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ORIGINAL ARTICLE

Strategic Market Growth and Policy Recommendations for Sustainable Solar Energy Deployment in South Korea

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Abstract

It is widely acknowledged that the solar energy markets have experienced increasing interest in the last decade in South Korea, due to a significant economic and ecological impact of solar energy in the coming years. Despite their great technical potential, the development and deployment of large-scale solar energy technologies in South Korea still need to overcome some technical, financial, regulatory, and institutional barriers in order to achieve a vision of the green and eco-sustainable energy. This article provides an updated comprehensive overview of the technical and economic strategies, as well as policies for the development and deployment of solar energy in South Korea. The article reviews and discusses: (1) solar energy resources and technologies, (2) economics and market status of solar energy, (3) policy support for solar energy development, and (4) obstacles to the development and implementation of solar energy technology. Policymakers are given recommendations in which the cost and impact of social, environmental, and geographical factors are considered. This review contributes towards the future of green and eco-sustainable solar energy in South Korea.

Keywords South Korea · Solar energy · Policies · Economics · Markets · Investment · Sustainability

1 Introduction

Access to sustainable, secure, clean and affordable energy sources is essential for prosperity and sustainable development of the solar industry at various levels [1]. For instance, it is a key factor for developing the economy, protecting the human health and environment, and boosting social stability. Energy security is defined as persistent availability of energy sources in both long and short terms and at affordable prices. It includes energy supply in a timely manner for addressing the economic and environmental demands. In addition, it involves the capacity to handle the sudden changes in supply and demand and to react accordingly. To guarantee energy security, several factors such as energy sources, capital and operational expenditures (CAPEX and OPEX), and environmental issues, should be considered [2, 3].

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1.1 Motivations of the Study

South Korea currently depends on a basket of power resources that includes fossil fuel, renewable and nuclear resources to address its increasing demands for power. According to official reports, South Korea relies on fossil fuels and other non-renewable resources to secure its energy demand by about 84% [4]. Imported oil and gas represent more than half of fossil fuel supplies in South Korea. Figure 1 illustrates the fossil fuel mixture in South Korea.

Renewable and nuclear energy resources represent only 6.5% and 5.9% of the total energy supply in South Korea. The country relies on oil imports for its power demand. The major share of imports to South Korea is power resources [5]. In order to reduce the OPEX, enhance the energy security, mitigate environmental challenges such as global warming and climate change, the government of South Korea increases its concern to include the renewable energy

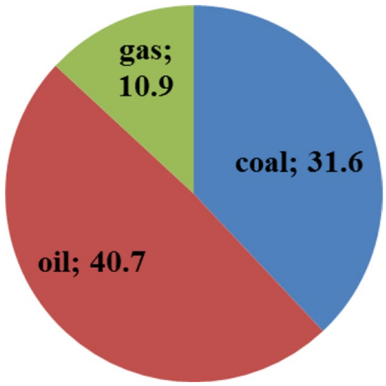

Fig. 1 Summary of fossil fuel mixture in South Korea

resources (solar, wind and hydro) and increase their share of the total energy basket [6, 7]. In addition, to achieve the country's target of reducing greenhouse gas (GHG) emissions by 30% in 2020, the government has developed short and long term energy strategies [8, 9] that depend on developing renewable energy and increasing its implementation in various economic and industrial sectors.

Renewables as well as nuclear energy are considered as sources for low-carbon power generation. However, there are limitations for using them as power generation resources. Nuclear energy can cause massive disaster while initial construction costs of the renewable energy are high. Also, the markets need considerable time to shift and adapt from fossil fuels to nuclear or renewable energy resources [10]. The Fukushima incident altered the public's perception of nuclear power and rang the bell toward its danger to human and environmental health. Consequently, this accident forced various countries, including South Korea, to vow to strengthen their renewable energy programs.

Renewable energy technologies play significant roles, substituting for existing power resource technologies. Presently, there are many efforts to assess it and determine its costs and benefits relative to existing technologies. The recently developed renewable power generation units are capable of providing minimal, yet advanced, capacity for existing energy systems, in addition to its area-flexible constructions such as floating solar power plant and offshore wind farm, when compared with existing fossil or nuclear power plants. Consequently, implementing various renewable energy projects is considered the best option to reduce dependence on the limited reserve of fossil fuels that will eventually be depleted. Renewables mitigate climate change and provide electricity in urban and remote areas [2]. Furthermore, they create new job opportunities and reduce the CAPEX to connect remote areas to the electric grid.

