CHAPTER

Energy security: role of renewable and low-carbon technologies

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Chapter outline

1. Introduction

Recently, the world's economy has sparked a remarkable rapid growth. The inflation of the population growth together with high interest in transportation has significantly increased the energy demand. This increase in energy means a rise in fossil fuel consumption such as coal, oil, and natural gas that eventually widespread greenhouse gas (GHG) emissions is touted by carbon dioxide (CO_2). A report produced in 2020 stated that electricity and heat production contribute 35.8% of 38.0 GtCO_2 total global emissions (Olivier and Peters, 2020). This is closely followed by manufacturing industries and road transport whereby each represents 16.7% and 15.9%. According to the country, China notably

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emitted the most, accounting for 26.1% of the global CO_2 emissions, followed by the United States at 12.67% (World Resources Institute, 2020).

The Intergovernmental Panel on Climate Change (IPCC) 2019 report has demonstrated that global warming is mainly due to the increase in GHG concentrations (I. P. on C. C. (IPCC), 2019). Subsequently, these lead to the fundamentals of developing new energy using low-carbon technology (Lin, 2011). In recent years, low-carbon technology has been the frequently discussed subject that acts as a key role in the global economic transformation to reduce the worldwide CO_2 level. Low-carbon technology is considered as a technology that helps to reduce GHG emissions, preventing global warming, hence adapting to a low-carbon economy (Lv and Qin, 2016). A low-carbon economy is translated as an economy that is based on low energy consumption with minimal carbon emissions into the atmosphere (He, 2009).

Low-carbon technology is classified into five categories: carbon reduction technology, carbon-free technology, carbon removal technology, carbon management technology, and resource conservation and recycling technology (Xing et al., 2011). Carbon reduction technology refers to the efficient energy use, widely known as energy efficiency (EE) by utilizing energy-saving technology such as a smart meter or energy-efficient light bulb. Meanwhile, carbon-free technology also known as renewable energy (RE) comes from natural resources and continually replenish solar, wind, hydro, or nuclear power to produce electricity. Carbon removal technology is an approach to promote photosynthesis in removing CO_2 such as farming and forestry. Other approaches such as bioenergy with carbon capture and storage and direct air capture are other alternatives to combat climate change. Meanwhile, carbon management technology encourages collaboration between the government and companies to work together in promoting the development of a low-carbon economy. This involves formulating assessment criteria, energy-efficient standards, and carbon emission audit system (Niu, 2011). Resource conservation and recycling technology help to reduce the generated solid waste by converting it into new materials and objects such as garbage power generation technology, recycling waste cement road construction and old building materials (Tseng et al., 2018).

Although there is a wide range of possibilities to generate economic and social development benefits resulting from climate change mitigation, its implementation poses challenges to developing countries. Due to the distinct political, economic, and social settings, the barriers to low-carbon growth in developing countries are quite different from those in developed countries. Apart from the locations, there are similar barriers existing to those in the developed countries such as high upfront investment costs, lack of information, and concerns about discontinuities in production. Furthermore, for access to public–private collaboration and global cooperation, the countries depend on transformative steps such as new policies and market models. The COVID-19 crisis has significantly affected the development of EE globally. However, RE has seen a continuous growth, where many RE plants were developed amidst economic crisis across the globe.

Despite the barriers, countries around the world are progressively focusing on RE resources in their energy transition such as wind, hydropower, solar, and biomass to meet global climate goals and to close energy gaps caused by the phase-out of nuclear and fossil energy output (International Energy Agency (IEA), 2020). The costs of renewable electricity generation continue to fall significantly in 2020 specifically due to the innovation in China (International Energy Agency (IEA), 2020f,g). The innovation includes the development of RE and electric vehicles (EVs) through the application of smart charging, battery recycling, and development of an open power market. China, on the other hand, is not alone in its energy innovations. Most countries, especially in North America, Europe, as well as India, are developing clean energy innovation hubs (IEA, 2020a). The resulting global surplus in RE generation, combined with advancements in EE technology and effective policy, paves the way for low-carbon economy to develop. In this chapter, the development status of RE and EE around the world will be first visited. Next, the role of RE and low-carbon technology in shaping a sustainable power generation mix, improving electrification, and empowering demand side participation will be discussed. Finally, the future roles of RE in enhancing energy security in a decentralized electricity market through peer-to-peer (P2P) energy trading, virtual power plant (VPP), and carbon pricing scheme will be explored.

2. Overview of global low-carbon technology status

In 2019, around 77 countries, 10 regions, and more than a 100 cities have announced their pledge to achieve net-zero carbon emissions by 2050 (REN21, 2020). The European Commission has also proposed a European Green Deal roadmap to establish a carbon-neutral continent by 2050. In 2019, the zero-carbon buildings initiatives were launched by the United Nations Climate Action Summit, aiming to expand the decarbonization roadmaps for buildings. On top of this, more than half of the countries in the world have submitted Nationally Determined Contributions under the Paris Agreement, concerning reducing GHG emissions (world resource institute (WRI), 2019). These joint efforts have remarkably changed the development and penetration status of renewable and low-carbon technologies globally.

2.1 Renewable energy technologies: global trends

In the last decade, the development of RE has been the world's focus due to the depletion and increasing cost of fossil fuels. It was reported by International Energy Agency (IEA) that RE is expected to lead the worldwide electricity sector by 2025 due to economic stimulus focusing on clean energy by global countries (IEA, 2020b). For the last five years, RE has grown three times faster than nuclear and fossil fuels (IEA, 2020c). It was also mentioned in the IEA report; the majority of RE share in global electricity production for the year 2019 came from nonrenewable electricity sources which contributes up to 72.7%. Whereas only 27.3% is from renewable electricity, where 15.9% of this renewable electricity comes from hydropower, 5.9% is generated from wind power, and 2.8% is from solar photovoltaic (PV). Fig. 4.1 illustrates the electricity production per technology with projections for the year 2030 (Ioannis et al., 2020). This projection is based from the European Commission's long-term strategy baseline scenario. It is shown that wind and solar power sector is estimated to generate 51% of electricity followed by nuclear energy, predicted to generate 28% of electricity. By 2030, it is forecasted this RE sector will replace the coal sector and reduce the coal output to 8%.

