, most countries faced a series of challenges very similar to a conventional recession with huge demand coupled with stress on the financial system. Despite the decision by most governments around the world considering fiscal as well as monetary stimuli to ensure their economies bounce back from the plight due to the crisis, there is still the need for more to be done [34]. The outbreak of COVID-19 caused spillover in all global industries; one of its more noticeable impacts it had was on oil-dependent countries. The COVID-19 pandemic has aggravated the situation of reduced oil prices by reducing oil demand [33]. In turn, this resulted in a fall in demand for aviation fuel, coal, and other energy products, which subsequently led to a fall in the oil price because of this low demand [35].

3 Impact of the COVID-19 Pandemic on the Environment

Most of the large economies across the globe came to a standstill in 2020 due to shutdowns, lockdowns, quarantine measures, and restrictions. Activities such as traveling, gathering, conferences, and social activities were halted due to the global pandemic [36]. The demand for energy during this period dropped drastically, and this implied a reduction in global CO_2 emissions, as shown in Fig. 3. It can be deduced that there has been a sharp decrease in all energy-related sectors such as aviation, hence less jet fuel consumption, and transportation, hence less gasoline and diesel consumption, for 2020, mainly due to the cessation of many activities. A reduction of about 17 % in global carbon emissions has been reported by early April 2020 as compared to 2019 mean levels, with an average yearly reduction of about 2–13 % depending on the duration and nature of taken lockdown measures [37]. Fig. 3a shows a reduction of CO_2 emissions by about 2 Gt in 2020, from 33.4 Gt in 2019 to about 31.5 Gt in 2020, almost four times the drop seen during the economic crisis of 2008. Additionally, Fig. 3b shows the emission reduction in the major affected countries, namely, the

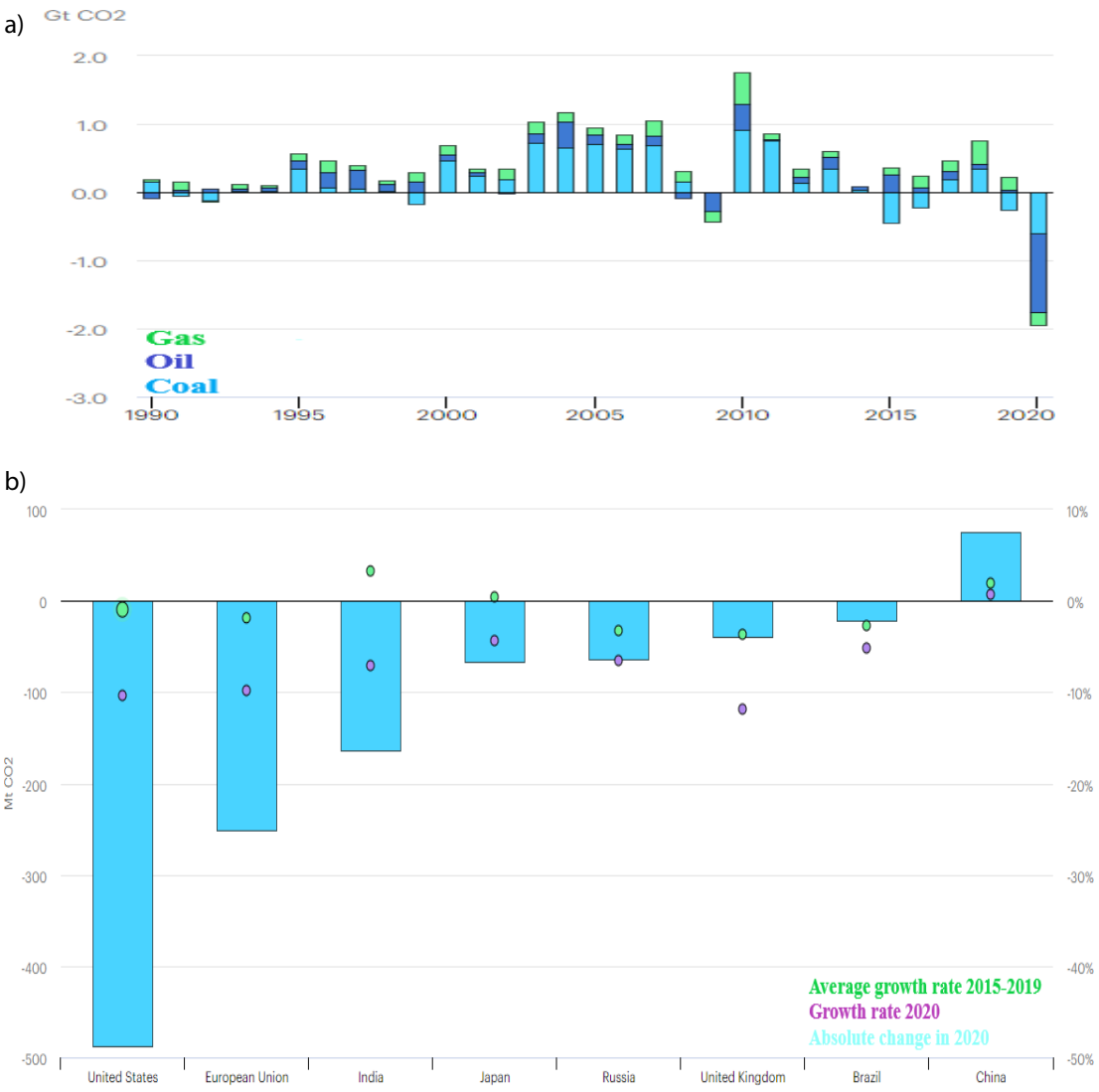

Figure 3. (a) Global CO_2 emissions from 1990–2020 by energy source, (b) CO_2 emission reduction in 2020 by countries [41].

USA, EU, and India, with about −480, −250, and −180 Mt, respectively. Harmful emissions into the atmosphere are also being reduced due to the reduction in energy consumption, which implies a decline in airborne-related diseases as well.

