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CHAPTER FOUR

Effect of the COVID-19 on access to affordable and clean energy

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1. Introduction

The present pandemic situation caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) shows rapid loss in human civilization. The current data (10th September 2021) shows 4,602,882 confirmed deaths and 223,022,538 active cases around the world due to this deadly virus. Report says, human-to-human transmission is the most causing factor of this disease, which resulted in complete lockdown of town and cities globally. Several researches have been performed on restoration of civilization in terms of social, environmental, and economic aspects. Public health management during coronavirus disease-19 (COVID-19) is one of the most concerned topics, which leads the developments in medical technology including molecular-based technology, nanotechnology, advanced biosensing, and immunotherapeutics.

The concept of sustainability in the recent decades has attracted global attention focusing on protecting the environment while providing socio-economic benefit and development to the present as well as future generations which is based on the concept of social, economic, and environmental sustainability. Several goals and targets have been implemented in global political agendas toward the adoption of a sustainable route. Keeping this objective in mind, the United Nations in September 2015 adopted the 17 interlinked sustainable development goals (SDGs) that were designed as a shared blueprint for achieving a sustainable future for the people and the planet under the 2030 Agenda for Sustainable Development. The partnership among developed and developing countries came up in the form of
SDGs for putting an end to poverty, reducing inequality, stimulating the
growth of the economy, and tackling with climate change and preservation
of forests and oceans.

The 17 SDGs consist of 169 targets with 1256 publications, 3031 organ-
nized events, and 5414 actions taken so far. These goals under the 2030
Agenda are universally applicable taking the policies and concerns of different	nations into consideration. The intention of these goals ranges from
eliminating hunger in the world to reducing inequalities and building sus-
tainable societies. Balance and integration of social, economic, and environ-
mental dimensions are necessary for implementing the SDGs. However,
the progress of these goals has been falling short of achieving the targets
by 2030. In addition to the insufficient progress, the outbreak of coronavirus
has been a major setback to the progress of achieving the SDG targets. The
year 2020 witnessed the outbreak of coronavirus disease 2019 (COVID-19)
with the World Health Organization declaring it a global pandemic by
March 2020. The novel coronavirus was first reported to have been
emerged in Wuhan, China, in December 2019 which spread rapidly to
other parts of the world impacting the global economy, energy systems,
and overburdening the healthcare system worldwide. The novel corona-
virus is a zoonotic disease with high reproductive rate thus spreading faster
than other coronavirus variations such as Severe Acute Respiratory Syn-
dromes (SARS) and Middle East Respiratory Syndrome (MERS). The
COVID-19 is a subtype of coronavirus with single stranded RNA
enclosed by spike glycoproteins that facilitate the entry of virus into the host
cells leading to symptoms such as common cold to respiratory diseases in
humans. The contagious nature of the virus and the rapid rate of transmis-
sion are reported to be the primary cause of the outbreak of the disease.
Such transmission from one human to another arises due to human contact
directly or indirectly via infected respiratory droplets either through inhala-
tion or contact with contaminated surface or body fluid. Such unprece-
dented catastrophe has taken the lives of more than 3 million with huge
impact on the global economy and imperiling the progress of SDG targets.

Achieving the 17 SDGs with its 169 targets is even more critical and nec-
essary now than before which would require worldwide solidarity and pri-
oritizing the susceptible socioeconomic sections of the world as well as the
environment. Among the 17 goals, SDG7’s main goal is to encourage sus-
tainable approach toward reliable and affordable energy. SDG7 encompasses
the goal of ensuring inexpensive, dependable, sustainable, and modern
renewable energy for all from resources such as wind, solar, and thermal.
It has 5 targets with 8 publications and 8 events that have been organized and 696 actions taken so far. Continuous rise in population and economic development have caused fossil fuel reserves to dwindle owing to over-consumption. This, in turn, has led to an increase in greenhouse gas emissions harming the environment. To counter the issue of global warming and removing our dependency on fossil fuels, the implementation of alternative renewable energy resource has become necessary. Socioeconomic development is constrained owing to the lack of access to clean and sustainable energy. People around the world require a reliable source of energy for their day-to-day activities, such as power for hospitals and schools, for cooking, heating, or cooling their homes. Earlier, the use of fossil fuels may have been cheaper than clean energy; however, with technological advancement and innovative research, renewable energy has become more affordable.

To mitigate the above-mentioned issues, progress of SDG7 and achieving the set targets is important. Efforts are being made to promote the use of renewable energy but the development has been slow. To fulfill the energy demand, a significant boost in renewable energy production across the globe is much needed. Infrastructure expansion and technology progression for providing clean energy in developing countries is essential for economic development and reducing the gap between rich and poor countries. The present chapter discusses the progress and challenges in achieving SDG7 and the impact of a pandemic on the goal’s momentum.

