Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Effect of COVID-19 virus on reducing GHG emission and increasing energy generated by renewable energy sources: A brief study in Malaysian context

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ABSTRACT

Coronavirus 2019 (COVID-19) has globally affected the human mortality rate and economic history of the modern world. According to the World Health Organization, COVID-19 has caused a severe threat to the health of the vulnerable groups, notably the elderly. There is still some disagreements regarding the source of the virus and its intermediate host. However, the spread of this disease has caused most countries to enforce strict curfew laws and close most industrial and recreational centres. This study aims to show the potential positive effects of COVID-19 on the environment and the increase of renewable energy generation in Malaysia. To prevent the spread of this disease, Malaysia enacted the Movement Control Order (MCO) law in March 2020. Implementation of this law led to a reduction in environmental pollution, especially air pollution, in this country. The greenhouse gases (GHG) emission , which was 8 Mt CO_2 eq. from January 2020 to March 2020, reduced to <1 Mt CO_2 eq. for April and May. The reduction of GHG emission and pollutant gases allowed more sunlight to reach photovoltaic panels, hence increasing the renewable energy generation.

1. Introduction

On March 11, 2020, the Director-General of the World Health Organization declared Coronavirus disease 2019 (COVID-19) a pandemic disease. He also briefed on the 13-fold rise in positive cases in China and 114 countries with 25,040,371 positive cases and 843,727 deaths (Coronavirus disease News, 2020). Covid-19, acute respiratory syndrome, has spread

Abbreviations: COVID-19, Coronavirus disease; MCO, Movement Control Order; MT, Million tonnes; SARS-CoV-2, Severe acute respiratory syndrome coronavirus 2; CO_2, Carbon dioxide; GHG, greenhouse gas; RE, renewable energy; PV, Photovoltaic

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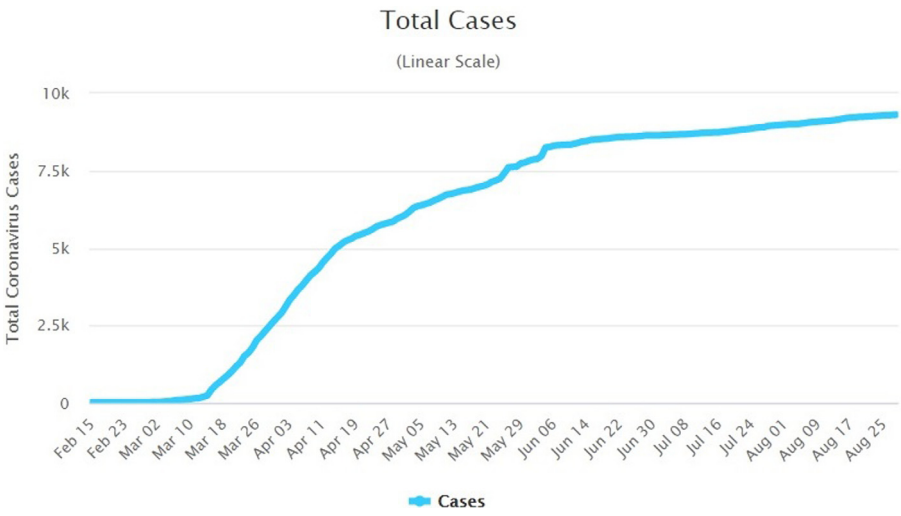

Fig. 1. Total Coronavirus Cases in Malaysia from Feb 15 2020, to August 25, 2020.
Source: Cases (2020).

across the world and has become a significant infectious disease. It has influenced public health all over the world. This disease has had such devastating effects that it has driven most companies to bankruptcy (Klemeš et al., 2020). The first patient was hospitalized on 12 December 2019, after which millions were hospitalized (Ryu et al., 2020). This disease's death toll increased to 250,000 by early May 2020. The United States, Spain, and Italy were among the most affected countries with the largest number of deaths (Guo et al., 2020). The virus is considered to have no direct effects on the human environment and energy sector. However, from the social perspective, such conditions have occurred that may potentially impact the energy and environment sectors. The results of some effective and conclusive steps that countries have taken to prevent COVID-19 are now emerging (Eroğlu, 2020).