On the other hand, the COVID pandemic has resulted in some negative environmental impacts due to the increased medical wastes and high consumption of sanitizing chemicals, which put a huge burden on wastewater and solid-waste management systems. The impacts of COVID-19 on the environment can be summarized as follows [37–40]:

- reduction in greenhouse gas (GHG) emissions from fossil fuels, such as CO_2, NO_x, SO_x, and particulate matter, due to cessation of transportation and aviation activities, which improved air quality and reduced airborne diseases.
- improved water quality of different water bodies, due to the shutdown of many industrial and commercial activities, which reduced wastewater discharge.
- increased medical waste, which loaded solid-waste management systems.
- increased organic load in wastewater, which loaded wastewater treatment systems with persistent medicinal and sanitization compounds, some of which are hard to treat and hence were discharged to water bodies.

4 Impact of COVID-19 on the Energy Sector

The COVID-19 pandemic has hit severely all aspects of human life with the energy sector at the heart of the impacted sectors. Due to the severe lockdown measures, all energy consumptions related to aviation, transportation, commercial activities, and industry have seen a dramatic drop, while those related to residential activities have seen a significant increase. In the USA,

jet fuel and gasoline consumption declined by about 50 and 30 %, respectively, while electricity demand dropped by 10 %, along with a 15 % reduction in carbon emissions, and hence about 200 lives saved per month [42]. Fig. 4 shows the impact of the COVID-19 pandemic on the energy sector in the USA as an example of well-developed counties with one of the highest energy consumptions. This has been associated with a dramatic drop in the oil price from about $ 60 in early January 2020 to $ 20 in April 2020 for Brent grade, while that of WTI grade dropped to negative values of $ –30 [43].

Jiang et al. have discussed the impact of the COVID-19 pandemic on energy demand and consumption, declaring challenges faced, lessons learned, and emerging opportunities [44]. They indicated a demand drop of 626.6 million tons of oil equivalent worldwide in 2020, along with a reduction in the weekly energy demand of up to 9, 17, and 24 % under limited restrictions, partial lockdown, and full lockdown, respectively. The pandemic has been suggested to bring some opportunities as well, which include enhancement of digitalization, a new lifestyle with remote work capabilities, and opportunities for developing localized RE resources. Similarly, Shanmuga et al. have studied the global impact of the COVID-19 pandemic on oil prices and energy and its association to the global economy, discussing the problems and opportunities related to the energy sector, and suggesting preventative and remedial measures through policy recommendations [25]. They indicated a huge potential of the COVID-19 pandemic to reform the global supply chain of raw materials and manufactured components, new economic structures to accelerate economic recovery, and green stimulus packages for green growth and information technology based solutions. The International Energy Association (IEA) has produced a comprehensive report describing the performance and status of the energy sector worldwide in 2020 in direct response to the COVID-19 pandemic [45].

During the lockdown, power demand dropped significantly due to most countries being shut down with a marginal increase in residential energy demand. During the easing of the lockdown measures in Italy and Germany in May 2020, there was a sign of recovering energy demand. This phenomenon was further observable in countries such as India, France, Spain, and Great Britain. By June and July 2020, the electricity demand was far lower than the demand in 2019 in the same period [45]. Countries in Europe by August 2020 had electricity demand closer to that of 2020 due to recovery measures put in place by their respective governments. Power demand further increased appreciably by October 2020 prior to further strict measures being put in place to curb the rate of infection in these countries. Some of these measures had a negative impact