2. **SDG7 targets: Access to energy, renewable energy, and energy efficiency**

SDG Goal 7 was framed to ensure inexpensive, reliable, and sustainable energy that is accessible to all. Easy accessibility to energy and power would help in providing smooth functioning in different sectors ranging from medicine to businesses, education, agriculture, communications, infrastructure, and other technology-related areas. There has been promising development in the accessibility of sustainable energy around the world over the last decade. Inaccessibility to electricity improved from 1.2 billion in 2010 to 789 million in 2018.²⁰ It has been reported that more than 2.3 billion people are dependent on wood, charcoal, waste from animal and crop, and other solid fuels for cooking and heating their homes. The use of combustible fuels resulted in 4.3 million deaths in 2012.²¹ The practice of using combustible fuels causes indoor air pollution that affects humans and the
environment. Such practices have resulted in 4.3 million deaths in 2012.\textsuperscript{21}

Energy efficiency enhancement with the usage of renewable energy can help in a 40\% reduction in emissions globally.\textsuperscript{22}

Therefore to ensure that the SDG7 objectives are met, five energy targets were created to attain universal access to sustainable energy. The five targets are as follows:

• Target 7.1 was formulated to guarantee universal access by 2030 to modern energy in the form of electricity and clean energy for cooking.
• Target 7.2 was aimed at increasing the renewable energy shares substantially by 2030.
• Target 7.3 was created for doubling the energy efficiency progress by 2030.
• Target 7.A was aimed at promoting access to research and technology of clean energy by enhancing international cooperation. Promoting investment in improving infrastructure and clean energy technology that included renewable energy, energy efficiency, and advanced and cleaner fossil-fuel technology.
• Target 7.B by 2030 was created for expanding the infrastructure and technology upgradation for supplying modern and sustainable energy services in developing countries following the respective countries’ programs of support. Priority would be given to least developed countries, Small Island developing states, and landlocked developing countries.

With the advent of different targets of SDG7, renewable energy has played an instrumental role in helping toward achieving this goal. By 2018 around 136 million people received electricity from off-grid renewables. Thus more efforts are needed so that around 620 million people who are still devoid of electricity can access affordable energy services by 2030.\textsuperscript{23}

3. Why affordable and clean energy matters?

Energy is an important aspect of our everyday lives, especially for the poor, since it is needed for doing the most basic things like cooking food, lighting homes, and heating purposes. A major percentage of the vulnerable section’s income is taken up by energy for basic needs. The rise of energy prices owing to the change in government policies not only affects their income but also their health and creates inequality which is a matter of social concern. Moreover, inaccessibility to affordable energy also impacts the environment. Difficulty in studying and improper storage of temperature-sensitive vaccines or medicines in hospitals are some of the issues faced by
people owing to the lack of electricity. Lack of access to clean cooking is of grave concern as the use of solid fuels exposes people to high level of indoor air pollution that can have serious implications on their health causing respiratory or cardiovascular diseases, thereby increasing their susceptibility to diseases like coronavirus. Thus modern electricity services are crucial for powering healthcare facilities to prevent an outbreak of disease and fighting off pandemics. It is also necessary for providing clean water to maintain hygiene and to enable communication for connecting people through technology. To prevent harmful consequences owing to the lack of access to energy, the adoption of the SDG7 is necessary to mitigate these issues. The targets formulated under the SDG7 further help in accelerating the progress to meet the goal by 2030.

Under SDG7, Target 7.1 which is subdivided into 7.1.1 and 7.1.2 focuses on accessibility to electricity and clean cooking, respectively. Over the years there has been considerable development in deploying inexpensive electricity to the people including on- and off-grid solution. People lacking electricity dropped from approximately 860 million in 2018 to 770 million in 2019. However, the progress is unequal as sub-Saharan Africa shares about 75% of the population that still lacks access to electricity. Developing Asian countries have shown improvement with 96% of the section gaining access to electricity in 2019 which was much lesser in 2000 with 67%. In India, the government launched Saubhagya Scheme in October 2017 which was able to provide 99% of the population with electricity in 2019. Africa also witnessed a surge in electricity accessibility, doubling from 9 million from 2000 to 2013 to 20 million from 2014 to 2019 due to the deployment of on- and off-grid connection.

Unlike the progress made in the accessibility of electricity, solution to clean energy for cooking purposes is still falling short. The access rate to clean cooking and technologies worldwide attained 63% in 2018. Around 2.6 billion people still require access to clean cooking worldwide and suffer from household air pollution that has been the cause for approximately 2.5 million untimely deaths annually with women and children being affected the worst. This occurs due to the dependence on solid fuels like biomass and coal or the use of kerosene for cooking. Programs for using liquefied petroleum gas (LPG) and policies for promoting clean air have helped countries like India and China in providing access to clean cooking since 2010. The rate of access to clean cooking attained 49% for India and 71% for China in 2018. In contrast, sub-Saharan Africa rate of access was slow with only 17% of their population having access to clean cooking in 2018 from 15% in
Owing to the population growth outpacing the efforts, urgent actions need to be taken to tackle the rate of access.

Target 7.2 which aims at increasing the share of renewable energy in the total final energy consumption (TFEC) has progressed from 16.3% in 2010 to 17.3% in 2017 owing to the use of modern renewable energy. The power sector witnessed a major increase with a 24.7% share of consumption of electricity globally in 2017 which surpassed the heating sector shares for the first time due to solar photovoltaic (solar PV) and wind energy. The renewable share in the transport sector was 3.3% in 2017 which was majorly contributed by liquid biofuels like biodiesel and bioethanol. The transport sector’s share of renewable electricity consumption was at 0.3% globally. Sub-Saharan Africa had the largest renewable energy share in 2017 although the region accounted for about 85% of its renewable energy usage owing to the use of conventional biomass. To improve the consumption of renewable energy and to fulfill the objectives of the climate goals of SDG 7 by 2030, decarbonization in heat and transport sectors electrification is the sought after solution in terms of energy scenarios in the long run. Brazil leads in modern renewable with a 45% share followed by Canada (23%). Policies formulated for renewable energy usage are important as they aid in procuring renewable electricity at a minimum price through auctions thus creating increase consumption and opportunities for local industry development through job openings.