This statement is also supported by a report published in IEA (Etoro, 2021), where it is estimated that by the year 2025, power generated by RE such as wind and solar PV will surpass the power generated by burning coal by 15.1%. Around this time, it is expected for RE to supply one-third of the world's electricity (IEA, 2020a). This global trend in achieving RE generation 2025 target is also supported by the International Renewable Energy Agency's (IRENA's) Global Renewable Energy Roadmap 2030 policy complied by 87 countries. It is projected that 721 gigawatts of new power generation in wind, solar, and other RE technologies to emerge over the next few years, according to BloombergNEF.

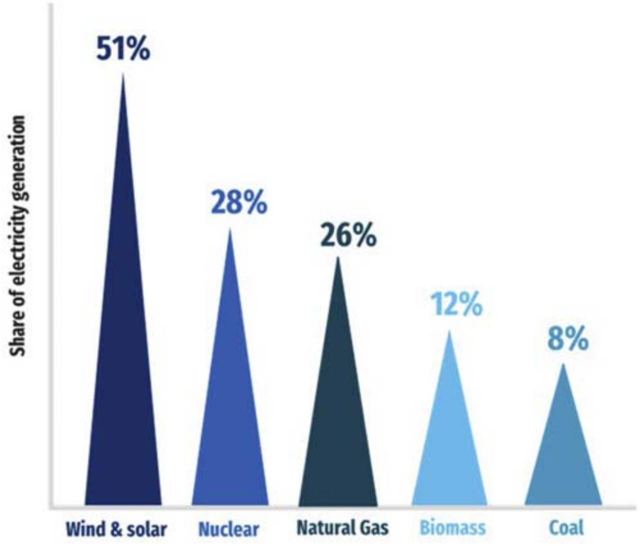

FIGURE 4.1

RE share of global electricity production with projections for the year 2030 (Ioannis et al., 2020).

Fig. 4.2 shows the RE partnership triangle which consists of the government, local community, and private sector. In general, the role of the government is to encourage and promote new development of RE by providing funds, subsidies, and policy support. In 2019, based on the statistic gathered by Statista, China has invested 83.4 billion USD into RE development. Public acceptance is one of the important aspects in determining the success of RE implementation (Kim et al., 2020). Public awareness and trust in the government's decision are the essential elements in determining the RE rate

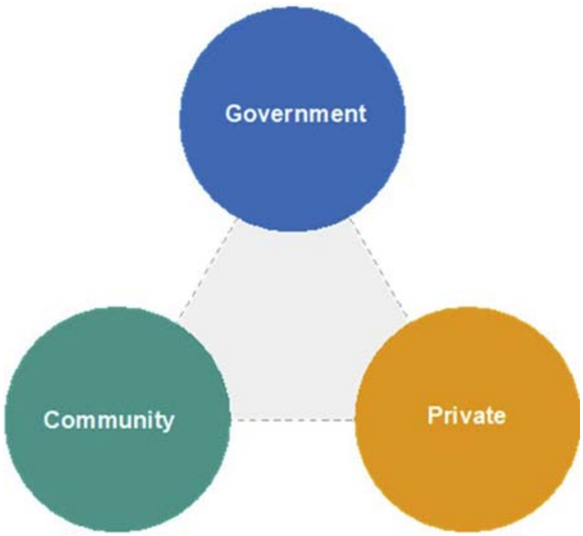

FIGURE 4.2

RE main stakeholder's relationship triangle.

of growth. Besides, private sector's involvement in achieving low-carbon power generation target has significantly accelerated RE growth. A report from Frankfurt School-UNEP Center has disclosed an increasing number of corporations registered to be under the RE100 group. RE100 is a global organization that has set its commitment to source its electricity from 100% RE. It is also disclosed that by end of January 2020, around 220 companies have successfully become part of RE100 (B. UNEP Frankfurt School-UNEP Centre). Corporations from all over the world are making a significant contribution to green energy. This effort is assisted with the introduction to Renewable Energy Certificates (RECs) and Power Purchase Agreement (PPA) (F. S.-U. collaborating Centre, 2020). PPA is a financial agreement between the green energy producer and buyer that allows the buyer to purchase energy from RE. While RECs represents the electricity generated from RE sources.

2.2 Energy efficiency technology global developments

EE plays an important role in clean energy transitions to achieve global climate and sustainability goals. A statement from the United Nations Economic Commission for Europe (UNECE) highlights that EE is the most cost-effective option to meet the growing energy demand in most countries as it contributes to energy security, better environment, quality of life, and economic well-being (UNECE, 2017). Meanwhile, the United Nations' Sustainable Development Goals target 7.3 aims to "double the global rate of improvement in EE by 2030" (UNECE, 2017).

Another supporting statement from UNECE on the global EE technology research, development, and demonstration (RD&D) expenditure has stated a continuous increment in global EE technology RD&D from the year 2017 until 2019. Between 2018 and 2019, a significant growth of 12% from USD 4 billion to USD 4.4 billion has been recorded for EE RD&D expenditure.

It is reported in International Energy Agency (2019a) that national financial incentives of USD 120 billion was invested to support the EE policy governed by 17 countries. These incentives vary from finance loan, grant/subsidy, guarantee, tax relief, direct investment, and equity finance. Apart from these incentives, governments also promote private venture capital funding for startups to develop emerging EE technologies. Majority of the investment was allocated to building technologies which cover the smart building devices, heating and cooling, building energy management system (BEMS), and building envelopes. There was a drop of USD 0.5 billion in investment between 2018 and 2019 in the smart building and other EE sectors observed in the UNECE report (UNECE, 2017). However, other sectors such as industry, BEMS, heating and cooling have managed to maintain their venture capital. The year 2019 has marked new developments of innovative cooling technologies including converting waste heat to power refrigeration and air conditioning, solar storage cooling technologies, and intelligent devices to improve EE for residential air conditioners (International Energy Agency(IEA), 2019).

Another report by IEA on "Renewables 2020-Analysis and forecast to 2025" has disclosed between the year 2010 and 2019 the EE investment has been focused on buildings, transport, and industry. Most of the EE investments are funnelled to buildings which mark 58% of the total global EE investment for the year 2018 followed by 26% for transport, and the other 16% investment is for the energy intensive industry sector (International Energy Agency (IEA), 2020f). The main investors in global EE are the United States of America, the European Union (EU), and China. Based on the report by IEA Sustainable Development Scenario, the year 2018 has seen deployment of EVs, rail and lighting technologies. It is estimated that around USD 250 billion was spent globally in EE across the buildings, transport, and industry for the year 2019 (International Energy Agency(IEA), 2019).