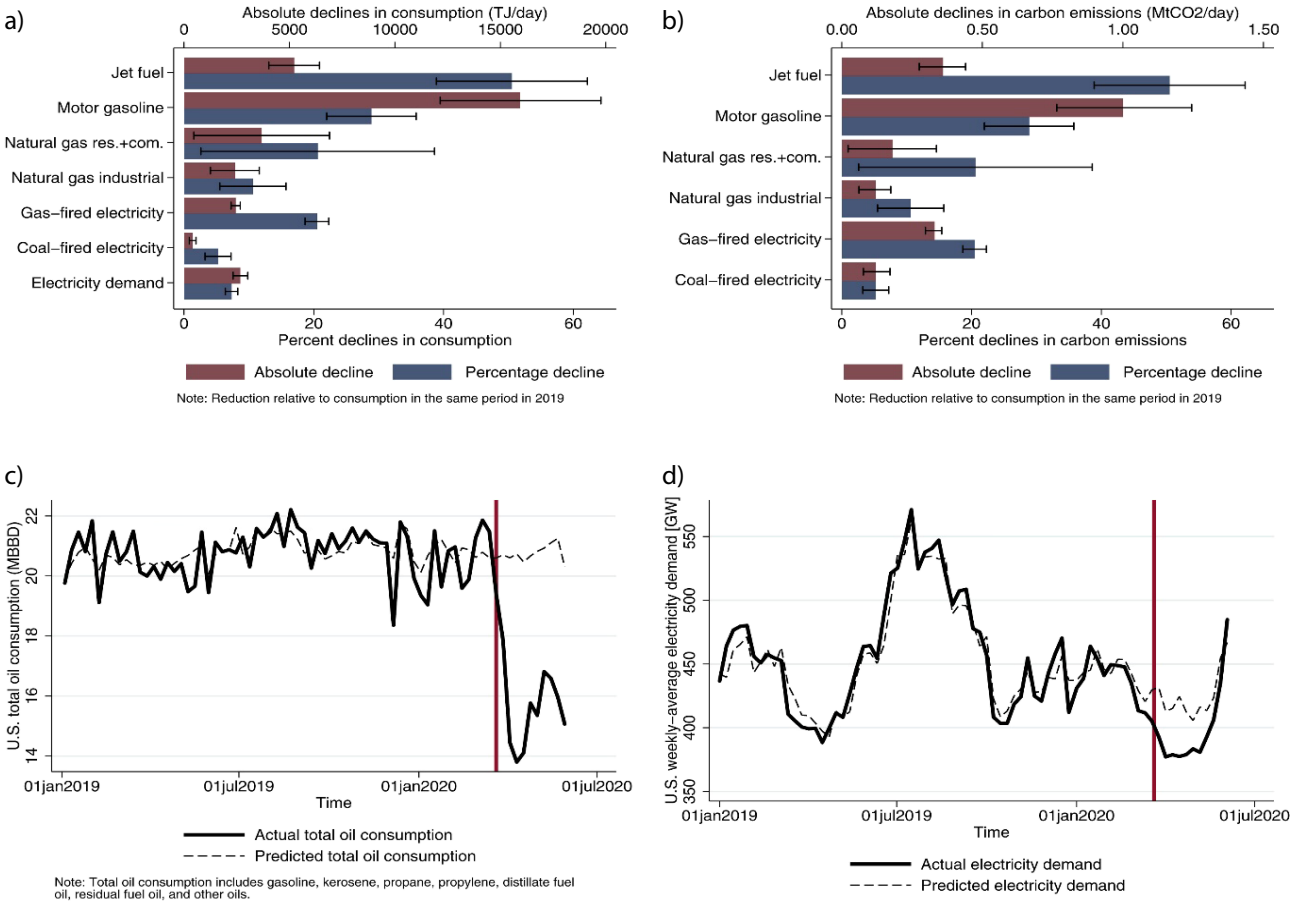

Figure 4. COVID-19 and energy consumption in the USA: (a) decline in fuel consumption, (b) decline in carbon emissions, (c) total oil consumption, (d) power demand [42].

on electricity demand by November, as the values recorded were closer to those observed in June. Not all countries experienced this phenomenon, as India saw its demand for electricity rather increase far more than what was recorded in 2019.

5 Impact of COVID-19 on the RE Sector

The above discussion has elucidated the significant impact of the COVID-19 pandemic on different dimensions of human life, with a focus on the economy, environment, and energy. The main focus of this review is to discuss the impact of the COVID-19 pandemic on the RE sector, as demonstrated by its impact on solar and wind projects, which account for the major share of RE by capacity, considering the countries with the largest share of RE generation capacity. Fig. 5a shows the evolution of different REs over the period of 2000–2020 showing a tremendous growth up to 310, 150, 1250, 14 500, and 300 % in total RE, hydropower, wind, solar, and bioenergy respectively, reaching a total capacity of about 2800 GW by 2020, with a share of about 25 % for each of wind and solar RE [46]. Fig. 5b shows the electricity capacity of REs of the major countries, with 32, 19, 10.4, 5.3, and 4.8 % for China, EU, USA, Brazil, and India, respectively.

Some recent studies have discussed the general impact of the pandemic on the RE sector. Interestingly, Khanna has described the pandemic as "a cloud with a silver lining for renewable energy" [27]. He considered the pandemic to be an action of "creative destruction" or "demand destruction" for fossil fuel industries with the significant drop in prices and employment levels, which can be seen as an opportunity to abandon dependence on fossil fuel, with great opportunity to "build back better" considering RE for power supply, depending on social and political responses and technological realities.

The impact of the pandemic on the environment and RE sector in the general and solar energy sector has been also reported in the literature [47, 48]. It has been indicated that there are some contradictory impacts of the pandemic on the RE sector. The RE sector is expected to witness a significant reduction in allocated investment due to economic turndown, holding up many RE projects. In addition, with the significantly dropped prices of fossil fuel commodities, the competition is not in favor of RE. Meanwhile, due to the problems with the supply chain, many projects have been lacking critical components [49]. On the other hand, the pandemic has indicated the need for reliable localized energy supply, with RE in the forefront, due to the drop in maritime trade restricting gas, oil, and coal supplies [50].

The COVID-19 pandemic has stalled several RE-related programs and projects despite the remarkable progress chalked up by the sector in previous years. The impact of the pandemic stems from the manufacturing facilities related to RE as well as supply chains. Today, the world is compelled to evaluate some existing energy-related policies, especially those that negatively affect RE-related companies. Most budget allocation devoted to specific programs to sustain the economies of some countries globally is today being diverted to mitigate the current global challenge. RE-related programs earmarked for commencement in 2020 are abrogated due to the global crisis. Most manufacturing companies that are involved in the development of RE technology materials and components have resorted to shelving their products until a solution to the challenge is found [26]. For instance, Morgan Stanley decreased their installation projections of solar photovoltaics (PV) in the USA, particularly in the third and fourth quarters of 2020, by 28 and 17 %, respectively [51]. The sudden interruptions in the supply chain due to the pandemic are more likely to impact RE programs negatively, especially for solar power plants. This is because several components for the installation of solar-related projects originate from Asia [52].

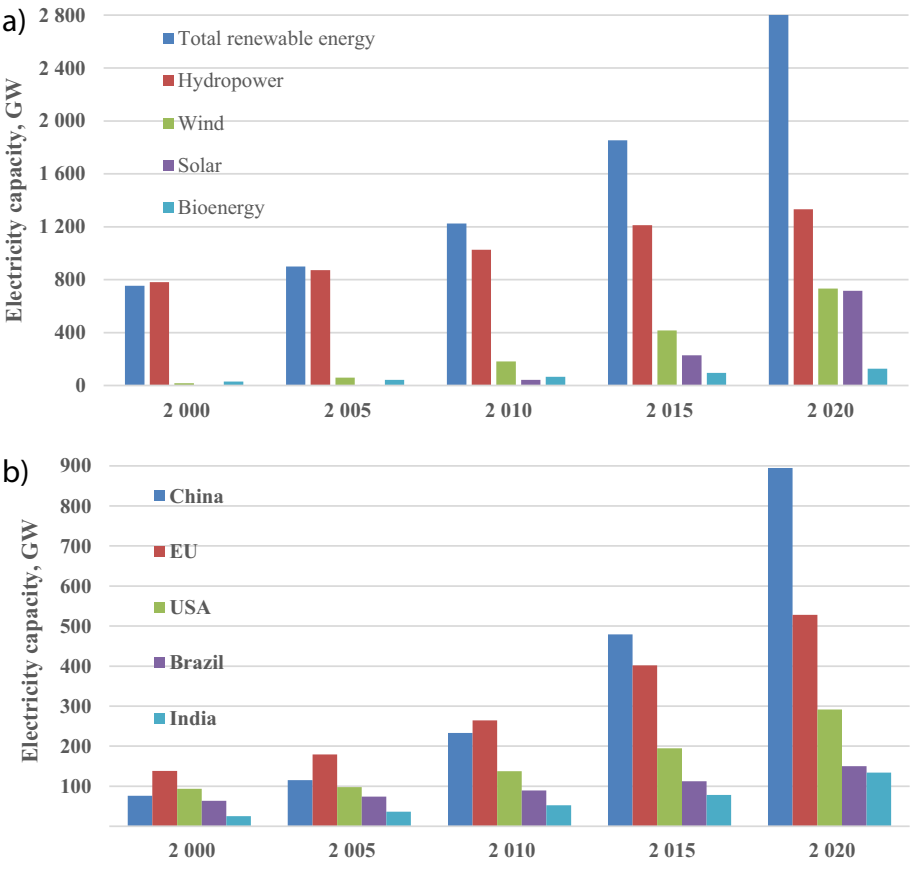

Figure 5. (a) The evolution of renewable energy resources over the period of 2000–2020, (b) renewable energy capacity distribution by countries over 2000–2020 [46].