The aim of target 7.3 under the SDG7 is to double the efficiency of energy globally by 2030. Measurement of energy efficiency is conducted in terms of energy intensity which is a percent decrease in the ratio of the total primary energy supply globally per unit of wealth produced or gross domestic product (GDP). Social and economic parameters are influencing factors in measuring the energy intensity which is inversely proportional to improvement in energy efficiency. Primary energy intensity worldwide in 2017 was 5.01 megajoules per US dollar with a 1.7% rate of improvement. A yearly improvement rate of 2.6% was estimated by United Nations to achieve the target by 2030; however, due to the slower progress rate than projected, the yearly average improvement rate was to be no less than 3% for achieving the SDG target. Asia showed the highest improvement in energy intensity rate while the lowest was the Middle East region. The variations in efficiency among the different regions are most probably due to the economy of the region and the easy supply of energy. Efficient measures through policies and investment can help in gaining pace to double the rate by 2030. Implementation of policies such as minimum energy
performance standards (MEPS) has proven to be successful in encouraging energy efficiency and being cost effective. The government could help in easing the bulk procurement of equipment that is energy efficient, thus reducing its cost and providing financial incentives. Steps for strict policy action encourage global investment in energy efficiency measures and favor clean and efficient operations. According to the Sustainable Development Scenario conducted by IEA, an average improvement rate of 3.6% in energy intensity is possible with the right policy measures and digital technology.

4. Modern renewable energy technologies

Renewable energy has been used for a long time in the form of solid fuels such as biomass for burning and hydropower for the generation of electricity. Renewable energy plays an important role in developing countries responsible for the final energy utilization of more than 50%. Renewable energy is defined as energy derived from natural processes sustainably through different forms of energy, such as geothermal, bioenergy, solar, biofuel hydropower, and wind energy. Renewable energy has shown progress in recent years driven by SDGs and policy support by the government. Modern renewable energy (without the inclusion of conventional biomass usage) accounted for 11% of TFEC in 2018 which was slightly higher than 2013 with 9.6%. Owing to the replenishing nature of renewable energy resources, it can be deployed over vast geographical regions resulting in significant economic progress and energy security. Renewable energy can help mitigate climate change, reduce air pollution caused by the burning of fossil fuels, reduce premature deaths caused due to household air pollution, and improve the health of people. Different renewable technologies that have been contributing to the progress of SDG7 are solar, wind power, hydropower, bioenergy, and geothermal power and heat.

(a) Solar technology utilizes sunlight for the direct conversion of light into electricity. Solar photovoltaic (PV) is a promising solar technology that is made up of cells. These solar PV cells are made of semiconductor materials that utilize sunlight for the separation of electrons from atoms for creating an electric current. For boosting the power of PV cells output, they are interconnected to form larger units called modules or panels. Several modules connect to form arrays. These arrays are connected to the electrical grid as a component of a complete PV system. The manufacture of solar PV module is possible in large plants thus allowing economies of scale. Another added advantage of using solar PV is
the modular technology that allows it to be deployed in small quantities at a time. These advantages give the system the freedom to be used for personal electronics or the generation of utility-scale power. Other established solar technology such as solar thermal electricity or concentrating solar power (CSP) uses mirrors to concentrate the sunlight into a solar beam that heats up the working fluid in the solar receiver causing the heat engine to generate electricity.

The global market for solar PV in 2019 was reported to grow around 44%. A total of 627 gigawatts (GW) including on- and off-grid capacity was reported globally which was much higher when compared to 23 GW a decade earlier. As solar PV plays an important role in the generation of electricity, by 2019 around 22 countries had enough power owing to solar PV to meet around 3% of their electricity demand while 12 countries were able to meet 5% of the electricity demand. Electricity generation using solar PV claimed high shares in different countries like Honduras (10.7%), Italy (8.6%), Greece (8.3%), Germany (8.2%), and Chile (8.1%).

To become the major source of electricity worldwide, solar PV are still faced with challenges such as instability of policy and regulatory frameworks and stress to the economy since electricity generated from nuclear and fossil fuel attracts more investors. Despite the challenges, corporate purchase of solar PV extending significantly and personal usage were important factors for the system distribution in many countries. China was reported to account for about 26% of new installation which was the highest share worldwide for the year 2019. In 2018 five countries, i.e. China, the United States, India, Japan, and Vietnam, collectively contributed to 56% of the newly installed capacity.

(b) Wind power uses wind turbines for the generation of electricity. When the wind hits the turbine’s blades, the blades rotate and turn the turbine connected to it, thus changing the kinetic energy into rotational energy by moving the shaft. This shaft which is connected to the generator helps in the generation of electricity through electromagnetism. Consumption of wind energy is on the rise owing to its cost-effective technology. Onshore wind is an established technology with a supply chain worldwide while offshore wind is projected to progress rapidly. As per the IRENA’s recent report, onshore and offshore wind generation capacity has increased by a factor of about 75 in the last 20 years with its growth from 7.5 GW in 1997 to around 564 GW by 2018.

(c) Hydropower generates electricity from the potential energy of flowing water from a height. Conventional hydropower projects comprise
run-of-the-river system, reservoir system, and low-head in-stream facility. Hydropower expands from large-scale projects (more than 10 MW capacities) to micro/mini capacity. This technology remains the largest renewable electricity source in the world and plays an integral role in the decarbonization of power system and improving their flexibility. Hydropower generation globally was approximated to be 4306 TWh in 2019 which was an increase of 2.8% from 2018. In 2019 Brazil took a lead in the commission of new hydropower capacity followed by China, Lao PDR, Bhutan, and Tajikistan. Hydropower production varies yearly in the world not only because of modification in installed capacity but also due to changes in the weather pattern and local operations. Climate change poses a risk to the hydropower industry owing to which climate variability and its effect are being included in planning of projects, design, and operational arrangements. System integration with other renewable technologies like solar PV and wind energy can help in reducing the risk and aid in building a resilient system.