It was a challenging start for the year 2020 for all of us worldwide. In this time of pandemic crisis, the Prime Minister of Malaysia, Tan Sri Muhyiddin Yassin imposed Movement Control Order (MCO) since March 18, 2020 on the whole nation in the hope to counteract the quick spreading viral disease, COVID-19. Although it may seem a risky strategy, some positive effects of MCO were observed in terms of recovery cases and flattening of the curve (Comments, 2020). The first case of COVID-19 in Malaysia was detected on January 24, 2020: a woman and her two grandchildren who had returned home from Wuhan in China (Pacific, 2020). The WHO Country Office in Malaysia has been working closely with the Ministry of Health to respond to this outbreak. Fig. 1 shows the spread of COVID-19 from February 15, 2020, to August 25 of the same year. It is evident from the figure that the spread of coronavirus accelerated after 12th of March in the entire country. As of April 25, 2020, there were 9,317 COVID-19 cases including 125 deaths and 9,038 cases of recovery reported by the Ministry of Health (MOH) in Malaysia (Covid-19 (Maklumat Terkini) Ministry of Health (Malaysia) 2020 Available, 2020, n.d.). In addition, Selangor, in Malaysia, recorded the highest number of confirmed COVID-19 cases ("Covid-19 (Maklumat Terkini) Ministry of Health (Malaysia) 2020 Available", n.d.). Anyhow, as MCO continues to prolong, for the time being, many industries are struggling to maintain their normal business operations. As most industries have been obliged to abide by the MCO by putting their businesses to a halt or having an alternative, e.g., working from home, these industries are facing a serious crisis. Particularly, these industries are striving hard to manage their long run as shutting down the operations during these periods may lead to the downgrade of their businesses. The Socio-Economic Research Centre Executive Director, Lee Heng Guie, has presumed that MCO extensions will certainly put the Malaysian economy at risk by 3% this year (Comments, 2020). Therefore, by the time when the industries are allowed to operate again, most would have the difficulty to cope with the losses. The positive news is that shifting from conventional utility to solar energy will provide a better and quicker recovery process. Solar energy can help the industries to reduce the electricity bill up to 30%–50% and, at the same time, fulfil the energy demand by providing sufficient energy for usage (Kabir et al., 2018).

In this era, people are more aware of the environmental consequences of burning fossil fuels and sustainability has become an ethical principle. Both issues encourage people to protect natural environment. But today, the emphasis is also on the long-term adequacy of energy supply as well as the environmental impacts of specific sources. The near-certainty of the costs of carbon dioxide emissions in developing countries has significantly changed the economic outlook of renewable energy sources. A market-determined carbon price would provide incentives for sources of energy cleaner than existing fossil fuel sources, without discriminating between different technologies. This places the burden on manufacturing firms to employ technologies that effectively deliver power to customers at a competitive price. The big contenders are wind, solar, and nuclear (August, 2020). Sun, wind, waves, rivers, tides, the heat from the earth's mantle's radioactive decay, and biomass are all abundant and constant renewable sources. Turning to the use of electricity of sufficient renewable energy

sources other than large-scale hydro, there are difficulties in actually harnessing them. The challenge is how to use solar photovoltaic (PV) systems (which directly produce electricity) in a way to make them transform dynamos to generate electricity (August, 2020). This study (Hosseini, 2020) proposed smart policies where the threat of COVID-19 could be turned into great opportunities for enhancing the global sustainable energy scenario. The reduction of atmospheric pollutant gases has increased sun ray radiation, which could improve the efficiency of solar panels as green and renewable energy. In (Le Quéré et al., 2020), the government policy and operation data were compiled to estimate the reduction of greenhouse gas (GHG) emissions during forced confines. During early April 2020, the global average CO_2 emissions have decreased by 17% relative to the mean rate of 2019, just under half of the changes in surface transport. At the peak of the emissions, the average emissions decreased by 26% in individual countries.