In the oil industry, the COVID-19 pandemic has impacted most oil and gas companies and reduced the price of natural gas well below $ 2, which is likely to trigger a sudden switch from coal-based power plants to gas [53]. The sharp decline of fossil fuel prices is likely to impose an extra burden on most developing countries. This also implies that most governments will resort to energy resources other than RE, which will directly affect global climate policy. Banks can help mitigate this challenge by offering interest-free loans to sustain the development of RE-related projects, which will curb the energy market from swinging towards fossil fuel-based power generation [54].

Before the COVID-19 outbreak, RE made significant progress in several countries with accelerated growth. The cost of RE became more affordable because of overwhelming research activities, technology advancements, and supporting policies in the sector. In terms of policies, most countries formulated strategies to ensure the accelerated development of the sector globally [55]. For instance, in terms of cost, solar and wind energy were in good competition with fossil commodities before the pandemic [56, 57]. When a barrel of oil was pegged at $ 60, most oil-related companies championed several programs aimed at carbon emission reduction. These programs cushioned and sustained RE immensely, but the inception of the COVID-19 pandemic has stalled investments into these RE-related programs. Suncor Energy Inc. reduced its 2020 budget to the tune of £ 1.5 billion. This budget allocation was to be used to develop two cogeneration units, mainly to curb carbon emissions, and a wind-powered plant in Canada. However, note that the RE sector saw accelerated development because money harnessed for the sector was obtained from the fossil-related sector [58].

By the end of 2020, it was reported that the global RE capacity was nearly 2800 GW. This meant an extra 1200-GW increment compared to the values recorded in 2015. However, it has been established that more than 70 % of the expansion in electric power generation in 2019 was due to the growth of RE. Wind and solar energy growths were pegged at 60 and 90 GW, respectively. Wind and solar energy ensured that 90 % additional RE was recorded in 2019 alone [59]. The USA, UK, Spain, China, and India were the countries with the highest installation capacities in 2019. Today, most of these countries have been compelled to cut their spending in the RE sector and redirect the funds to other sectors, mainly medical and social support, subject to their needs.

According to the Global Wind Energy Council, these obstructions regarding the supply chain as a result of the negative impact of the COVID-19 pandemic on the RE sector were likely to affect the development of wind energy projects in 2020 [60]. Before 2020, solar power plant installation was pegged at 129.5 GW, but these projections had to be reduced to 106.4 GW, signifying a reduction of 18 % in the installation capacities. A solar PV project being championed in India has stalled due to the impact of COVID-19. It is projected that there will be further delay if the global challenge of the COVID-19 pandemic is not resolved. Installations of solar-related projects are dwindling more, because most solar PV modules are imported from Asia [61].

In February 2020, wind-related projects in Europe were hit hard, as components for such projects were restricted due to the global pandemic. The wind industry is gradually recovering after the crisis, and currently most companies manufacturing wind energy components are still in active business [62]. Iberdrola continued to install its first megawatt hour in April 2020, as part of the 500 MW solar PV project being championed by the Spanish company, which is a massive boost to the RE sector [31]. With the negative impact of COVID-19 in Europe, the share of RE grew to 41 % from January to March, and this was higher than the share in 2019 by a margin of 16 %. Germany, Ireland, and Denmark were able to produce 50 % of the energy from wind energy resources [63]. For most countries globally, the power mix has drifted to REs due to low electricity demand, lower operating costs, and priority access to the grid through regulations. The electricity demand shifted back to initial trends before the lockdown in 2020 in most countries.

5.1 China

China is currently the country that has the largest RE electricity capacity, which amounts to about 32 % of the global capacity with about 895 GW mainly from hydropower, wind power, and solar PV, which correspond to about 41, 31.5, and 28.5 % of the generation capacity, respectively. This has been backed by China being the major manufacturer of different RE components and modules, more specifically for PV solar energy, so that RE represents about 25–35 % of the energy mix in China, next to coal, which has a share of 60–70 % [45]. Interestingly, China was the birthplace of the COVID-19 pandemic and the country with the first and most restrictive lockdown measures [28]. China has been severely impacted by the pandemic, resulting in cessation of many industrial operations and economic turndown, which affected the global supply chain of many commodities and products [64]. At the heart of this was the supply of RE components, more specifically PV modules, with China having 65–75 % market share, which lead to an increase in their cost from $ 0.228 W^{-1} to $ 0.25–0.28 W^{-1} [48]. Tu et al. analyzed the costs from 97 offshore wind power facilities, which indicated that although the cost has decreased by about 16.3 % over the period 2014–2019, it increased by 10.85 % in 2020 alone due to the COVID-19 pandemic [65]. The authors have stressed the need for increased green financial support to counteract the impact of the COVID-19 pandemic, which can help maintain the cost close to that of 2019. Fig. 6 shows the energy mix in China in 2020 and indicates a drop in coal-based power generation due to a decrease in maritime trade and shortage in coal supply, and hence an increased share of REs, which was restored once coal-fired power plants were back in operation. This also indicates the high reliability of REs during the crisis, which are a localized source of energy.