(d) Bioenergy encompasses the utilization of biological materials for a wide range of energy purpose. The energy derived from biomass can be converted to energy for use in heat and power generation and transport sector. Many bioenergy pathways have been well established and technically proven for commercial purpose. Biomass contributes to the largest share among all the renewable resources in the world energy supply. Bioenergy accounted for about 12% of the TFEC in 2018. Modern bioenergy excluding the conventional biomass usage accounted for around 5.1% of the total final energy demand globally in 2018. The contribution of modern bioenergy is significant in all sectors with a five-fold higher contribution than solar PV and wind power combined. Owing to strong policy support, bioenergy has shown accelerated progress. The electricity sector reported an increase of about 6.7% annually, while the transport sector showed an increase of 4.4% and about 1.1% for bio-heat. The liquid biofuels industry is more focused on bioethanol, biodiesel, and hydrotreated vegetable oil (HVO) and hydrotreated esters and fatty acids (HEFA). Ethanol production in 2019 was reported to be around 114 billion liters which was 2% higher than ethanol production in 2018 with 111 billion liters. Biodiesel production increased to 47.4 billion liters in 2019 with Indonesia leading as the largest producer of biodiesel in the world.

(e) Geothermal power and heat can be used for electricity generation or it can be directly used for heating purposes such as space heating and heat
input for industries. Heat energy is generated from the earth’s crust as hot water and steam which can be converted into electricity in a thermal power plant. Geothermal electricity generation was around 95 TWh (terawatt hour) and direct usage of thermal output was around 117 TWh in 2019. Geothermal plants located near the source can cogenerate both electricity and heat for different applications. Thermal application from geothermal energy has grown over the years to nearly 8% on average with the space heating segment growing 13% annually. Geothermal energy found its direct use in swimming and bathing followed by heat spacing, greenhouse heating, industrial purposes, aquaculture, agriculture, melting snow, etc. The active markets for geothermal energy are spread across regions of Europe and China. Countries with the major supply of geothermal power in 2019 were the United States, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland, and Japan. The United States leads in the area for the largest geothermal power capacity installation with a net operating capacity of 2.5 GW in 2019.

The year 2019 saw progress for the geothermal industry with construction activity and government support. However, the industry still is faced with challenges of high project cost, inadequate funding, and risk mitigation. In-depth research and innovative technologies can aid geothermal energy in pushing forward toward an optimistic future.

5. Impact of COVID-19 on SDG7

The world has been facing climate and socioeconomic crises which can be addressed through the low-carbon energy transition. As per the Intergovernmental Panel on Climate Change (IPCC), 70%–85% of the global electricity by 2050 should be supplied by renewable energy to mitigate the pressing issue of global warming and steps toward decarbonization. The UN Secretary-General in September 2019 initiated a decade of action to speed up the progress of SDGs. Unfortunately, within 6 months of its initiation, the world faced a global pandemic that impacted all sectors and the 17 SDGs. The COVID-19 pandemic highlighted the vulnerability of our society depicting how a health crisis quickly turned into a socioeconomic crisis. The government now faces the challenge of framing economic policies and recovery plans to bring back the pace of the economy and energy market. Progress in the renewable energy sector plays a crucial part in the low- and middle-income countries for socioeconomic development.
The governments worldwide were compelled to undergo lockdown to mitigate the spread of the virus. The world witnessed a halt in the economy and a drop in energy demand. During the complete lockdown, the monthly demand for electricity reduced by 20% on average. The worldwide electricity demand reduced to 2.5% in the first few months of 2020 while oil and coal demand fell by 5% and 8%, respectively. Amid the crisis, renewable electricity was the only resource that showed growth in demand owing to the low operating expenditure and access to the electricity system. This pandemic has highlighted the essential role that electricity accessibility plays in saving lives, sustaining the essential services, supply chains, and the livelihood of the people. Such circumstances have made the case even stronger as to why efforts on energy accessibility need to be accelerated.

Although restrictions on mobility and safety rules were able to slow the spread of the virus such measures delayed the construction of renewable energy installations of solar PV and onshore wind temporarily as well as interrupted the supply chains. Renewable projects, supply of equipment, policy execution, and investments were affected owing to the pandemic. During the first wave of COVID-19, cases rose rapidly spreading across the world. Europe witnessed a rapid surge in COVID-19 cases by the end of summer. Even with such a surge in cases, most countries did not introduce or reintroduce lockdown measures keeping the economy of the country in mind. With movement restriction and tightened quarantine rules, the manufacture of renewable equipment and construction activities were minimal. Investments in renewable projects and incentives also took a setback during the crisis with the government focusing the incentives on fighting against the virus. According to the International Energy Agency, the governments were advised to extend the warranty and contract of the projects for reducing the financial risk of the investors.