In addition, the COVID-19 outbreak has a devastating impact on the global supply chain for renewable energy. If the to-be-made incentives do not achieve renewable energy goals, a significant decline in clean energy investments and a domino effect will likely occur (Eroğlu, 2020). The damage caused by global warming occurred much faster than that predicted by scholars. Since the Kyoto Protocol was signed in 1997 to combat global warming by reducing global GHG emissions, countries have had to adhere to this principle and strive to achieve it. The developing countries voluntarily play roles to respect and comply with GHG emissions reduction. However, the global climate pattern has deteriorated faster than expected (Thapa et al., 2018). As almost all GHG emissions are resulted from the energy sector, energy policies and related regulatory frameworks play a key role in achieving the goals of the Kyoto Protocol (Lee et al., 2018). Carbon footprint is considered as one of the major indicators where it is mostly reported in terms of GHG emissions, which is directly and indirectly created by human activities, and typically quantified as carbon dioxide equivalent (CO_2 eq.). Carbon footprint can be considered as one of the major tools to measure the environmental safety and health status (Ercan et al., 2016).

The Covid-19 outbreak has positive impacts, too, on the environment. Studies initiated during the outbreak in the home community increased Home Office applications. This will minimize emissions of carbon dioxide by limiting people's mobility in their outer environment (Eroğlu, 2020). There has been a lockout in most countries with people not able to travel around, leading to GHG emissions reduction. During the Covid-19 outbreak, the reduction of GHG emissions is observed under limitations imposed by some countries such as China and Italy (Le Quéré et al., 2020). A reduction of around 25% in carbon emissions in China is announced (Brief, 2020). As CO_2 is considered as the main member of GHGs, carbon trading has become an essential indicator to measure the implementation of the Kyoto Protocol (Christiansen and Wettestad, 2003). A turning point in the Kyoto Protocol was recently marked by the Climate Summit 2018 (Michaelowa et al., 2019). Malaysia has pledged to commit to the Kyoto Protocol. Coordinated efforts by the Malaysian Government have been made to minimize the carbon footprint in Malaysia, including the implementation of energy efficiency projects (Lim and Lam, 2014). Even though Malaysia is not listed in the Kyoto Protocol Annex I countries, this developing country has been actively involved in GHG reduction under the programmes of this protocol. The development rate of GHG generation in Malaysia due to conspicuous industrial advancement and population growth has forced the government to invest in GHG reduction through various programmes (Hosseini et al., 2013). Moreover, several projects, conferences, producers' fines, and plans have been considered to reduce carbon footprint, few of which have failed to reduce GHG emissions to an acceptable level. On the contrary, a good example is the International Conference on Low Carbon Asia (ICLCA) that serves as a yearly conference to provide a platform for the researchers and stakeholders from the academic community, industry sectors, and governments in Asia. ICLCA provides such a solid and fundamental platform for those researchers and even other sectors to share their experience, knowledge, and expertise in sustainability in line with reduced GHG emissions with the help of invited professional and experienced researchers (Kamyab et al., 2020).

The literature survey shows that, so far, very few studies have been focused on the effects of the Covid-19 outbreak on the energy sector and the environment. Therefore, this study is aimed at filling the research gap in this area. The main focus of this work is to make comparison among the performed designs and investigate how the spread of COVID-19 could reduce GHG emissions, notably in terms of the amount of clean energy generated by the solar PV systems. The novelty of this paper lies in the study of the COVID-19 effect on clean energy with a focus on renewable energy. Behavioural patterns will be assessed and potential demand will be forecast to address the key question of this research paper. Improvements in global demand for energy will result in substantial energy savings and GHG emission reductions if any. This paper is interesting since it discusses a recent and evolving global problem arising due to the COVID-19 pandemic.