5.2 European Union

In the EU, the decrease in energy demand, as well as the higher demand for energy from renewable sources, has caused a sharp decline in energy harnessed from nonrenewable sources. From February to July 2020, energy generation from renewable sources increased compared to that from fossil products. This

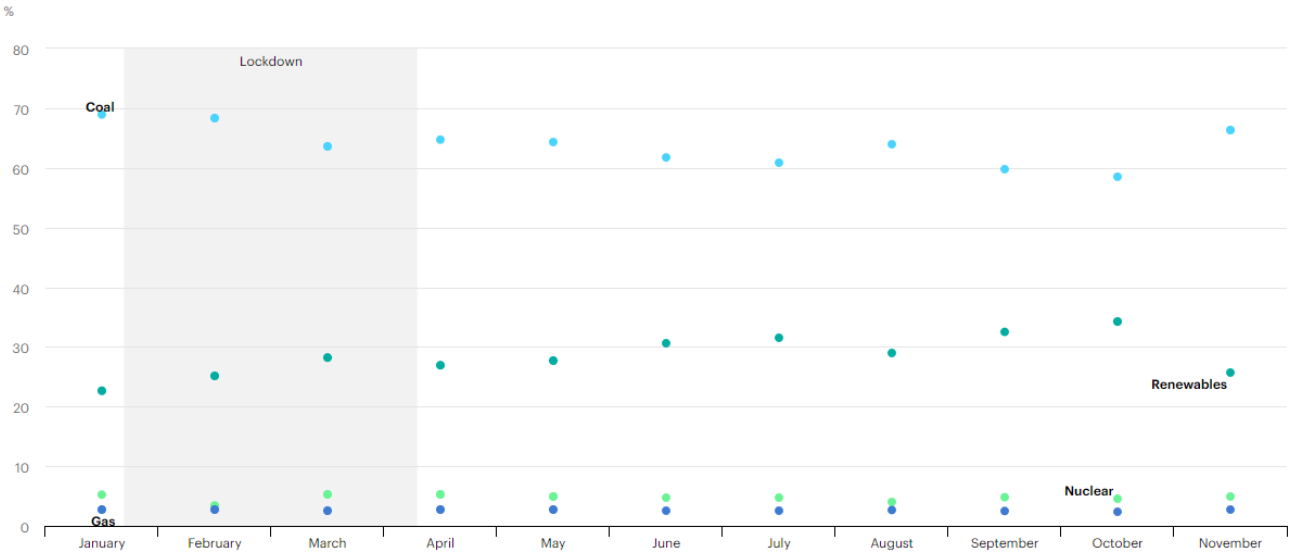

Figure 6. Energy mix in China in 2020 [45].

scenario changed due to low wind energy production. Energy harnessed from natural gas has also seen a sudden surge due to lower gas prices. From January to August 2020, nuclear generation has dropped. Nuclear power share saw a marginal increase after September. Production of coal also dropped within the same time frame but increased with respect to demand. There were, however, sporadic peaks in weekly renewable generation in the fourth quarter of 2020, as depicted in Fig. 7.

5.3 USA

The USA has been impacted severely by the COVID-19 pandemic, having the highest number of confirmed cases of about 65 million cases and 0.9 million deaths by mid-January 2022. Since March 2020, natural gas has been a primary source of energy generation in the USA, due to its decreased cost. On the other hand, REs outperformed energy generation from coal-fired sources during the lockdown when the electricity demand was low [45]. Measures put in place by the government by June 2020 further consolidated the energy generation from natural gas. There was a surge in energy harnessed from nuclear and coal by July and August 2020 in tandem with the growing demand. These sources outpaced energy harnessed from RE due to a decrease in energy harnessed from wind and hydro sources. Energy generation by August 2020 was way more than that of 2019 and this was able to mitigate the growing energy demand due to an increase in temperatures. A decrease in temperature in September implied a decrease in cooling demand as compared to that of 2019 in the same period; hence, coal power

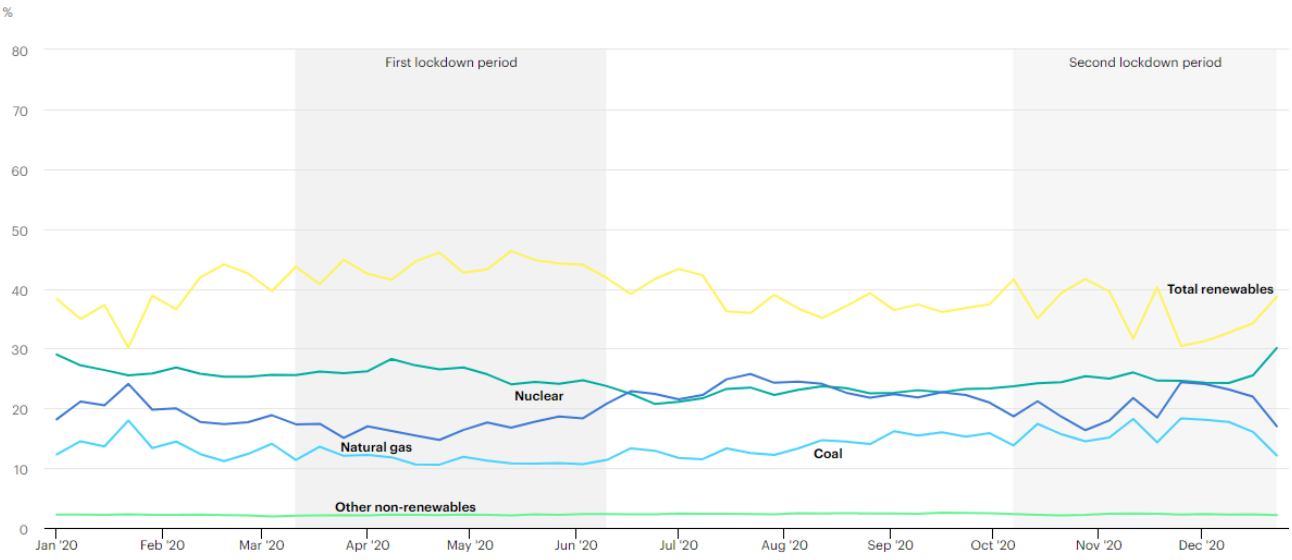

Figure 7. Energy mix in the European Union in 2020 [45].

production declined during this period. In October 2020, the total generation was similar to that of 2019. Solar and wind energy declined by December, and hence the RE share was reduced, as depicted in Fig. 8.