In the first half of 2020, the electricity generation from renewable sources was reported to be 11% lower when compared to the first half of 2019. The solar PV and wind expansion were found to be 17% and 8% less than 2019, respectively. Unlike solar and wind, hydropower saw an increase in the first 6 months owing to the large-scale project commissioned in China. Thermal power production fell to 9% in the beginning months of 2020 in China. It also witnessed a decline in installation for wind by 50% and solar PV by 25% owing to shortage in manpower and limited construction activity. Similarly, Europe also reported lower renewable energy capacity addition in the first quarter of 2020 than 2019; however, it gained pace for installation during the second quarter with lockdown relaxations.
Conversely, United States reported a twofold increase in the renewable capacity addition in the first 6 months of 2020 compared to 2019. As the wind and solar PV development is dictated by policy deadlines, the developers sped up the commissioning of the projects for meeting the deadline of federal tax incentives. India, on the other hand, had a slow growth of renewable energy capacity even before the lockdown was imposed. This was due to financial instability and project setbacks. Likewise, the ASEAN countries also reported 60% lower installation capacity in 2020 compared to 2019.

Distributed renewable for energy access (DREA) is a separate off-grid system capable of producing and distributing energy independent of a centralized electricity network. This system played an integral role during the beginning of the crisis by providing energy to rural and remote places, thus powering essential services and health facilities. But strict lockdown caused its operation to a halt as it did not come under essential services. Suppliers and project developers faced a shortage in cash as there was an economic recession and unavailability of the credit system. The fall in oil and gas prices put a lot of pressure on renewable technologies.

The energy demand in the world was reported to fall by 6% in 2020. Restricted activity owing to lockdown during the pandemic projected a drop in the CO₂ emissions by 8% in 2020 however, such restriction resulted in economic adversity and rise in unemployment. Such fall in CO₂ emissions and reduced usage of coal are temporary circumstances which would eventually rise as economy rises. Thus, to reach climate goals of Paris Agreement, the government needs to formulate policies and regulations that are sustainable and is able to cover all sectors. Amid the crisis, renewable electricity has been resilient; however, other renewables were not able to sustain their growth. Biofuel production was projected to fall by 13% in 2020 which is the lowest in 20 years. Of all the renewable energy, biofuels were greatly impacted mostly due to restriction in movement and plummeting oil prices. The production of biofuels was projected to reduce to 11.5% in 2020 compared to 2019.

Consumption of renewable heat owing to restricted activity also declined in 2020. Before the pandemic itself, the energy efficiency progress was slow and below 3% annual rate improvement. Now with the pandemic situation, the efficiency has dropped sharply due to reduction in investments, construction activity, and decrease in equipment manufacture and purchase. Prioritizing sustainable renewable energy and efforts to bring in energy project investments are important for energy transition and recovering from economic and financial damage caused by the pandemic. Therefore, to
overcome from this crisis, the government should come up with post-
COVID-19 recovery plans that would help the SDG7 come back on track
and accelerate its progress so as to achieve its targets by 2030.

6. Role of energy in COVID-19 response and post-COVID-19 scenario

Due to the pandemic nature of COVID-19, humanity faces a hercu-
lean challenge. This crisis has confined the world indoors, thereby impelling
an existential economic downfall. One of the major stepping stone of world
economy is the energy sector. To restrain the disease transmission, almost
half of the world inexplicably followed a lockdown from the middle of
March 2020, impacting the economic trajectory at a cosmic scale. This quar-
antine period associated with different socioeconomic restrictions, including
the work-from-home policy, has declined the normal industrial strategies,
curbing the energy demand sharply. Most of the agencies, including insti-
tutional, industrial, as well as the business sectors, which occupy the lion’s
share, reduced the manual mode of operation, wherever possible and shifted
to the digital platforms. This transition diverted the commercial energy load
toward the residential side, which ultimately altered the energy requirement
profile of the society. Hence, the governments and the power sectors should
join hands to nullify the effects of this drastic shift in power demand along
with the development of new strategies to dodge any other future pandemic
scenario. On the flip side, this lockdown period had positive impact over
several environmental concerns at an unprecedented level as the sharp
decline in energy demand, transport, and industrial operations have led to
a remunerative output over air quality control and greenhouse gas emissions.

Elavarasan et al. explicitly illustrated the pandemic footprints over the
energy sectors and allocated them into two major categories, i.e., direct and
indirect impact. Direct impact instigates the consequences of the energy
requirement shift over the existing power grid industry. Each and every sec-
tor ranging from industrial, commercial, residential, or agriculture has its
exclusive energy load quota, but the drastic energy demand variation during
pandemic constrained the power operators to modify the power load pattern
and generation accordingly. The industrial and transport sectors, which
demand major share from the energy sector, had to halt their operations dur-
ing COVID-19 outbreak. This led to a substantial downturn in the energy
demand, resulting in the curtailment of energy market valuation. In several
European countries like Belgium, France, Spain, Netherlands, and Italy, the
market figure of power exchange has diminished by 23%, 20.1%, 17.4%, 18.2%, and 17.7%, respectively.\textsuperscript{43,44} Oil price collapse at global scale during March 2020 was the lowest reported since 2003 due to the consequence of COVID-19, causing a fall in the demand of oil and due to business-related issues among Saudi Arabia, Russia, and USA.\textsuperscript{45} As a result of remarkable transposition in the energy currency, the existing power system management becomes a cumbersome task to administer. The governments of the countries affected by the pandemic should plan an emergency roadmap for utility operators by collaborating with their policy-making stakeholders to overcome the post-COVID-19 implications.