In recent years, digitalization technologies have sparked high potential in improving EE. These digitalization technologies are currently applied in smart BEMS where the system combines the data obtained from various wireless sensors and individual devices. These data are then analyzed using artificial intelligent algorithms to facilitate the consumers' need.

2.3 Impact of COVID-19 pandemic on renewable energy and energy efficiency

The global pandemic outbreak caused by coronavirus 2019 (COVID-19) has caused people to live in limited social freedom and mobility. The closure of commercial buildings, schools, and factories has resulted in a significant drop in energy demand in commercial buildings (Eroğlu, 2020). Due to social distancing and teleworking, electricity usage in residential buildings have grown by 20%−30% (IEA, 2020d). This mobility restriction has disturbed the supply chains and temporarily delayed RE construction projects, equipment supplies, and policy implementation (IEA, 2020a). In the year 2020, the global economic crisis has delayed investments in households' efficienct technologies business and also triggered dramatic changes in markets behaviour which add to uncertainty in EE progress (IEA, 2020d).

Despite the mentioned delays due to COVID-19, RE auctions are breaking new records. In this renewable electricity auctions, governments from various countries call for tenders to install a certain capacity of the RE plant. It is reported in IEA report entitled "Renewables 2020 Analysis and forecast to 2025," there is an increase in the number of global renewable electricity auctions in the first half of 2020. During this term, China has auctioned almost 25 gigawatts renewable electricity followed by India with 12 gigawatts. In addition, 13 countries are awarded almost 50 gigawatts of new renewable capacity starting from 2021 to 2024. It is also recorded in IEA report; in the first half of 2020, a total of 42 gigawatts of solar PV global capacity have been awarded followed by 4 gigawatts onshore wind capacity (International Energy Agency (IEA), 2020f). This surged rate has testified regardless of the pandemic issues; the growth rate of RE and EE is stimulated with continuous financial and policy support from the government. With this increasing incentive from worldwide countries on EE, it is estimated to create an equivalent of 1.8 million full-time jobs between 2021 and 2023 (IEA, 2020d).

3. Roles of renewable and energy efficiency technologies for enhancing energy security

According to IRENA, the global roadmap for the energy transformation is driven by the dual critical factors of limiting climate change and improving energy security for sustainable growth (IRENA, 2019). In addition, the ascending growth of energy demand, fluctuations in fossil fuels price, interruptions in energy import and export (Bekhrad et al., 2020), depletion of fossil fuels reserve, and dependency on a single fuel for electricity generation are the major concerns of countries around the world. Energy security is dependent on the ability to secure fuel for generating electricity. The classical definition of energy security is a stable supply of cheap oil due to embargoes and price manipulations by exporters (William Colglazier and David, 1983; Yergin, 1988). In contrast, the modern energy security is more challenging and not limit to the oil supply issues but also entangled with other energy policy problems such as providing equitable access to modern energy and mitigating climate change (William Colglazier and David, 1983). The contemporary concept of energy security was then introduced by Asia Pacific Energy Research Centre (APERC) through its 4As of energy security which are availability, accessibility, affordability, and acceptability. Furthermore, this section will discuss the roles of RE and EE in shaping sustainable electricity generation mix, increasing electrification, and empowering active consumers (prosumers) through demand side management to enhance global energy security.

3.1 Renewable energy paving world sustainable electricity generation mix

Energy mix diversification is an imperative for energy security and sustainability transitions (Ang et al., 2015; Akrofi, 2021). In electricity sector, power generation mix is a combination of various fuels used to generate electricity in each geographic region. In a regulated electricity industry, the generation mix planning problem is a country's choice and involves determination of types, capacity, and construction time of new candidate generation technologies which should be added to the existing system to meet the growing demand. Meanwhile, in a decentralized electricity industry, the generation mix is resulted from investment decisions of generating companies in a competitive electricity market. The power generation mix varies considerably from one country to another, depending on global markets, national policy, local fuel production and demand. IEA (IEA) reports the evolution of the world electricity generation mix from the year 1971to 2018. Being a cheaper yet abundant resource despite higher CO_2 emission, coal has been the dominant fuel since the earlier years. In fact, coal is still the main source of fuel for world electricity generation especially in the developing countries, accounting for more than 38% of the mix in 2018 (IEA).The share of RE and gas increases each year to accommodate the reduction from oil and nuclear. These specifically happened after the global oil crisis in the 1980s that resulted in increased oil price and Fukushima nuclear plant disaster in 2011 that caused some nuclear plants to close, and many countries deferred or abandoned their nuclear power plan. With the growing demand, it is expected that the implementation of RE projects will be intensified and contribute significantly to the overall generation mix. The IRENA's RE map reveals that the share of renewables in power generation mix would rise from 26% in 2018 to 86% in 2050 and would account for 60% of total energy generation in 2050, particularly from solar PV and wind (IRENA, 2019).

Despite challenges from the COVID-19 crisis faced by the energy industry, the share of renewables in the electricity generation mix rose considerably. This is due to the recent installed capacity of wind and solar PV plants worldwide and priority dispatch received by the plants protecting them from the impacts of lower electricity demand (IEA, 2020a). IEA (IEA, 2020e) reports the renewable technologies' capacity addition from 2013 to 2019 and future projections under the main and accelerated case. The report reveals that solar PV has shown a significant increase every year accompanied by wind and is expected to grow steadily for the next five years. The aggressive growth of renewable technologies would be driven by continuous decline in the cost, strong policy support, and preferential access to many grid systems (IEA, 2020a, e).

Many countries around the world are rapidly pushing forward with their own energy transitions. Low-carbon technologies such as RE and EE have become the choice of these countries in shaping their new energy policy. The EU is among the most vulnerable countries due to its high energy import dependency and scarcity in fossil fuel reserves. Germany and Spain are among the leading countries in utilizing the renewable resources. In Germany, the strongest renewable technology growth is wind power, bioenergy use, and recently solar PV (Hinrichs-Rahlwes, 2013). Meanwhile, in Spain, the 2050

RE transition will be deployed in three phases to replace coal in the first phase, nuclear phase-out in the second phase, and natural gas plants in the third phase (García-Gusano and Iribarren, 2018). The success of Spain in RE efficiency lies in solar investments, wind, and hydro. Unlike Germany, Spain does not have significant savings in oil and natural gas, but has savings in coal (Gökgöz and Güvercin, 2018). Different as in the EU case, the energy security concerns in Southeast Asia are caused by the depletion of indigenous fossil fuels and shortage to meet growing demand. In the worst scenario, some net exporting countries of the fossil fuels are now turning into net importers (IRENA, 2018). Consequently, to ensure the security of fuel supply as well as to meet country climate pledge, Southeast Asian countries have also started their energy transformation by deploying low-carbon technologies, although a slow movement was observed (NBR, 2020). However, the rapid deployment of solar PV in Vietnam and geothermal power in Philippines and Indonesia can be the pilot projects and lesson learned for scaling up the RE transition elsewhere in the region. Large hydro comprises the majority share which is over threequarters of the RE generation. Similar with other regions that rely on large hydro, the Southeast Asia also has a declining share trend of hydro generation due to rapid growth of other renewables technologies such as geothermal and solar PV (IRENA, 2018).