2. Energy consumption and GHG emissions in Malaysia

The magnitude of the COVID-19 global crisis is exceptional; thus, the consequent impacts are unparallelled. Energy demand has risen in Malaysia over the last few decades to sustain the economic growth of the nation. This demand is expected to increase in the coming years, where GHG emissions will increase as long as fossil fuels remain as the main source for generating energy. Malaysia depends on fossil fuels, mainly natural gas, coal, and petroleum, to generate energy. It ignores the expense of the environment by following the market, and induces a large rise in energy consumption. The greenhouse effect brought about by energy consumption has gained growing attention from the international community since signing the Paris Agreement, which has placed pressure on developed countries' economic growth. To achieve "economic growth no longer depending on energy consumption", several countries are researching how the relationship between economy and energy consumption can be organized (Wang et al., 2019). Fig. 2 shows a summary of CO_2 emissions

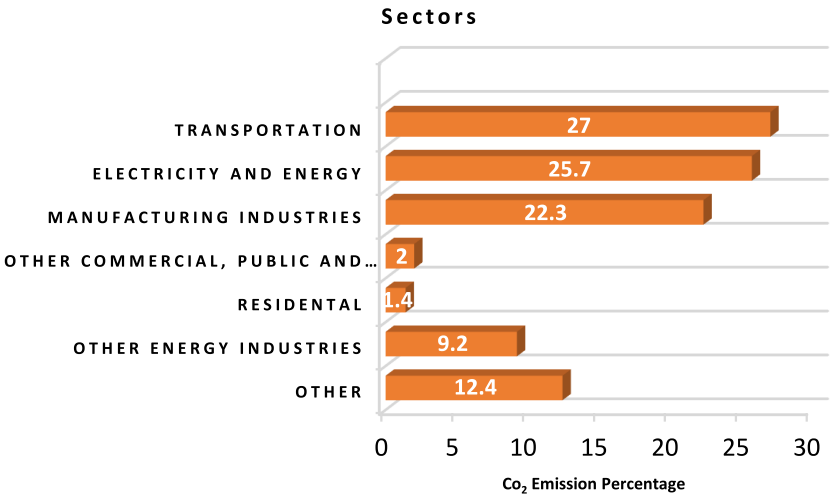

Fig. 2. GHG emissions induced by energy consumption of different sectors in Malaysia in 2019. *Source:* Begum et al. (2015).

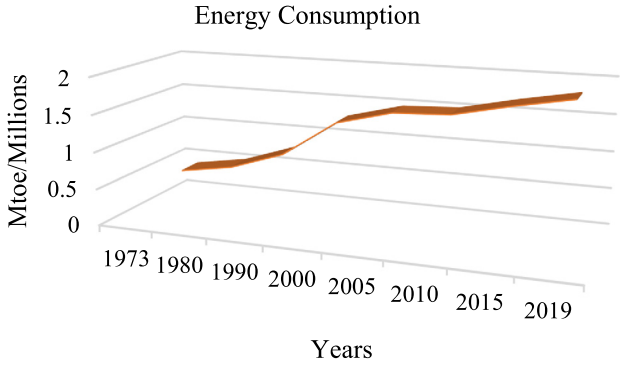

Fig. 3. Total primary energy consumption.

from energy consumption of different sectors in Malaysia in 2019. Note that the transportation sector is almost entirely dependent on petroleum-based fuels.

The transportation sector is the most significant contributor to CO_2 emissions, followed closely by various energy sectors mainly powered by fossil fuels such as petroleum, natural gas, and coal. The total GHG emission in Malaysia has risen sharply since the end of the 1990s and by 2020, the emission level has reached above 1600 Mt CO_2 eq./y and have since remained above this amount (Brief, 2020). As shown in Fig. 3, future energy demand is expected to grow at an annual rate of 5–7.9% by 2024 (Shigeoka, 2004). The total energy consumption in Malaysia was calculated at approximately 1.055 $\times$ 10^{18} joules as in 2019, which is an improvement from the early 1980s as shown in Fig. 3. This is considered to be fairly high compared to the global average long-term atmospheric concentration of CO_2 measured in parts per million (400ppm) in some developed countries (Ritchie and Roser, 2020). The COVID-19 pandemic has clearly contributed to beneficial environmental impacts by reducing transport sector GHG emissions. As stated in [27], the Canadian transportation sector GHG emissions increased by 19% between 2000 and 2017. The closure of the transport sector in the months of March, April, May, and June would have saved around 45 Mt of CO_2 eq. In fact, the annual 2020 GHG emissions of the Canadian transport sector are expected to be 93 Mt CO_2 eq, a substantial reduction unheard of over the past two decades.