The South Korean government seeks to increase the percentage of renewable energy occupation from 6.5% in 2017 to 11% by 2030 as reported in the 4th Basic Plan for New and Renewable Energy [9, 11, 12]. The government will dedicate its efforts to increase attention to solar energy that will play significant roles to cover the energy demands and to satisfy the country's obligations toward the climate change international deals and GHG emissions reductions. This will involve the extensive and various applications of solar technology over different levels (industry, commercial and households). For instance, it will involve solar lighting, energy efficient lighting, cooking, solar water heating, and solar architecture for houses.

Solar energy is also used in medium-scale appliances, such as steam generation and water heating for tourist facilities, hotels and guesthouses. On the large and industrial level, solar energy may be utilized for heating inlet boiler water, transportation, telecommunications and generating power [13]. In the construction sector, it is expected to complete the work of the world's largest floating solar power plant by 2020. This power plant is planned to generate about 100 MW of electricity that can satisfy around 140,000 residents [14]. Moreover, these projects are the cornerstone for the government's long-term vision to increase the solar energy contribution in the country's power basket. It is expected to increase the solar power contribution in the total renewable energy mix from only 4.9% in 2014 to more than 14% by 2035 [6, 15].

1.2 Objectives of the Study

Several factors boost the rapid expansion of a solar energy market. They include: (1) increasing energy demands on short and long terms, (2) the contemporary climate change challenges caused by GHG emissions, (3) fossil fuel price volatility, and (4) decreases of manufacturing and installation costs of photovoltaic panels (PV) [16, 17].

Since 2010 the solar energy market has experienced a significant shift in responses to the impressive technological shifts that led to the phenomenal growth of its market. Moreover, the government has expanded its interest in research, development and commercialization of solar energy technologies. This is reflected by its expanding total project capacities. For instance, as a result of government efforts, the total deployed capacity of solar-wise electricity generation has doubled many times in the last decades, to reach more than 5700 MW by the end of 2017. However, despite the recent exponential growth of the solar energy market, its contribution to the total energy supply mix is still negligible and unfulfilled [6, 15]. This raises a question about the minimal solar energy contribution in the energy supply mix. What are the key barriers that hinder large-scale solar energy system deployments in the country? What are the required policies and instruments to boost the solar energy markets? What are the effects of the currently implemented policies?

Have they achieved the desired targets? If not, what new policies and tools are needed? This study helps answer these questions. The main topics that will be considered in this study are shown in Fig. 2. It covers the economic, institutional, and technological barriers for developing solar energy in South Korea.

1.3 Data Sources

Determining the solar and wind energy contribution to all energy resources is essential for conducting a comprehensive assessment of both sectors, exploring their development potential for increasing their contribution in the future. Equally important is knowing the long-term government plan for this sector and how it intends to increase the potion of renewable energy to the total energy production. Also, it is important to know the requirements for advancing these plans.

Information sources are diverse and numerous. Several data factors, like mining and evaluation tools are implemented to assure data accuracy, suitability, and adequacy. Only data from original and reliable sources, particularly government agencies and reputable journals, are considered and collected for this article. Examples include: the officially published reports by Korea Meteorological Administration (KMA) [18], Meteorological Sciences (NIMS) [19], Korean Statistical Information Service (KOSIS) [20], Korean Ministry of Trade, Industry and Energy (MOTIE) [21], and National Institute of Korea Energy Economics Institute (KEEI) [4] were reviewed and analyzed. Moreover, the 7th Basic Plan for Long-term Electricity Supply and Demand [22] and the 2nd South Korea Energy Master Plan [23] were analyzed and included. These plans provide detailed information on the installed renewable energy capacity and provide estimations for future solar power generation and electricity consumption for the next decade.

The remainder of this paper is organized as follows: Sect. 2 describes the solar energy resource and technologies; Sect. 3 discusses the economics and market status of solar energy in South Korea; Sect. 4 identifies the policies that support the development of solar energy; Sect. 5 describes barriers to the development and deployment of solar energy technology; Sect. 6 provides the recommendations for policymakers; and, Sect. 7 presents the conclusions.