3.2 Renewable energy microgrids for enhancing electrification

IEA reported that 1.1 billion people around the world have lack access to electricity (IEA, 2017). The microgrids system is foreseen to play a critical role in supporting centralized grid system for electrification solutions. Microgrid is a decentralized energy system that supply power from interconnected local distributed energy resources (DERs) over low or medium-voltage distribution networks and usually connected to main utility grid but can function independently (Nosratabadi et al., 2017; Burger, 2016), as depicted in Fig. 4.3. DER includes behind-the-meter generation, RE, energy storage system (ESS), controlled loads, inverters, and EVs. The recent increased activity in the microgrid sector serves not only for electrification but also to remove barriers that inhibit deployment of large-scale renewables and to provide ancillary services to the grid for system reliability (Tjäder and Ackeby, 2018). A small-scale DER could be found in many users known as prosumers that installed PV on the rooftop. A prosumer is an individual who produce and consume energy, enabling themselves to participate in energy trading by selling excess solar energy and buying energy from the grid.

However, overdeployment of renewable DER would be threatening the network as the sources are highly unpredictable and intermittent that could disrupt the supply and demand balance, hence security of the power system. For that reason, various hybrid RE solutions with battery storage and demand response (DR) considering energy management and control strategy have been proposed to improve reliability of microgrid. For instance, a study by Kafetzis et al. (2020) developed an energy management strategy for the control of islanded off-grid hybrid energy systems with ESS, diesel, hydrogen, and RE sources such as solar, wind, hydropower, and biomass for industrial and residential loads. Meanwhile, Mohamed et al. (2021) proposed a renewable microgrids considering solar, wind, and storages in the presence of EVs. Mehdi Hakimi et al. (2020) presented a management strategy of cooling system in buildings in smart grid with high shares of RE. The study found that managing the cooling system would simultaneously increase the reliability of the microgrid. The effect of different prosumers' penetration levels on hybrid electricity dispatch in Australian National Electricity Market is analyzed by Verbič et al. (2019) The simulated case revealed that the increase in renewable penetration requires more energy from gas. With increasing of ESS, the prosumers' self-reliance on the

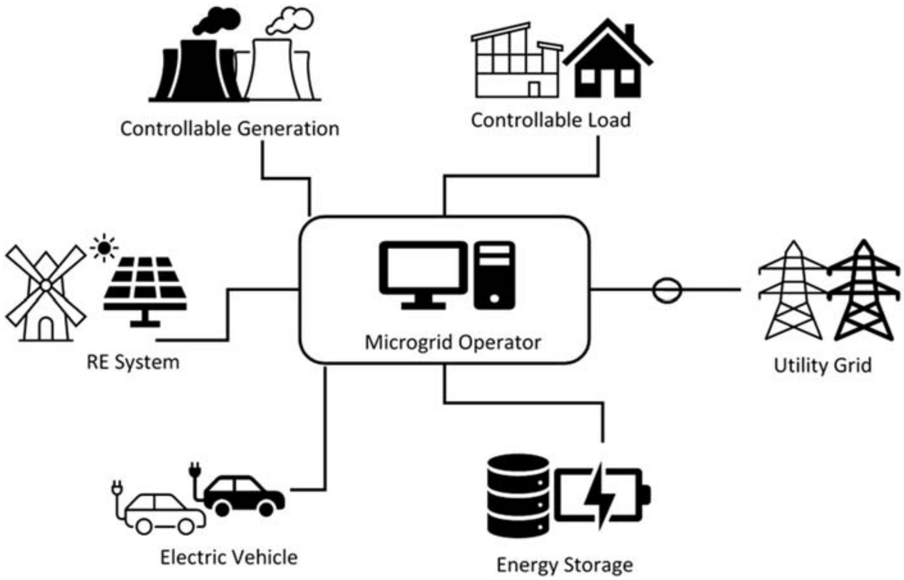

FIGURE 4.3

Visualization of a microgrid system.

grid is reduced. In the absence of storage, the solar PV supplies the load during the day, and the grid supplies the rest. In contrast, with the storage system, RE charges the batteries (mostly by PV during the day and wind during the night) when the grid price is low and discharged in late afternoon to reduce the demand when electricity price is high. In the literature, many authors have also explored the techno-economic performance of various hybrid energy systems as optimal combinations. In general, studies showed that optimized hybrid RE system with battery storage would provide a lower cost of energy while achieving environmental benefits to supply the demand (Kotb et al., 2020; Das et al., 2021; Li et al., 2020).

3.3 Low-carbon technologies through demand side management in buildings

Fig. 4.4 presents different energy savings measures for each level in an energy savings pyramid. The pyramid system suggests that the demand side management strategy in a building should start with energy conservation measures (ECMs) followed by EE and then RE. The ECM can be defined as human's behavior toward the use of energy that results in less energy consumption and usually regards as a low-hanging fruit solution. The awareness is a soft measure but complementary which can potentially lead to more consistent ECM actions. Additionally, an energy audit can be considered as an awareness measure, where it provides technical and detailed feedback on the energy use leading to effective ECM recommendations (Mustapa, 2020). Meanwhile, the ECM involves energy management initiative that can be implemented by introducing good housekeeping measures, regulating the energy use of electrical devices, building automation, control and optimization, DR, zonal heating or