The indirect impact implies the roundabout effects of this pandemic scenario over several platforms like research investments and consumer relations which influence the energy and power division. Power generation based on fossil fuels witnessed low energy demand during COVID-19 but increase in grid from renewable energy.\textsuperscript{46} Council of European Energy Regulators (CEER) in association with International Renewable Energy Agency (IRENA) has tried to mitigate these issues by stressing the relevance of power source diversification integrated with the environmental concerns to establish a “clean energy system”.\textsuperscript{47}

6.1 Indian perspective

The power distribution system of the world’s third most power demanding country (about 1.54 trillion kWh per year) is divided into five regional segments: North Eastern Region (NER), Eastern Region (ER), Northern Region (NR), Western Region (WR), and Southern Region (SR).\textsuperscript{42} These segments were monitored and controlled by India’s Power System Operation Corporation (POSOCO) in its entirety.\textsuperscript{48} Indian government imposed ‘Janata Curfew’ on 22nd March 2020 and nationwide lockdown from 25th March 2020 which was maintained in a full-fledged manner till 17th May (as per announcement by Government of India). The national energy demand decreased from around 3500 GWh (prior to the Janata Curfew) to 3000 GWh and reached the lowest at 2500 GWh on 1st April 2020. The regional power demand declined in NER and ER to about 22.5% and 20%, respectively, while the WR and SR witnessed a moderate reduction of 14.5% and 16%, respectively, and the least in the NR region with 10% drop, causing adverse effect on the power sector both economically and technically. Drastic decrease in the demand of power led to the Under Frequency-based load shedding (UFLS) due to mass disturbances in the frequency stability and
generation schedule variation in the national power grid system, as encountered by the Frequency Variation Index (FVI),\textsuperscript{42} which was mitigated and stabilized meticulously by Deviation Settlement Mechanism (DSM), regulated under Central Electricity Regulatory Commission in association with National Load Dispatch Centre, State Load Dispatch Centre, and Southern Regional Load Dispatch Centre through efficient generation according to the demand forecasting.

\textbf{6.1.1 The famous “light-off event” in India}

Indian prime minister addressed the nation to switch off their lights on 9th April at 9 pm for 9 min for cataloging the country’s fight against COVID-19 and the largest democracy welcomed this note with immense pleasure. A preparatory practice was performed on 4th April 2020 to make a precision about the total power consignment abatement at the time of actual event. On the time of the actual event, total demand declination has been figured to be 31,089MW with a minimum of 85,799MW, documented at 21:10 h. POSOCO deduced earlier about the drastic fluctuations due to this abrupt change and the aftermath payload and had taken several controlled measures to diminish the consequences of this drastic shift. Hydrogeneration started to ramp down to 17,543MW (from 25,559MW to 8016MW) at 20:45 h. This hydrogeneration was again ramped up from 8016 MW to 19,012MW from 21:10 h to 21:27 h to meet the increase in demand after the event. Reduction of total 10,950MW generation was achieved through thermal (6992MW), gas (1951MW), and wind generation (2007 MW) from 20:45 h to 21:10 h.\textsuperscript{42}

\textbf{6.1.2 Post-COVID-19 socioeconomic challenges for India}

Increased unemployment, truncated transportation along with the work-from-home policy transpose and taper the energy exigency in India under the COVID-19 scenario, which has not only imposed a lot of hurdles to the stakeholders to uplift the economy during the post-COVID-19 platform but also created budgetary burden, perturbing the Indian socioeconomic standpoint as follows:

\textbf{6.1.2.1 Downfall in the earning trajectory}

As a result of massive work loss and gross downfall in the industrial as well as commercial belt, the earning trajectory of a large population dropped down severely, thereby making them impotent to pay the electricity bill. Under such circumstance, the revenue of the energy sector is adversely affected,
thus triggering the increment in the electricity tariffs, which may cause future burden.

6.1.2.2 Dilution in the investments and subsidy relaxation over renewable energy projects
The pandemic has exposed the vulnerability of health sector with an overwhelming fiscal expenditure being expected during COVID-19 period as well as in the post-COVID-19 scenario. So the chance of curtailment in the funding and subsidy outlay in the research about renewable energy generation can be speculated for near future. In addition, the COVID-19-related financial liquidity crunch, agitation in the supply chain, and the labor-poverty also have slowed down the thriving advancement of the renewable energy sector intensively. For example, Indian solar energy sector relies over the Chinese supply chain for the production of photovoltaic solar panels and modules. Needless to say, this pandemic, with its origin in China, will delay the acquirement of the sourcing materials. Indian distribution companies have faced 7.2 billion US dollars financial liquidity crunch, in addition to 4 billion US dollars revenue loss, during this crisis period.

6.2 Post-COVID-19 challenges in the global context
A strong realization is essentially needed to combat with various post-COVID-19 challenges in the energy sector, although nobody can guarantee about exactly when we can add the ‘post’ prefix before the phrase ‘COVID-19 scenario.’ So it is high time to amalgamate the business game plan with the scientific strategies to settle down the concerning global turmoil. Some implementation measures are recommended as follows (Fig. 1).