Air pollution caused by the emission and leakage of polluting gases from the burning of fossil fuels is one of the most important pollutants in the energy sector (Müezzinoğlu, 1998). Table 1 shows the amount of CO_2 emitted by different types of conventional fuel (Analysis & Projections Monthly Energy Review, 2020). The reduced emissions of CO_2during 2018–2019 showed that some measures had been taken to reduce CO_2 emitted by conventional fuels.

The GHG emissions generated from conventional power plants and combined power-heat plants have increased during 2008–2019 in Malaysia. (See Table 2.)

There is a stronger focus on the adoption of renewable energy in the last decade. Ensuring reliable and competitive energy is very important for the industry and affects the dominant energy policies in each country. The role of governments and policies in adopting renewable energy is becoming more important (Dalenback, 2004). The latest

Table 1
The emissions of CO_2 (in Mt) by conventional fuels.

	2018	2019	2020F
Petroleum and other liquid fuels	2373	2354	2189
Natural gas	1636	1689	1670
Coal	1260	1084	885
Total energy	5280	5138	4755

Note: F = Forecast.

Table 2
The GHG emissions from conventional power plants in Malaysia.

Year	GHG emissions (CO_2 eq.)(*kt*)
2008	2,484,012
2009	2,269,508
2010	2,388,596
2011	2,287,071
2012	2,156,875
2013	2,173,806
2014	2,168,284
2015	2,031,452
2016	1,928,401
2017	1,849,750
2018	1,874,346
2019	1,858,273

Table 3
Predicting RE production capacity (MW) during 2015–2050.

Year	Biomass	Biogas	Mini-Hydro	Solar PV	Solid waste	Total
2015	330	100	290	65	200	985
2020	800	240	490	190	360	2080
2025	1190	350	490	455	380	2865
2030	1340	410	490	1370	390	4000
2050	1340	410	490	1870	430	21370

findings have demonstrated the beneficial indirect effects of reducing concentrations of PM 2, 5 and NO_2 in France, China, Germany, Italy, and Spain. In fact, high concentration of these gases is among the most significant environmental problems developing countries are faced with. It is important to note that while the pandemic has caused some GHG emissions to fall, this decrease may have little impact on the total concentrations of GHGs accumulated in the atmosphere for decades. There may be a long-term structural change in the countries' economies to a major decline.. As the pandemic ends, countries are more likely to revive their economies, and GHG emissions will once again skyrocket (Sharma and Dhar, 2018).

Malaysia introduced renewable energy (RE) as the 5th fuel strategy in the 2001 Mixed Energy under the National Energy Policy. The goal was to generate 500 MW grid-on power from RE resources in 2019 (Solar Energy in, 2020). Malaysia has vast resources of RE in the form of biomass, solar, and water. At the COP15 held in Copenhagen, Denmark, Malaysia pledged to voluntarily reduce GHG emissions by up to 40% by 2025 compared to 2005. The amount of power generated by RE should reach 985, 2080, and 2100 MW in 2015, 2010, and 2050, as shown in Table 3 [19].