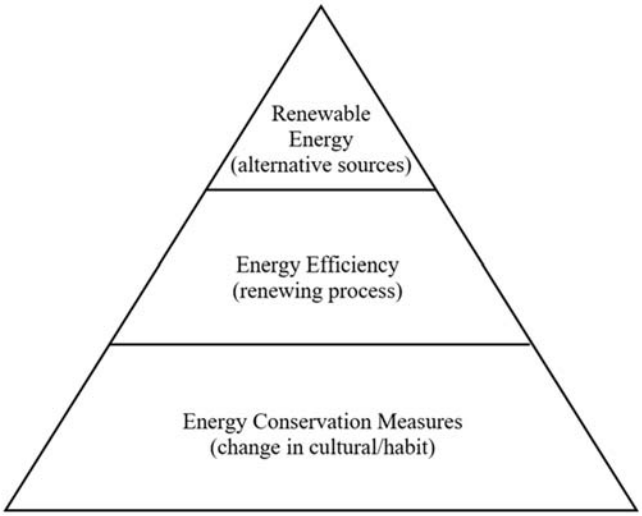

FIGURE 4.4

Energy savings pyramid.

lighting, and fault detection and diagnosis (Mariano-Hernández et al., 2021). A study by Mustapa et al. (2020) evaluates savings from awareness, walkthrough audit, and simple energy management program in a campus building such as switching the lights when not in use and setting air-conditioning temperature to 24°C. The energy savings obtained from the implementation was between 12% and 34%. Meanwhile, Sulaima et al. (2019) investigates simultaneous DR strategies such as valley filling, load clipping, and load shifting for consumers under the Time of Use (ToU) pricing. Findings showed that the commercial and industrial consumers should utilize 20%−50% of load management to acquire optimum benefits of the ToU incentive.

On the other hand, EE is the use of technologies that utilizes less energy to do the same amount of work. The EE requires an inefficient equipment to be replaced with more efficient ones and involves cost to be borne by building owners. Typical EE in buildings include installation of energy-efficient lighting system, lighting controls, variable speed fans and pumps, and efficient heating and air-conditioning system (UNIDO). Building owners may also consider building shell envelope measures such as external walls' insulation, windows' glazing type, air tightness (infiltration), and solar shading (El-Darwish and Gomaa, 2017). Recent emerging business model for EE is Energy Performance Contracting (EPC). EPC is an effective mechanism which can facilitate capital allocation required to retrofit buildings that use the cost savings from reducing energy consumption to repay the capital investment cost. The cost of the ECMs will be borne by Energy Service Companies (ESCOs), and the savings will be shared between the ESCO and building owner on an agreed percentage within a contract period (Aris et al., 2015).

The third level of energy savings measure in buildings is RE. Usually, the building owners employ a small-scale RE such as solar PV panels on their rooftop. The energy generated from the RE is used for own consumption, and the excess can be sold to the grid under incentive schemes such as Net Energy Metering (NEM) or Feed-in Tariff. By optimally managing the production of RE and energy consumption, the prosumer would be able to effectively reduce their energy cost and carbon footprint.

In the NEM scheme, generally the revenue from selling the excess energy will be credited in the bill, hence reducing the energy cost. Additionally, the commercial and industrial consumer can also reduce their maximum demand by consuming the solar energy generated during the daytime. As many countries are now achieving solar grid parity (Martín, 2019), there are emerging business models evolved to drive the expansion of solar rooftop markets. These include solar power purchase agreements (SPPAs) and solar leasing (Tongsopit et al., 2014). The SPPA typically involves customer who is the roof owner, solar developer, and utility company. The contract permits developer to install, own, and operate the solar PV system on the consumer's site and sells the solar electricity to the consumer at a discount, typically 5%−10% lower than the grid electricity tariffs for 20−25 years contract period. Meanwhile, the solar leasing model allows the leasing company (or solar lessor) to enter a leasing contract with the customer (solar lessee) to own, install, and operate a rooftop solar on the customer's roof. The solar lessee will pay for the solar system based on an agreed rate comprising the down payment and monthly instalments. Fig. 4.5 shows the solar PV rooftop installation in seven campuses of Universiti Teknologi MARA (UiTM), Malaysia, with total of 10 MW capacity. The installation is made through SPPA with a private company. It is expected that the solar PV rooftops will generate 66,116 MWh annual energy which provide 45% of UiTM energy consumption and reduce 75,000 tonnes CO_2 annually.

FIGURE 4.5

Solar PV rooftop in seven UiTM campuses, Malaysia, through SPPA

4. Future roles of low-carbon technologies in decentralized energy market

Power networks are enduring with the remarkable energy transition landscape whereby the traditional centralized large-scale generating power plants are now operating in a decentralized manner. Several dominance features are added, enabling bidirectional communication and power flow control. In realizing the actual solutions for low-carbon energy in the future decentralized renewable power landscape, various technological innovations have been embraced. Three enabling technologies toward clean energy and achieving a 1.5°C climate target according to the 2015 Paris Agreement are defined as EVs/electric transportation, ESS, and solar PV (International Energy Agency (IEA), 2017). As these happened, the consumers will become active players in a decentralized energy ecosystem. The deployment of P2P energy trading, VPP, and carbon pricing scheme are currently being the most prominent innovations and actions toward low-carbon solutions to drive the uptake of clean energy technologies (IRENA, 2020). Withal, that requires proper coordination in supplying continuously energy parallel with the economic development and environmental needs along with grid resilience. This is to assure that the power grid will withstand and react promptly to any disruption and changes in the power grid operation system (International Energy Agency (IEA), 2019).

4.1 Peer-topeer energy trading

Due to the high proliferated integration of DER at electricity portfolios, it can potentially create a new approach on electricity being traded at the distribution sides. The P2P energy trading is a business model scheme that emerged to compensate the distribution consumers by allowing them to be prosumers to share the benefits of generating electricity from renewables within the communities bent. Initiated from the P2P economy concept, it can be implemented within a local distribution system (i.e., region, cell, microgrid, and premises) such that the energy trading activities occur among utility providers, prosumers, and consumers (Zhang et al., 2018). P2P energy trading is aiming to transform the grid in becoming more flexible with the usage of RE, provides a balance of energy supply and demand in real time, autonomous in decentralized manner, and empowering the consumers and prosumers. The prosumers in this platform enable them to vigorously manage their DER that includes the interconnection of distributed generation, EVs, ESS, and DR without a mediator, as illustrated in Fig. 4.6 (Liu et al., 2019). Only in some cases, the distribution system operator is responsible for administrating the P2P trading market to ensure the reliable and secure auction operation system happened between prosumers and consumers (Long et al., 2018).