6.2.1 Quality control and continuous monitoring over the fuel foundation
The pandemic situation restrained the movement of people with strict lockdown rules diminishing the mutual integration between certain parts of the world, from national to international level. Therefore it is extremely necessary for the stakeholders to realize the fuel potential of their own at its entirety for minimizing their dependence over other nations for fuel exchange. It will be challenging for the developing countries to stake the sourcing materials like LPG, LNG, coal, and crude oil from the international business market in post-COVID-19 period. In addition, fuel transportation can become another obstacle for power generation, as transport sector is affected by the pandemic. Thus focus should be given in finding indigenous
6.2.2 Concentrating hydrogen-based generations

We can efficiently decarbonize the transportation sector through hydrogen-based fuel generation as the source material can be generated in a clean and green way, i.e. through electrolysis of water (as this process does not rely upon the production of CO$_2$), and can effectively substitute the fossil fuel-based generations. As a result of COVID-19, EU and Germany focused their attention toward hydrogen production which was able to uplift their fiscal share in the energy sector.$^{46}$

6.2.3 Imprisonment of the solar energy

Solar photovoltaic systems can be installed in the rural settings, where the demand is relatively less, which can be immensely helpful to reduce the postpandemic extended power burden. This can make village life independent of the worldwide fuel price fluctuation, thereby ensuring rural fuel security. For example, Bangladesh government has implemented a total of about 4.13 million solar home systems (SHS) in the rural belts, which have lasted long at about 7–8 years without any tussle.$^{42}$
6.2.4 Step-by-step acceleration of the power load
It is expected that there will be an extreme overburden in the energy sector when everything will be opened up. To control this, the load should be enhanced gradually to maintain the grid viability, otherwise this tripping may cause derogatory system-wide blackout.

7. Green recovery—How future investment can drive sustainable energy progress, energy gap, and how to close them?

Under the present scenario, the billion-dollar question is when this crisis will come to an end and what will be the exact strategies of the policymakers and the stakeholders for the power sector to cope up with the curse of this satanic ‘Lilliput.’ To combat with this ongoing economic lethality, it is very much important to ignite the flame of sustainable and net-zero emissions economy to perpetuate the future climatic caliber. So, policymakers may view this as the two sides of the same coin; the long-term panacea to drive no-emission economy and the emergency of exigency to resist the economic swing in the new normal, but the uncertainty remains inherent in the questions about whether the urgent surge for a clean and green recovery will fuel up this process or the pandemic stretch will detain the metamorphosis of power industry.\textsuperscript{51} Henceforth, the gradually amplified frustrations from the orthodox energy system drive the diversion in the world energy landscape. Undersupply of fossil-based source materials and reasonable cost of renewable resources have compelled several countries (for example, about 60\% in Denmark) to complement the gap at a reasonable manner.\textsuperscript{52} However, it is essential to say that, this renewable endeavor will definitely not make the industries qualitatively poor, in order to be renew-ably rich. Consistently, the investment tendencies have also been diversified to reach a sustainable goal.

For example, the Confederation of British Industry, Energy UK, the energy utility SSE, and the National Farmers’ Union astonishingly received the ‘building back better’ motto, to stay tuned with the ‘green’ struggle. So, needless to say, recent jobs reboot, essence of clean air, government priorities along with the consumer concern are the battery for these low-carbon transitions in the low-contact future.\textsuperscript{53} The possible ways for post–COVID-19 recovery are summarized in Fig. 2.
7.1 Post-COVID-19 renaissance in the electricity sector

The sectorial twist in the energy stipulation pattern in association with a sharp demand declination has paved the potential for clean energy transition. Emerging needs in the new normal, like virtual smart-working, work from home, and online education, can be regarded as the key players of this twist and the assumed hike in the post-COVID-19 energy demand. However, it is very easy to dilute these demands for the economic giants, as they cherish abundant, reliable electricity services, but for the developing countries this is not going to be a cakewalk. To drive out a sustainable recovery, European countries brought down fossil-based generations to about 25% during the first quarter of 2020 and renewable candidates, attaining 43% share of the total production during this period, efficiently complement this. In Italy, during March 2020, 45% of the national production has been contributed from renewable generations. According to IRENA, utility-scale wind and solar photovoltaic generation has the potential to outcompete and substitute the fuel-based power plants in a cost-effective way. Another study, conducted by Enel foundation over Brazil, Chile, Argentina, Colombia, Peru, and Ecuador, has advocated mainly the Latin American trends and the results suggested that “almost 50 gigawatt (GW) of photovoltaic and 71 GW of wind can be installed by 2030, covering about 25% (up from today’s 1%) of the total electricity demand, with economic benefits estimated at about US$3.6 billion by 2030, considering the fuel savings and the annuity of the investments needed for the additional renewable
capacity.” Among the developing nations, majorly in some sub-Saharan Africa as well as some Latin American countries, still there are several lacunae in electric accessibility. So on the whole, investment in renewable priorities can support the balance between technologies and operational approaches even in the poorest parts of the globe. Interestingly enough, the dynamism in the world’s energy landscape, as outlooked by IRENA, particularly among the Latin American countries, these transition-associated technologies significantly expand the employment scenario, assuming to provide 3.2 million jobs by 2050, almost 8% of total employment opportunities over the continent.52 Likewise, The Global Commission on the Economy and Climate54 reports have estimated about 65 million job opportunities and $26 trillion financial yield by 2050, in this low-carbon economy.53

“Looking at the full year, the IEA (International Energy Agency) foresees a scenario where global energy demand contracts by 6%, the largest fall in percentage terms since World War II. Fossil fuels have been the most impacted: oil demand for the full year could drop by 9%, coal by 8%, and natural gas by 5%. Even nuclear could see a drop of 2.5%. The only energies not negatively affected are renewables, which could see their production increase by 0.8% as a result of new investments”.22

7.2 Conclusion in the combustion engine era—A new engine for future

In order to restrain the dirty vehicles, several cities have introduced electrification policy in the transportation sector. To pass the eligibility test, set by EU car CO2 rules, cars sold throughout 2020 have to restrict their CO2 emission level below 95 g CO2/km. Consistent with that, European car market has been shined by 8% share of the electricity-driven vehicles, among the total retail between January and May 2020. The best example is the Zwickau plant, the electric vehicle manufacturer from the Volkswagen factories.55 Throughout Europe, transport industries are ready to produce 3.5 million electric vehicles in 2020–21 and about 12 battery gigafactories are going to be functional by 2023. In order to achieve the EU car CO2 rule, it is necessary to grab 30%–40% of the new vehicles to be electrically mobile by 2030, which would be expected to reduce 11% of the total oil demand. German government decided to reduce taxes over the e-mobility sector and related areas. Likewise, US government has launched a benefit-in-kind regime for the e-mobility sector. Most devastatingly, restrain in the international travel policies severely hampered the aviation
industry. However, this is not only the European scenario but Asian and American stories are also somewhat same.