3. Impact of COVID-19 on solar energy in Malaysia

COVID-19 has claimed hundreds of thousands of lives and significantly impacted the global economy. The world is yet to recover from the losses caused by the pandemic even six months after the outbreak. It has indeed impacted the worldwide economy, and industries in Malaysia are not exempted. An increased generation of solar power can be anticipated if energy generation by the PV panel is enhanced due to a lower level of air pollutions. Following the MCO law implemented in Malaysia since mid-March 2020, air pollution has substantially reduced, leading to increased intensity of solar radiation on the solar panels (How, 2020). As GDP continues to be hard hit by the COVID-19 pandemic, the government, via the Ministry of Energy and Natural Resources (KeTSA) Committee, has announced a new clean energy quota as an immediate way to boost the Malaysian economy. KeTSA has agreed to open a competitive bidding process for the Large Scale Solar (LSS) programme led by Malaysia Electricity Industry in order to attract renewable energy investment. The increase in PV installations between those years has resulted in increased job opportunities for the country. In 2020, the Malaysian government wants to benefit from solar energy investments as much as possible to speed up economic growth.

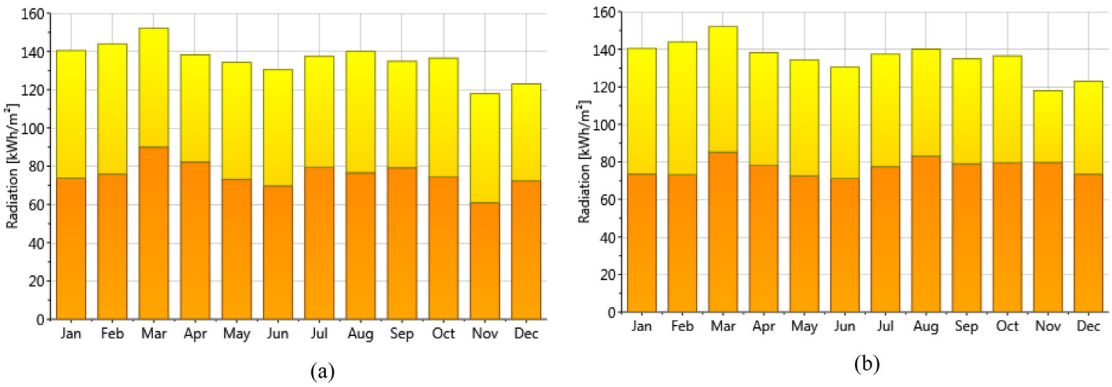

Fig. 4. The amount of irradiance curve in Malaysia (a) 2019 and (b) 2020.

Air quality is important for people's well-being; moreover, 91% of the world population resides in countries where bad air quality exceeds the permissible limits (Ambient, 2020). The effects of deteriorating air quality are manifested in the large percentage of global mortality each year (Zhang et al., 2017). In this regard, the 2016 study conducted by the World Health Organization (WHO) suggests that air pollution leads to around 8% of total deaths worldwide; the countries most affected are in Africa, Asia, and some parts of Europe. In the current pandemic, social acceptability problems may not be as high as fears of infection, which may overshadow any concerns about environmental footprints, including GHG and pollutants (Klemeš et al., 2020). NO_2 concentration is one of the main air pollution indices (Bonn, 2003). NO_2 particles reflect the rays of the sun, which could minimize the energy emitted by solar panels. Fig. 4 displays a diagram of the sum of irradiance collected by Meteonorm 7 software in Malaysia between 2019 and 2020. For example, strong social distancing measures were introduced in the province of Hubei (China) in late 2019. These initiatives have influenced the principal economic activities of the world. This caused power stations and industrial plants to discontinue their production processes. The use of automobiles also decreased significantly. All of this has resulted in a dramatic decline in concentrations of Nitrogen Dioxide (NO_2) and Particulate Matter with a diameter of less than 2,5 μm (PM 2 ,5) in the major Chinese cities (Zambrano-Monserrate et al., 2020). In other parts of the world, like Europe, air pollution dropped significantly after policymakers ordered people to stay home to avoid the spread of the new coronavirus. Main factories and other regular operations stopped, the use of cars diminished, thereby reducing GHGs emissions (Coronavirus lockdown leading to drop in pollution across Europe, 2020).