2 Solar Energy Resource and Technologies

2.1 Geographic Location

South Korea is located between 33° and 39° N latitude and between 124° and 130° E longitude. In terms of geographical

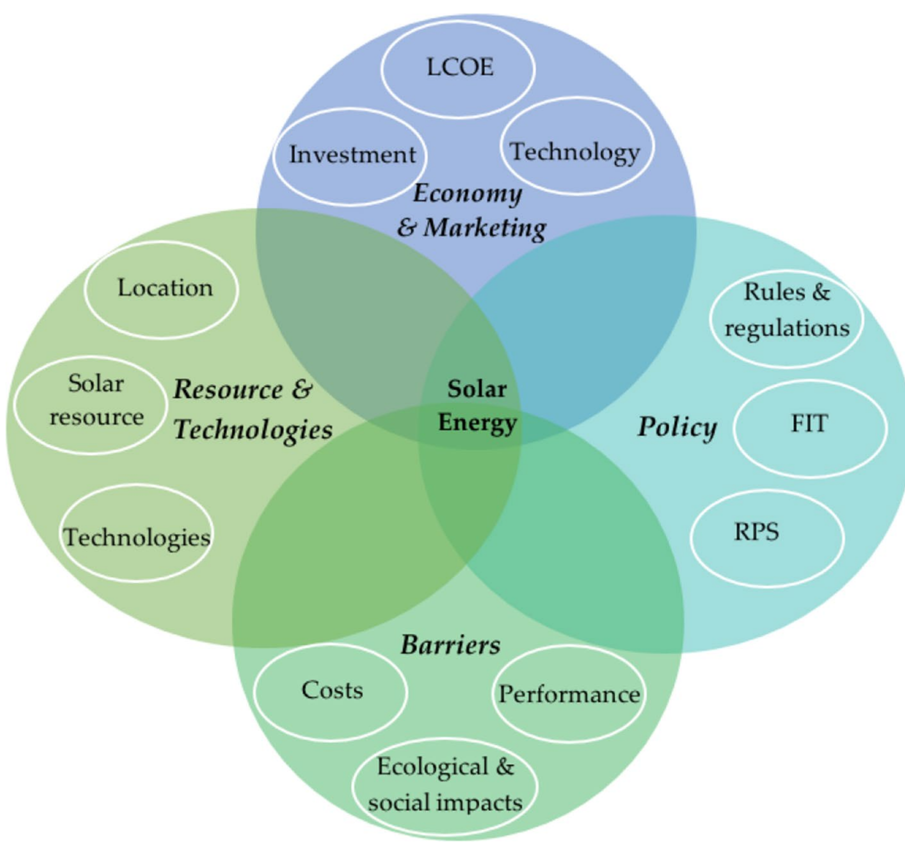

Fig. 2 Main topics considered in this study. *RPS* renewable portfolio standard, *FIT* feed-in tariff, *LCOE* levelized cost of electricity

features South Korea is divided into four general regions [24]: (1) eastern region of high mountains and narrow coastal plains; (2) western region of broad coastal plains, river basins, and rolling hills; (3) southwestern region of mountains and valleys; and (4) southeastern region dominated by the broad basin of the Nakdong River. South Korea is a mountainous peninsula that is flanked by the Yellow Sea from the west and East Sea/Sea of Japan in the east. The southern tip lies on the Korea Strait and East China Sea as shown in Fig. 3.

2.2 Solar Energy Resource

Implementing a solar energy plant has a significant impact on the project cost, as well as on social, environmental, and geographical factors. Furthermore, it affects the stability of a power system and the ease of its transmission [13]. The precise data about solar radiation over various regions is essential to solar energy projects.

Various models have been developed to estimate the solar radiation in South Korea. For instance, Park et al. developed a model for predicting solar radiation from sunshine hours in 2015 [25]. In order to overcome a complex terrain problem topographical factors were implemented in the solar energy modeling. Then using the Kriging method, a map for monthly solar radiation was developed for the country. However, the results showed that the topographical

Fig. 3 Geographic map of South Korea

and atmospheric features are primarily responsible for the spatial variation of the incidence solar radiation, while the latitudinal gradient is nearly irrelevant.

Nematollahi et al. [9] conducted an assessment of maximum, minimum, and average values of the annual horizontal radiation for the period of 2011–2015. This study included 24 stations. It considered the sunshine hours over various locations in South Korea based on the data readings from 78 stations for a period of 3 years. A summary of their work is shown in Fig. 4. It identifies the annual average global solar radiation for 24 provinces. Also, it shows that the central and southern regions of the country receive relatively high quantities of horizontal radiation. The Daejeon province has the highest average annual solar radiation, followed by Jinju and Andong. Seoul receives the lowest annual solar radiation with an annual average of about 140 W/m^2.