5.4 India

India has been hit by the COVID-19 pandemic a bit lately, with two infection peaks in August–September 2020 and May–June 2021, and hence recorded the second place worldwide in terms of the number of confirmed cases. Deshwal et al. have indicated that only 720 and 188 MW for solar and wind RE were installed by March 2020, which is lower by 60–70 % as compared to 2019 [26]. The authors have indicated that a scheduled installation of about 3 and 2.5 GW of solar and wind REs in 2020 is likely to be deferred; this also due to a drop of about 25–30 % of power demand during the lockdown. This has been attributed to (i) halt in construction activities during the lockdown, (ii) disruption of the global supply chain, and (iii) revenue deficit with less budget available for capital expenditure. These factors have been stressed as well in the work of Pradhan et al. while discussing India's COVID-19 impacts in the present and future [66]. The authors have indicated import and supply chain disruption along with lockdown as the major obstacles for achieving RE targets for 2020 and afterward. Shekhar et al. have critically analyzed the RE stability in India under the COVID-19 pandemic, giving some key policy recommendations and insights [49]. They recommended that policies have to work on investment subsidies considering reduced upfront costs, import relaxations, and accelerated appreciation, as well as operational subsidies of generation incentives and power purchase agreements.

The difference between the energy harnessed from coal and renewables dropped slightly during the lockdown in India. By mid-August 2020 the share of renewable energy resources exceeded 30 %, as shown in Fig. 9. By the end of August 2020, this gap increased and in December 2020, the share of renewables in energy generation in India decreased to below 20 %, and this was similar to what was reported before the lockdown. The levels of energy demand since May 2020 have recovered in India. The generation of electricity increased in July 2020 compared to that in 2019 within the same time frame. This trend lasted for four weeks, and by late August there was an inversion of this trend compared to that of 2019. Generation of electricity increased in September and October.

5.5 Africa

Although Africa has a small share of world RE capacity with only 1.9 %, it is well established that the continent has a huge RE potential, more specifically for hydropower, solar, wind, and bioenergy, along with a very high growth rate in RE capacity, with the main limitation of funding availability. Amir and Khan have indicated that in spite of these huge RE potentials in Africa, the COVID-19 pandemic made the situation worse in terms of further unavailability of capital investments for RE projects, which slowed down the growth rate of renewables [50]. The share of renewable and non-renewable energy resources tends to vary significantly from one country to another in Africa. Due to variations in the COVID-19 pandemic impacts, the interventions in place to mitigate the crisis also tend to vary from one country to the other. Very few works have delved into some of these interventions and their effect on the energy sector in Africa. Reduction in the export of energy

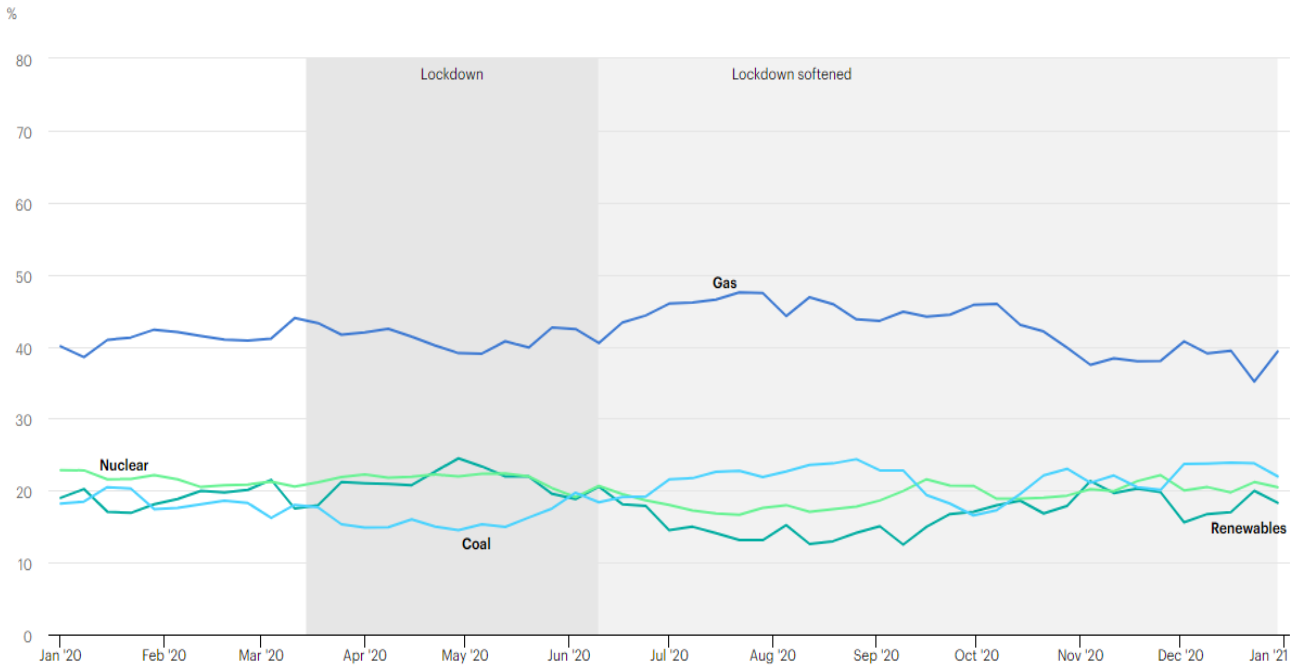

Figure 8. Energy generation in the United States in 2020 [45].