In this energy trading market platform, the bidding process will occur between prosumers and consumers to meet their requirement in terms of electricity price, cost, benefits, energy preference, and demands. In return, the sellers can make profits through higher electricity price sold. At the same time, buyers can save the cost since they are not imposed with other utility charges than the traditional trading mechanism that offered relatively high tariff and low buyback rates through fixed tariffs and ToU tariffs (Park and Yong, 2017). Motivated by this cost-saving factor, various utilities, high technology startup companies, and manufacturers had initiated projects to access further benefits by deploying P2P energy trading. Numbers of trading platform have been developed as the enabling technology for P2P energy trading that applied the centralized and decentralized concepts such as

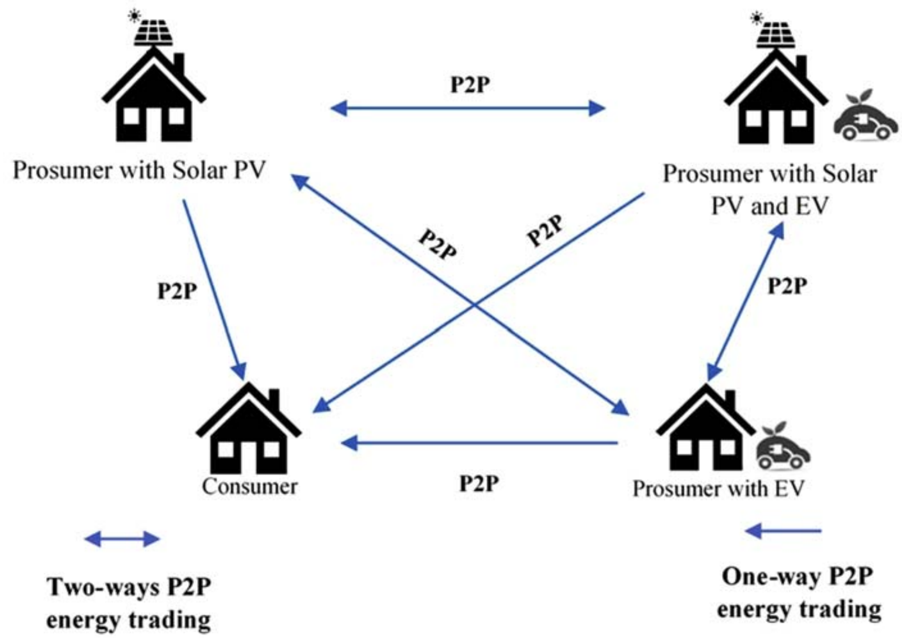

FIGURE 4.6

Structure of P2P energy trading within DER (Liu et al., 2019).

Elecbay and blockchain technology software, respectively (Zhang et al., 2018; Han et al., 2020). Projects such as Brooklyn Microgrid, TransActive grid (the United States), and Centrica plc (the United Kingdom) are examples that deployed blockchain in the trading platform (Mengelkamp et al., 2018).

Through the literature of various P2P projects globally, it was observed that different business models were structure based on market design, trading platform, and information communication technologies (ICTs) infrastructure that provides diverse characteristic for monetizing profits (Zhou et al., 2020). Projects such as Vendebron and sonnenCommunity charged a monthly subscription that amounted to USD 12 and USD 24, respectively, from prosumers and consumers that adopted their trading platform (IRENA, 2020; Park and Yong, 2017). The sonnenCommunity project applied the battery business entity in making profits by binding the agreement for prosumers to buy and use Sonnen's batteries while performing a virtual energy pool to trade the surplus generated renewable electricity instead of feeding it into the grid (sonnenCommunity, 2019). Some projects focused on the ICT infrastructure to support energy sharing as implemented by Smart Watts and PeerEnergyCloud (Germany). Narrowing down to the developing countries, Malaysia and Bangladesh have started in piloting P2P energy trading projects in 2019 and 2015, respectively. Malaysia's pilot project, focusing on highly used commercialized consumers ended in June 2020 and had remarkably gained prosumers profits at about 11% for its excessive solar PV trading that applied blockchain as transaction platform (SEDA, 2019). While in Bangladesh, the SOLshare started its first P2P project in a remote microgrid allowing electricity to be shared within locality to ensure the consistency of power network. This project is envisaged to benefit 2.5 million people in that region by 2023 (SOLshare, 2020).

As P2P energy trading reap exquisite contributions to the power sector, practical implementation is a challenge worldwide. The efficiency and security of virtual layer platform need to be improved regularly since P2P energy trading involved heavy consumption in handling peers and bidirectional energy and communication exchange. Another challenge is applying a conducive regulatory framework and policy to ensure prosumers and consumers trade their RE with relatively cost involved. The EU Directive 2018/2001 enacted in 2018 was the first mandate defined for P2P energy trading using RE under the Clean Energy Package of legislation (European Commission, 2018). While in the United States, only a few projects of P2P energy trading were implemented due to limitation in a regulatory framework that only allowed the trading to be conducted within islanded microgrid (IRENA, 2020). In realizing the P2P concept, the virtual energy trading platform developed should operate efficiently and reliably using distributed ledger technologies. For this purpose, blockchain technology is introduced to assure security, privacy, and prevent information leakage (Shipworth et al., 2019).

Over the decades, world energy consumption has been escalating due to expanding population, rapid revolution in economic growth and industrial development that eventually widespread the emissions of GHG and CO_2. This decentralized renewable market design may lower the environmental impacts on pollution, provide grid resilience, and reduce cost in managing and maintaining electricity infrastructure (IqtiyaniIlham et al., 2017). From the perspective of its business model, the P2P energy trading concept offered a socioeconomic incentive whereby prosumers with surplus energy will sell it among the community in order to generate extra profit while maximizing the energy utilization.

4.2 Virtual power plant

VPP appeared as a new cloud-based model that aggregates a bundle of dispersing connected DERs in the electricity power market operations to improve the grid flexibility, security, and reduce environmental risks. With VPP, better integration of RE is envisaged through supply side flexibility by optimizing power generation sources (i.e., solar PV, wind, combined heat and power and ESS) and demand-side flexibility by aggregating DR (Saboori, 2017). A decentralized energy management system will control all data related to the weather forecast, power supply, DR trends, and wholesale market's electricity price (Maanavi et al., 2019). Fig. 4.7 illustrates an overview of VPP structure that afford several grid services such as forecasting and trading of DER, operating reserve capacity, energy curtailment, and frequency regulation to create a new share of the energy economy. It is a model that creates a new concept that is able to reduce the technical and financial risk contributed by the intermittent nature of RE (Pudjianto et al., 2007).