The amounts of irradiance in the listed countries were compared between two periods, i.e., March of 2019 and March of 2020. The results showed the positive points of coronavirus' presence, which have increased the radiation volume and the amount of energy provided by PV systems. Based on estimations made in (Forster et al., 2020), 30% decline in NO_2 will contribute to a short-term cooling of up to 0.01 °C over the period 2020–2025, almost exclusively from reductions in tropospheric ozone. NO_2 trends also contribute to an insignificant warming effect from the decrease in nitrate aerosol. As the ozone response is expected to have strong regional variation, we tested the ozone response in a more sophisticated emulator. To track the expansion of SARS-CoV2, China has put strict traffic restrictions and self-quarantine measures in place. These actions also caused air quality changes. NO_2 was reduced by 22.8 $\mu g/m^3$ and 12.9 $\mu g/m^3$ due to quarantine at Wuhan and China, respectively. In Wuhan, PM 2.5 decreased in 367 cities by 1.4 $\mu g/m^3$, but by 18.9 $\mu g/m^3$ (Zambrano-Monserrate et al., 2020). On the other hand, the Copernicus Sentinel-5P satellite readings suggest a significant decline in NO_2 concentrations over Rome, Madrid, and Paris, Europe's first cities to implement strict quarantine measures. Fig. 4 estimated concentrations of NO_2 from 14 to 25 March 2020 compared with average monthly concentrations in 2019 (Zambrano-Monserrate et al., 2020). In addition, the European Union's Copernicus Atmosphere Monitoring Service (CAMS) announced the last February a fall in PM 2.5 compared to the previous three years. By comparing the difference between the February 2020 average and February 2017, 2018, and 2019 monthly averages, a decrease of about 20%–30% of PM 2.5 can be observed in large parts of China.

4. Conclusions

There is widespread popular support for using renewable energy, particularly solar and wind energy, which provides electricity without giving rise to any carbon dioxide emissions. There are many sources of renewable energy in the form of biomass, hydropower, and solar power. The national energy policies and strategies of Malaysia are aimed at involving a substantial contribution of renewable energy in the composition of electricity generation. There have been many challenges preventing renewable energy from being implemented, but the government has approved specific tariffs to resolve such problems. COVID-19 is considered as one of the major challenges that not only the Malaysian government, but also most governments across the world have failed to overcome to date. However, the Malaysian government's

efforts made to enforce the MCO law has led to closing most cities and industrial and recreational centres and has led to a curfew. Implementation of this law has resulted in reduced air pollution, carbon footprint, and CO_2 emissions. Thus, the maximum amount of sunlight is reaching the Earth, radiating the solar panels in photovoltaic (PV) systems, and leading to increased energy production. Finally, solar energy is a mature, clean, and sustainable technology that is seen as the future leader of energy options. It is safe, convenient, and affordable. Most importantly, it is environmentally friendly as it does not emit carbon emissions during operation and helps in mitigating climate change. Results showed significant energy savings and pandemic-related GHG reductions. Future research may focus on using pandemic trends to develop more sustainable and reliable trends and policies on transportation. Policymakers should adopt current GHG performance as the new baseline for future years. That will help to limit emissions of this sector. Transportation, as well as the energy sector, will experience high demand with physical distancing in effect as it approaches 100% operational capacity. Therefore, it would be a lucrative opportunity to expand the fleet with environmentally friendly solutions. Lastly, a short-term reduction in GHG concentrations is not a sustainable way of cleaning our environment. In addition, the virus crisis brings about other environmental problems that can last longer and may be more challenging to manage if countries neglect the environmental impact of the epidemic.

CRediT authorship contribution statement

Amirreza Naderipour: Conceptualization, Methodology, Software. **Zulkurnain Abdul-Malek:** Supervision, Validation. **Noor Azlinda Ahmad:** Writing. **Hesam Kamyab:** Visualization, Investigation, Writing. **Veeramuthu Ashokkumar:** Data curation, Writing - original draft. **Chawalit Ngamcharussrivichai:** Supervision, Validation. **Shreeshivadasan Chelliapan:** Visualization, Investigation.

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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