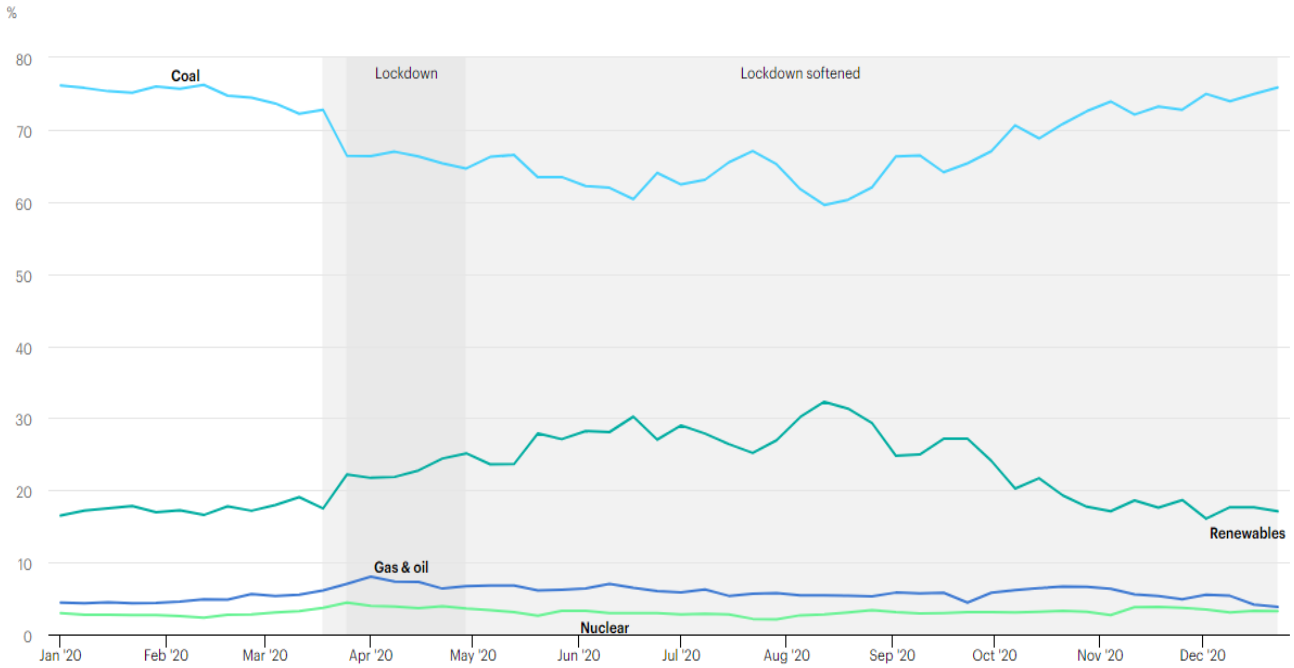

Figure 9. Energy mix in India in 2020 [45].

coupled with the complete shutdown of energy-related projects in Africa is a key issue confronting the energy sector during the lockdown. Most countries around the world depend largely on Africa for their raw materials [50]. For instance, industries in China rely on Africa for iron ore, cobalt, and lithium to sustain their economy. The shutdown of industries during the global lockdown implied that the demand for these raw materials was equally reduced as well [67]. The sharp decrease in oil demand impacted most oil and gas countries and companies negatively [68]. Due to the closure of most ports in Africa coupled with disruptions in the production of raw materials for its industries, China had to truncate agreements with most African countries during the lockdown [68].

The energy sector has also been impacted negatively. It has been reported by Haverhill Synergy that equipment to sustain the smooth running of the company has stalled due to the closure of the port in Nigeria [69]. This has led to the stagnation of renewable-related projects in Africa. A report by Global Off-Grid Lighting highlighted the fact that half of off-grid energy companies are going through financial difficulties due to the impact of the COVID-19 pandemic on the sector. Nearly 67 % of mini-grid companies and 75 % of solar home system companies could survive, but during the lockdown, most of them planned to undergo insolvency [68].

Residential energy demand increased appreciably during the lockdown period. The IEA argues that the imposition of the lockdown led to a cut in disposable incomes [69]. Most households in Africa raised issues on how they could afford their electricity bills due to the lockdown and shutdown of companies [68, 69]. The use of off-grid energy applications saw a massive increase due to the pandemic according to a study by GOGLA, which revealed that 16 % of users showed more than normal increase in their reliance on off-grid applications, while 18 % showed normal usage [69]. The majority of 51 % had not changed, but 4 % of the participants of the study showed "much less than normal usage". Like in other parts of the world, COVID-19 has seriously impacted the transportation sector of most African countries. Due to issues relating to their negative energy infrastructure coupled with a high rate of poverty, most African countries paid holistic attention to the energy sector, especially during the lockdown. Decisions by most governments during the global lockdown helped reduce the rate of poverty in the continent [70].

6 COVID-19 Impacts: Mitigation Strategies

Despite the challenges encountered by the RE sector due to the global COVID-19 pandemic, it still made some massive strides. By the first quarter of 2020, the share of RE globally exceeded 28 %. This was significantly higher by 26 % compared to that recorded in 2019 within the same time frame. The growth of the RE sector has also declined in 2020. However, it has been reported that 167 GW of renewable power capacity will be added to the existing share, and this is 13 % lower compared to the shares added in 2019. This is due to construction delays often stemming from supply chain disruptions, lockdown, and social-distancing measures. Production of biofuel for automotive purposes dropped by nearly 13 % in 2020, and this is the first time the sector has encountered such a sudden drop in the last 20 years [71]. In general, biofuels struggle in terms of competition with other energy generation sources due to the reduced oil and gas prices. One key strategy the government can do is adding the renewable sector to their emergency stimulus packages to cushion various sectors of the economy.

Through a healthy investment in renewables whose prices have dropped tremendously, job creation can support most global economies bouncing back to normalcy. This approach will have a direct impact on the quest for emission reduction as well as supporting technological advancement.

Global growth in terms of energy efficiency before the COVID pandemic was around 3 %. The primary energy intensity in 2019 also saw an appreciable increase of 1.6 %. Money allocated for energy efficiency has also been reduced significantly. However, it has been projected that before the end of the year 2020, budgetary allocation of end-use applications is anticipated to be reduced by 10–15 %. Purchase of these end-use applications is, however, anticipated to drop significantly as well. Formulation of policies to incentivize the building, technology, and infrastructure upgrades across varying aspects of the economy will be the key to sustaining jobs associated with end-use applications [72].