The cumulative solar energy in the central and southern regions is higher than that in the other regions (Fig. 5). Hence establishing floating solar power plants at the East China Sea represents a good opportunity. In addition, it saves space. Construction of floating solar power plants enables the government to save social costs, particularly those associated with conflicts of land requisition. Moreover, it enhances land usage plans to accommodate potential population growth in the neighboring locations by saving the land [24].

An assessment to run Seoul city (about 25% of total population of South Korea) by solar power was conducted by Byrne et al. [27]. The assessment was based on installing rooftop solar panels. It identified a potential to generate about 30% of the city's power demand using rooftop-based PV systems. Or it covers around 66% of the daytime demand in Seoul on a typical day.

An expanded framework for analyzing the possibility and requirements to construct a rooftop PV system to achieve net-zero energy solar buildings was performed by Koo et al. [28]. To validate the proposed outline, the study included 5418 elementary schools in 16 administrative divisions of South Korea.

Another study was performed by Park [29] to propose the optimal renewable power configuration using the hybrid optimization of multiple energy resources (HOMER) software. The evaluation addressed the financial feasibility of renewable energy generation systems in 17 South Korean cities. The results ranked each city in terms of renewable energy utilization potential. The study identified the most promising cities for utilizing renewable energy resources are Jeju and Incheon. Furthermore, economic feasibility maps for South Korean cities were shown and discussed along with the implications and limitations for each city. It concluded that South Korea's climatic conditions are generally conducive for extending the utilization of solar energy systems.

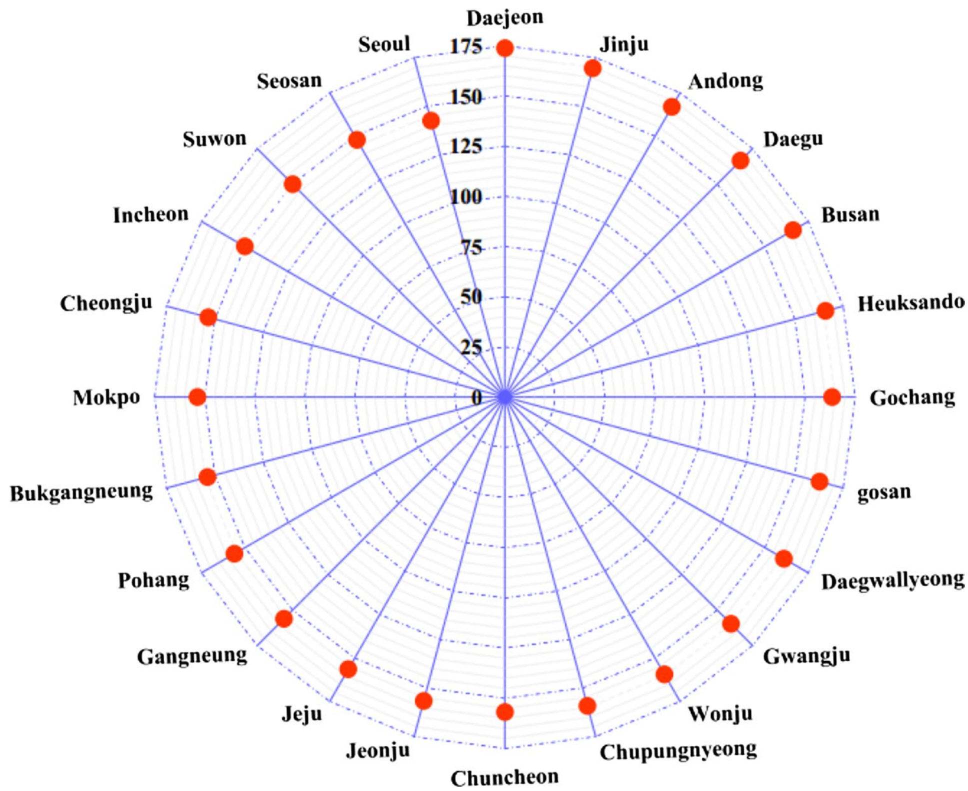

Fig. 4 Annual average global solar radiation (W/m^2)