### 7.3 Shift in the business blueprint of the oil companies—Signals for recovery

The international oil market has already started to accustom with the post-COVID-19 decarbonization policies to achieve competitive fitness against the low-emission perceptions. Indian Oil Corporation (IOC) has also taken new business opportunities, focusing on lower emission of toxic gases through restoring carbon, reducing methane emissions, decarbonizing natural gas, etc. The feasibility and competitiveness for decarbonization at a scalable way did not receive much attention by the political leaders, hence public-private partnerships are the only option to promote innovation.

### 7.4 Vaporization of the global gas markets

According to the IEA, the volatilization of gas market remains less (4% fall by 2020, in comparison with 8% in coal and 9% in gas industry) severe than the other power source sectors, because of its potential for low CO$_2$ production operations than other fuel-based emissions. In Australia, pandemic became responsible for a drop of about AUD$80 billion of investments in gas and LNG projects. Russian government also decided to invest in this sector for high-speed economic retrieval. United Nations planned on adopting a zero-emission target from 2020 by declining the usage of natural gas and decarbonization through carbon capture utilization and storage (CCUS).

### 7.5 Recommendations—A ray of hope

For the sake of a quick economic upswing, the Energy Transitions Commission (ETC) keeps faith over several master policies to foster the economic stimulus packages. According to the perception of ETC, there will be four to fivefold increase in the energy demand, so it is extremely necessary to fuel up the renewable generations by at least 10-fold. The regeneration capacity should be uplifted at a level of 1500GW per year on average within next 30 years to fine-tune this upcoming global energy hunger in addition to improving the grid armature. Needless to say, besides sustaining a low-emission future, investments in the renewable energy sectors can also elaborate the societal economic footprints through incepting job opportunities. Taking lessons from history, after the financial catastrophe in 2008, US government revived 9,00,000 jobs within a five-year time span through massive
investments in clean energy projects. Likewise, another forecasting from IRENA recommends about the possibility of 17 million jobs throughout the world in this platform by 2030. The transportation sector also becomes severely standstill by the hit of disease transmission. For the ease of urban transport, two conflicting issues, one is the biasness toward private vehicles over public commute and the environmental safety concerns, can make the electric vehicles winner in the rivalry with its combustion-based cousins. Therefore it is high time to diversify our perceptions toward the never-ending, eco-friendly resources to ensure a green future, with serenity in its entirety.

8. Conclusion and future perspectives

The worldwide emergency of COVID-19 and the incurred economic backwash have increased the worry of policymakers of various developed as well as developing nations, triggering a scout for recovery efforts about the economic frame shift consolidated with environmental sustainability. Capital investment may be the major driving force for technological propagation and to fine-tune the grievance. For the perspective of post-COVID-19 energy landscape, there is an array of options toward the low-emission future, but not all the options will go well at every part of the world. Due to differences in geographical location and topography, advantages vary from place to place. While some regions are suitable for building intermittent renewable resources which can be connected to larger hydropower resources for load stabilizing, some regions have abundance of solar resources along with natural gas. Geological advantages alongside industrial complexes having the capacity to make hydrogen with carbon capture and sequestration are also viable. With rapid exhaustion of fossil fuels a demand for low-cost and renewable energy resources will increase among various sectors too.

The European Union (EU) aimed at increasing their renewable energy share to 32% gross final consumption of energy by 2030 for the purpose of reaching the SDG7 target and decarbonizing its energy system. The EU underlines the significance of renewable energy usage in comparison to fossil fuels that take million years to renew itself and are the cause for greenhouse gas emissions in the atmosphere leading to global warming. The stimulus packages, in addition, can help in strengthening the fiscal policies in alignment with climate-neutral policies/targets and alleviating the disruption in the economic frameshift due to COVID-19 pandemic. To
materialize all the efforts, boosting the shift in a more coordinated and integrated manner toward the zero carbon energy shift is absolutely necessary along with continuation of fiscal investments in a multilateral approach. Needless to say, COVID-19 strongly exposes the laxity of global economy at a time of system crises associated with an abrupt collapse in international trade as well as in GDP. Besides environmental concerns, the sectorial shift toward clean energy generation may be an excellent platform for short-term job creations promoting a long-term, sustainable economic growth.

The dispute for the establishment of a universal principle and approaches varies across groups, disciplines, and countries. In a broad term, energy shift can be accounted as timely and effective progress of the energy triangle: environmental sustainability, economic development and inclusive growth, and energy security and access. While the long-term impact of COVID-19 on energy systems remains to be seen, lessons can be learned from individual behaviors and international cooperation. Energy transition is the need of the hour with emerging and changing economies. Keeping the future in mind we must persist in our endeavors to overcome any upcoming situation.

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