Most countries have made efforts to come up with stimulus packages to subdue the challenges and hardship brought to their citizenry as a result of the impact of COVID-19. Most of these packages are focused on public health, economic recovery, and climate change, with priority given to public health with a major share. Despite these plans by most governments being legitimate, drawing a balance between economic recovery and climate change issues will create a win-win scenario for countries worldwide. This is very important, because oil prices have dropped and could mean its sole dependence will negatively impact the environment. However, it was argued that the low oil prices favored consumers but not specifically people under lockdown. Therefore, this puts RE technologies in a better position regarding energy security and climate change. Decarbonization via the exploitation of RE technologies should be one of the pragmatic approaches adopted post-COVID-19 era.

During the lockdown, most people were made to work from home via various internet services. This implied that most of the energy generated globally during that period was used for domestic purposes. Should the world continue to follow this pattern of work, energy demand for domestic purposes is likely to surge; hence, a sustainable medium for energy generation would be required [72]. Integration of RE technologies with digital technologies can also ensure future energy demands are met. However, an investment in hydrogen, batteries, and carbon capture has been reported to be part of contingency plans to sustain the energy sector post-COVID-19. RE technologies post-COVID-19 must be aligned to create jobs in the economic recovery process. Energy harnessed from the sun or wind can augment energy from existing electricity generation sources. When demand is low, particularly during the night, energy from the wind can be utilized, and when the demand is high, solar energy can be utilized as well [71, 72].

Developing the RE sector can improve the manufacturing industry as well as create jobs. It also has a direct ripple effect on the cost of energy people will have to pay [73–75]. It will become imperative that other structures already in existence are changed into energy-efficient buildings. The heating, cooling, lighting, and energy storage systems must be as efficient as possible [76]. Projects with a primary focus on energy efficiency must equally consider the replacement of inefficient electrical appliances and the introduction of energy-efficient materials. For instance, India replaced 11 million existing streetlights with light-emitting diodes, leading to the creation of over 10 000 jobs. This project by the Indian government led to a total reduction of GHGs by five million tons over nine years. This particular transition will require a tremendous amount of capital and labor force. Stimulus plans proposed by governments across the world must equally factor energy efficiency into their budget.

Energy generation via anaerobic digestion resulting in methane gas is also gaining lots of attention in recent times. The process involves breaking down organic waste material and is not susceptible to any weather variation, as opposed to energy harnessed from the wind and sun [76]. Anaerobic digestion is very reliable and maintainable because the feedstock required, which is waste, is abundant. The IEA has proposed that anaerobic digestion can supply 20 % of the gas required by the world [77]. The reliance on biomethane as a source of energy generation must carefully be considered in place of fossil commodities despite the sudden drop in fossil prices on the world market [78]. Scaling up biomethane technology will also require better storage and grid systems to ensure constant and uninterrupted energy supply. During peak power demand, biomethane can augment existing electricity generating systems such as wind and solar systems to meet energy demand globally [79].

Carbon capture and storage can be coupled to bioenergy systems, and this will support the global switch to RE technologies. Best practices in terms of land management as well as mechanized agriculture should be encouraged post-COVID-19. This will support the storage of carbon in the soil instead of it being emitted into the atmosphere via traditional practices in agriculture [80]. From the literature, the economic crunch in 2008 highlighted the key role that investment in renewable energy technology systems could play in the recovery of the economy under such harsh unforeseen circumstances. However, it was further observed in 2008 that there was an increase in wind and solar energy, leading to the establishment of sustainable energy systems. Support from the government during that period through stimulus packages supported the development of the clean energy sector. It has therefore become imperative that future policies are formulated to encourage investors to consider this sector. To meet this target, governments all over the world must consider an ambitious and cost-effective method for renewable energy generation.

7 Conclusion

The outbreak of the COVID-19 pandemic has exposed many cracks in many sectors of the economy globally. The impact of the pandemic on human health has been very significant, and most articles have elaborated and discussed of these negative impacts. However, as with any challenges and crises faced, opportunities emerge for improvements. Although the restrictions imposed by most countries worldwide have resulted in economic turndowns, they have led to improved air quality and decreased air pollution by GHG emissions due to cessation of transportation and aviation activities. Similarly, the shutdown of many industrial activities has led to the improved

water quality of water bodies, despite the increased burden of organic load in wastewater treatment. The energy sector was at the center of the sectors impacted by the COVID-19 pandemic owing to the significant drop in energy demand. Fuels demand for transportation and aviation has dropped by almost 75 % due to lockdown measures, along with reduced energy demand for industrial and commercial activities. Only residential power supply has seen some increase due to quarantine measures imposed worldwide.

The RE sector was also significantly impacted by the COVID-19 pandemic, but interestingly in a unique way. The power supply from REs has not been affected like those for coal- and natural gas-fired power plants that have ceased operation or reduced operational capacity due to reduced power demand and limited fuel supply with the drop in maritime trade. The RE sector has been affected mainly due to lack of capital investment and supply chain disruption, along with lockdown measures and hence reduced workforce. The COVID-19 pandemic has demanded additional budget from many governmental entities to manage such crisis and save peoples' lives; hence, less budget for capital expenditure or subsidy has been available for execution of RE projects. The disruption in the supply chain has resulted in the unavailability of RE components, more specifically PV modules, either due to lockdown measures at manufacturing facilities or cessation of transportation operations, which has led to the deferral of many REs projects along with increased cost. Additionally, the lockdown measures have resulted in ceased construction work in many RE projects.

Nevertheless, the pandemic can present some opportunities once proper mitigation strategies and policy recommendations are considered for the post-COVID-19 era. The economic stimulus packages announced globally along with enhanced green finance can be beneficial to restore or even to increase the growth rate of REs. This can be simply achieved by directing most if not all of the stimulus packages allocated for the energy sector toward RE projects. Along with these better green finances, relaxed taxation and improved carbon credit or tax can further motivate the growth rate of RE projects. The localization of RE component manufacturing can help to overcome challenges associated with the disruption in the supply chain and presents opportunities for improved economic performance, GDP growth, and increased employment. Chemical process industries, like many other sectors, can benefit from the support provided to new RE projects in several ways, first by establishing processing facilities to manufacture RE components, along with shifting their electricity demand to be met by RE and hence make use of financial and administrative incentives.

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Abbreviations

GDP	gross domestic product
GHG	greenhouse gas
PV	photovoltaics
RE	renewable energy

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