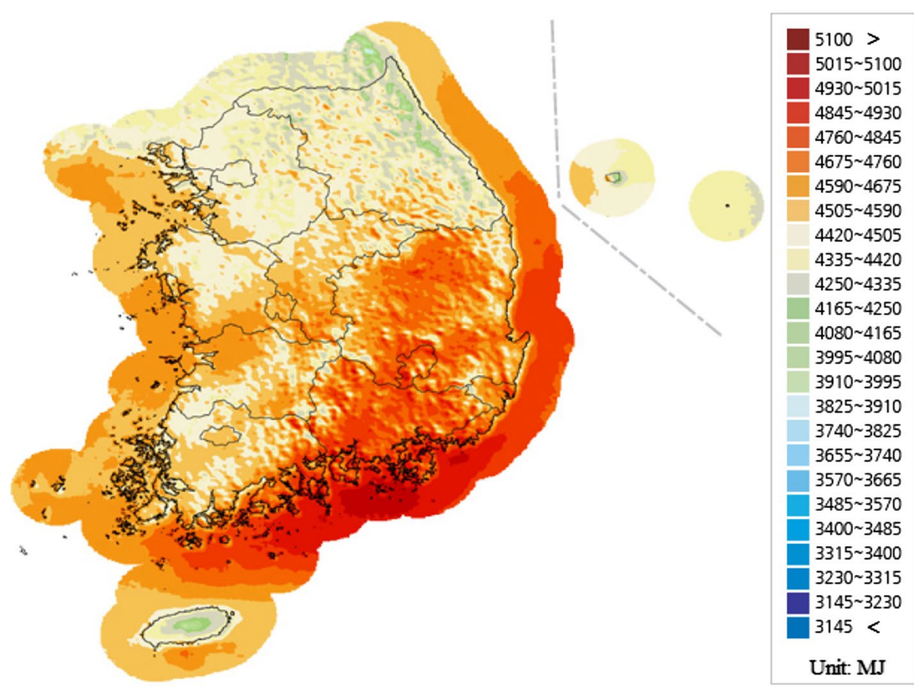

Fig. 5 Solar energy map of South Korea [26]

2.3 Solar Technologies

Solar energy technologies are generally classified as passive and active, depending on their use. Passive solar energy does not include any power conversion. It absorbs the light and/or heat from the sun and uses it directly. It just involves enhancing the use of daylight or heat through optimizing buildings' designs [17, 30]. Passive solar energy technology has a few applications that can be utilized in the presence of sunlight. By contrast, active solar energy technologies convert or store solar light and/or heat into other forms of energy. It can be broadly classified into two groups: (1) PV and (2) solar thermal. Currently, there are two types of PV technologies on the market. First one is crystalline silicon-based PV cells, and the second is School Cosmic Ray Outreach Detector (SCROD) which is thin film technologies that are made of a range of different semi-conductor materials, like amorphous silicon, cadmium–telluride and copper indium gallium dieseline. Thin film cells have lower efficiency than silicon-based cells but are more affordable and versatile than crystalline silicon-based counterparts.

Solar thermal technology implements solar heat that can be used directly for either heating application or power generation. Solar thermal technology can be divided into two categories: (1) solar thermal non-electric and (2) solar thermal electric. Non-electric applications include agricultural product dryer and solar water and air heater. Solar thermal electric applications, also known as concentrated solar power (CSP), refer to steam generation using solar heat in order to produce electricity [31]. Currently, there are four types of CSP technologies in the market: parabolic trough, fresnel mirror, power tower, and solar dish collector [32, 33]. However, according to [9], there has been a rapid increase of CSP globally. At the end of 2015 the operation of CSP capacity had been increased more than ten times, from 420 MW to nearly 4.8 GW [9].

3 Economics and Market Status of Solar Energy

3.1 Economics of Solar Energy

This section discusses the economic aspect of solar energy technology under various scenarios (i.e., residential, commercial, and large ground-mounted). It compares the economic feasibility of solar energy technology with other technologies that are used in electricity generation. The main challenges for such a comparison analysis are (1) variations in the costs across PV technology type, size, and time, (2) fossil fuel price volatility, and (3) the relatively high variations in solar technology capital cost.