As many countries in the world have started deploying VPP, the recent global market value for VPP amounted to USD 762 million in 2016, and the number is projected to reach USD 4597 million by 2023 (Fortune Business Insights, 2019). Countries like Australia, the United States, the Netherlands, Germany, Denmark, and the United Kingdom are the most actively involved in VPP activities with an established regulatory framework acknowledging VPP trading. Toward the path in transitioning the world to sustainable energy, in 2018, South Australia (SA) has initiated developing the world's largest VPP by installing 5 kW solar PV rooftop at 50,000 households. Each home was equipped with ESS, smart meters, and a computer system to control the activities between houses and the grid in terms of storage and renewables used (Government of South Australia, 2020). The five-year project positively

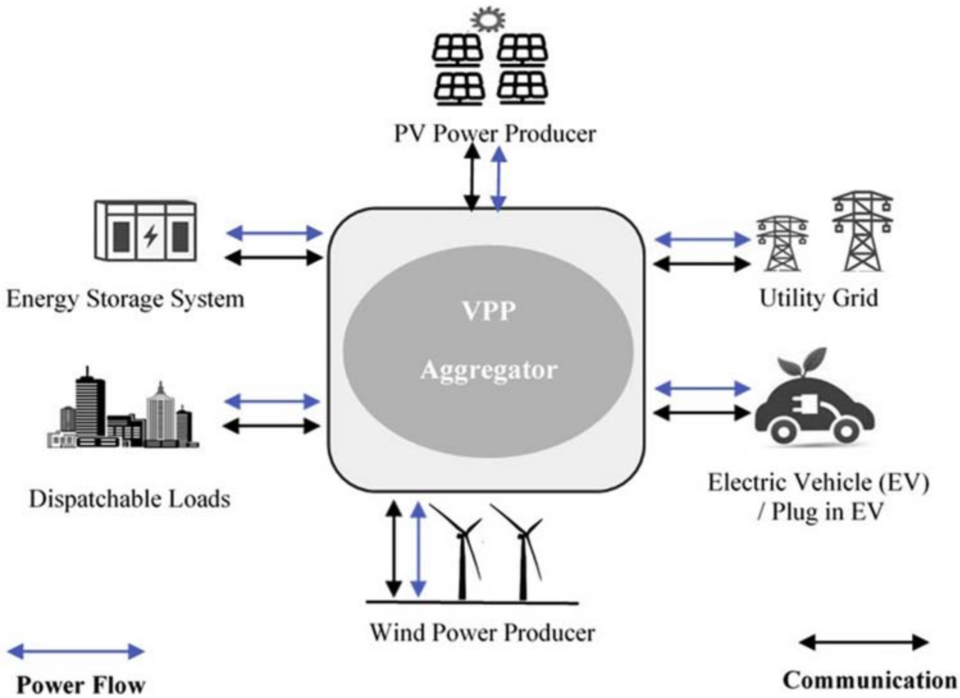

FIGURE 4.7

Overview of VPP structure and its bidirectional flow.

impacted the grid flexibility with RE integration that would add 250 MW during peak capacity to the system. Such stability provided by VPP had support to the significant events during power station trip in Queensland and frequency variation issues happened in 2019. Furthermore, for each 50 MW solar PV capacity brought into the system, the wholesale price is expected to reduce about USD 6/MWh that is equivalent to USD 65 million/year in cost reduction considering engagement from participants fully. Consequently, the VPP consumers can reduce their electricity bills up to 30% (Frontier Economics, 2018).

The VPP model can be designed based on three business cases, namely: (1) forecasting, trading, and energy curtailment with renewables, (2) grid flexibility aggregation from RE, and (3) Demand Response Aggregator. Some projects are also combining all the above-mentioned cases through a large-scale, systematic, and well-coordinated VPP. For instance, the Statkraft's VPP developed in Germany is known as large-scale RE integration into grids that deployed 100% renewable energy system (RES) incorporating about 1300 wind farms, 100 solar power producers, 12 biomass power plant, and eight hydropower plants. The VPP is capable to generate more than 10,000 MW at its peak period comparable with 10 nuclear reactors that provide real-time data management, remotely control of DER, energy forecast, scheduling, and trading based on day-ahead and intraday (Statkraft). Countries in Southeast Asia are also experiencing the rapid growth of economics that motivated them to strengthen their VPP market share anticipation to ensure grid resiliency. Malaysia, for instance, is an exemplary country in that region that has enormous opportunities for VPP deployment considering the high penetration of RE on a large scale and DER as well as its regulatory flexibility to response. Hereof, in 2019, Malaysia's government partnering with South Korea, commenced 30 months copilot project of behind the meter batteries to provide the grid services during peak demand with RES. The VPP pilot project is still operating and is envisaged to contribute to the decisive impact on power sector transformation, especially to consumers and the local network (The New Strait Times, 2019).

Despite various benefits obtained through bundling DER becoming VPP in power system operation and wholesale market, several key challenges to spur the development of VPP can be listed as technology maturity, system integration from various discipline, and regulatory barriers (IqtiyaniIlham et al., 2017; Wang et al., 2019). By changing the electricity generation landscape, it will affect the current network design and control. Withal, it is imperative that the technologies used to enable VPP must be matured and available to assure the supply security. The above-mentioned technologies can be defined as advanced metering infrastructure and advanced forecasting tools that can capture real-time communication data and forecast weather, supply, load, and wholesale prices. Despite all the listed technical key features, government and private sectors' support through financial incentives and flexibility on regulatory framework is essential, enabling aggregators to participate in the wholesale market and contributing to ancillary services. For instance, SA and Grid-Scale Storage Fund supports SA VPP project by giving the financial incentive amounted USD 12 million grants and USD 20 million loans from Renewable Technology Fund (Government of South Australia, 2020). Tesla as the private sector is currently working closely with SA VPP in supplying behind the meter batteries and identifying the participants for this project. Ultimately, without decent incentives and a revised regulatory framework in the energy market, the commercial projects involving VPP will remain a challenge though it has fulfilled the indicators of huge prospects.

4.3 Carbon pricing

The first international carbon market was set up under the United Nation Framework Convention on Climate Change (UNFCCC)—1997 Kyoto Protocol. However, following widespread reports of corruption and abuse of the system, the market collapsed, with the United States refusing to ratify the agreement further. Europe prohibits its member states from buying carbon credit starting in 2012, leaving only a few potential buyers (World Bank Group, 2018). Since then, there has not been a consensus on the best way to implement a carbon market scheme globally. Just during the Conference of Parties (COP) 21—Paris Agreement in 2015, the world unites to fight climate change by limiting global warming to 1.5°C (Intergovernmental Panel on Climate Change (IPCC), 2018). Moreover, unlike the earlier Kyoto Protocol agreement, the 2015 Paris Climate Agreement commits all signatories to impose carbon emission targets. Paving the path for global climate mitigation plan, several ways and policies have been implemented to obtain the same. Initiatives like deploying low-carbon technologies such as EVs, abatement subsidies for fossil fuels, carbon pricing system, and purchasing and manufacturing green energy and EE products are the proactive actions taken by most countries globally to decrease the emissions (Yuyin and Jinxi, 2018).

In the aspect of carbon pricing system, it can be further classified into carbon emission trading system (ETS) and carbon taxes. The ETS is a market-based system that allowed emitters to trade emissions to reduce the countries/businesses' environmental footprint (Narassimhan et al., 2018).

Contrasted from voluntary carbon offsets such as reforestation projects, ETS is a legally binding scheme that caps the total emissions and allows organizations to trade their allocation through cap-and-trade system (Narassimhan et al., 2018). There are several emission trading markets available around the world at both national and regional levels such as European ETS, baseline and credit system (Canada), California cap and trade (the United States), baseline and offset system (Australia), and carbon ETS (China). On the other hand, carbon taxes have been implemented in 25 countries globally, including the EU, Canada, and Japan as one way for climate actions. The carbon tax system defines a tax rate imposed by the respective government to any businesses/organizations that emit the GHG (in per tonne) surpass the allowable rate due to burning fossil fuel activities. As many countries tightened the environmental standards, the total value of global carbon markets grew 20% in 2020, reaching USD 272 billion (Fjellheim, 2021). Currently there are 61 initiatives involving carbon pricing that cover 12 $GtCO_2e$ equal to 22.3% global GHG emissions already in place and scheduled for implementation globally (The World Bank). The number is likely to increase as many countries, cities, and companies worldwide try to meet their ambitious pledge of neutral carbon emissions by 2050 set by UNFCCC.

Every year, in Europe, the government and policymakers will set a cap (carbon credit) to all heavy energy using organizations based on their historical emissions. The allocated cap can be bought and sold on a secondary market to limit the environmental damage. Between 2015 and 2019, about 35% reduction in GHG emissions was recorded through European ETS (European Union, 2020). Apparently, the EU is targeting a 55% net reduction in GHG emission by 2030 in order to achieve climate neutrality by 2050 (European Council, 2019). For the past two decades, the world has started assigning the price in CO_2 emissions. Sweden imposed the highest carbon tax rate globally with USD 126/metric tonne of CO_2 emissions from fossil fuels activities. In turns, the GHG emissions had reduced by 25% since 1995, while at the same time significantly expanding their economy sector by 75% (The Organisation for Economic Co-operation and Development (OECD), 2019).

While in Asia, China has been the world's biggest polluter for more than a decade with three billion tonnes of CO_2 emission on average per year (Ilham et al., 2019). For that reason, the carbon market undoubtedly will be complex. Realizing that fact, the government had started to deploy China ETS (CETS) in handling the climate threat. Nevertheless, the carbon tax is yet to be implemented and still under consideration by the government. The pilot ETS platforms had already started in 2011 covering nine cities and provinces under National Development and Reform Commission. The projects had substantially improved China's green production performance by 10% (Yang et al., 2021). A decade after, in February 2021, the official CETS had rolled out by focusing on eight key emitting sectors starting with the power sector for their first phase implementation. The CETS is targeting the emission reduction at 2200 electric power producers accountable for 30% (3.3 billion tonnes of CO_2) from the total country emission (ICAP, 2018). Paving the carbon neutral path by 2060 will be a challenge for this country, considering the size and complexity of the Chinese national carbon market. For that, the country had built an extensive preparation to improve decarbonization such as constructing more solar park and wind farms, carbon capture technology adoption for heat production and in-house power generation, phasing in the EVs usage by enhancing the batteries technology, and charging infrastructure along with EE innovation in buildings. Apparently, the country had become the world's largest producer of wind and solar energy with 30% of global capacity expansion, and it is leading the deployment of EVs globally reported in 2019 (International Energy Agency (IEA), 2019c, 2020f).

In the past, carbon trading systems have been successful in tackling environmental problems such as reducing acid rain in the United States of America by reducing sulfur dioxide emissions. Compared with carbon taxes and direct regulations, the carbon trading system does not require much interventions from government, thus leaving the businesses/organizations to attain their carbon cap and trade solutions. While for carbon taxes, it requires much involvement from the government/international sectors to ensure the carbon tax is uniform globally. As for now, the European ETS is a valuable model for other countries to emulate. Furthermore, 2021 is remarked with the recent creation of largest carbon trading in China, and the United States react in UNFCCC Paris Agreement, hence remitting the decisive outlook in global carbon pricing to growth. Nevertheless, as long as the cost of emitting GHG is high enough to produce, the carbon pricing mechanism, together with the low-carbon technologies innovations, could be relatively an efficient way to drive global decarbonization for the electricity sector.

5. Conclusion

This chapter discussed the role of RE and low-carbon technology in shaping sustainable energy security. As most countries globally are experiencing an extensive technological breakthrough, fossil fuels still stand as a dominant source for energy propelling. The overdependency on these finite sources has contributed to energy security, sustainable and environmental pollution issues. The continued emissions of CO_2 and GHGs may result in long-term changes worldwide, thus putting people and ecosystems at risk of severe and permanent consequences. However, the world has seen a positive transition of RE growth for the last five years, notably in solar and wind power. RE is expected to lead the worldwide electricity sector by 2025 due to economic stimulus focusing on clean energy to enhance energy security. Despite the unprecedented COVID-19 outbreak, the growth rate of RE and EE projects are stimulated with continuous support from the government, local community, and private sectors.

On a global scale, switching to a low-carbon technology could have substantial benefits for both developed and developing countries in the aspects of environment, society, and economy. The business concept involving DER has inaugurated the electricity wholesale market toward decarbonizing and competitive. Furthermore, the deployment of VPP, P2P energy trading, and carbon pricing are seen as the most prominent innovations and actions to upsurge the energy security and clean energy technologies in global energy transition. Adopting elements such as energy-efficient vehicles, ESS, and DR in a decentralized energy ecosystem could be the prudent path. In molding the future electricity sector, the availability and maturity of technologies and policies imposed in green energy should be appropriately monitored to avoid any delays in progress. The deployment of RE and low-carbon technologies can be an impetus to relook at the electricity industry with the aim of promoting energy security as a long-term efficiency.

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