The levelized cost of energy (LCOE) method is the method usually used to compare various power generating technologies. LCOE is calculated as follows [17, 34]:

$$\text{LCOE} = \frac{OC}{CF \times 8760} \times CRF + OMC + FC \text{ with } CRF = \frac{r \times (1+r)^T}{(1+r)^T - 1} \quad (1)$$

where OC denotes the overnight construction cost which usually has a value in the first years of the project, $O\&MC$ denotes operation and maintenance (O&M) costs or project running cost, FC denotes the fuel costs, CRF denotes the capital recovery factor, CF denotes the capacity factor, r denotes the discount rate, and T denotes project life span. A summary of LCOE and O&M is presented in Fig. 6. In addition, it shows the fuel costs independent of the report of International Energy Agency (IEA) for the baseload technologies of power generation at a 3% discounted rate [34]. However, nuclear energy is appealing because of its distinguished economic advantage over the other energy sources. Conversely, the construction and post-closing costs of nuclear power plants are extremely high, but they are affordable to operate. However, the exact economics of nuclear power plants are still ambiguous because their emission-related virtues do not show up in the costs [10, 35].

Based on reported estimations, the renewable energy technology on average is 20% more affordable than nuclear

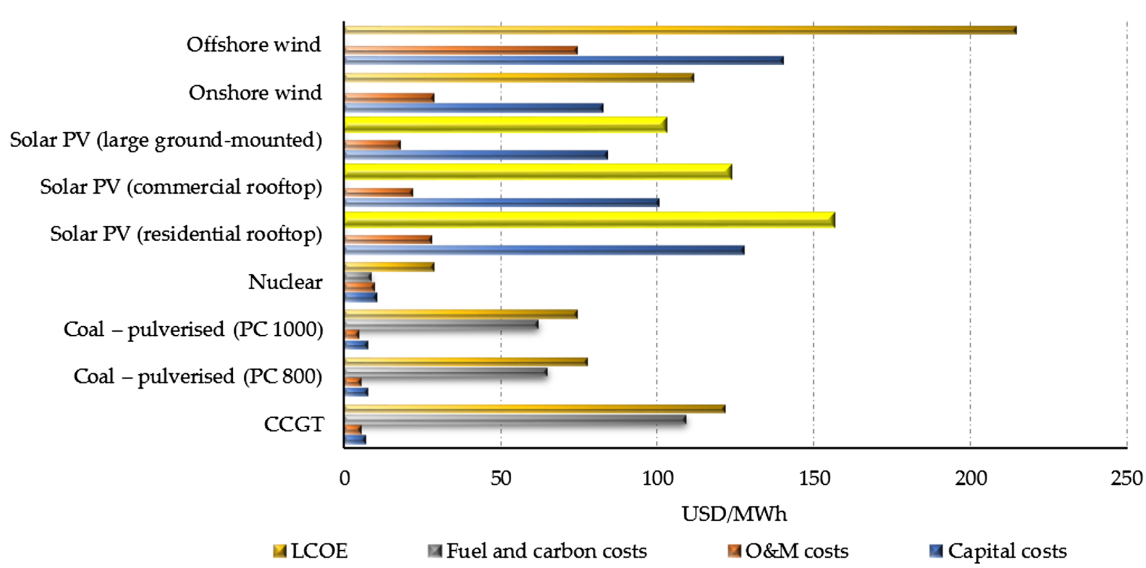

Fig. 6 LCOE, O&M, and fuel costs for the baseload technologies of electricity generation [34]

energy in terms of plant construction cost. However, renewable energy involves high fees because of its low efficiency, yet it is very capable of decreasing environmental pollution and allaying the safety fears related to nuclear power plants. Therefore, the economic assessment of renewable energy usually considers quantitative costs and perceived benefits and costs [10].

The LCOE for residential and large ground solar energy plant (ground-mounted) are US$155.5/MWh and US$101.8/MWh, respectively. By contrast, LCOE for conventional fossil fuel technologies such as coal-pc800 is US$77.6 per MWh and combined cycle gas turbine is US$121.8 per MWh.

Despite the sustained decrease in the costs of solar energy over the last few years, the cost estimation of solar energy technology using LCOE is still substantially higher compared with other conventional power generation technologies. This is due to large variations in capital costs. In the LCOE method, capital cost accounts for over 80% of solar energy technology cost while it represents less than 60% of traditional fossil fuel technologies (for example, coal and gas combined cycle). Fuel costs represent the major portion of overall operation cost in the fossil fuel power generating technologies. In contrast to the fossil fuel local impacts (for example, local air pollution) and global level impacts (for example, GHG emissions), solar energy technologies do not have these costs or impacts [35]. Performing comparisons among solar energy technologies and fossil fuel technologies and accounting for these externalities may be biased and therefore their results would be in doubt.

3.2 Market Status

Solar energy markets in South Korea have experienced significant increases in recent years due to impressive technological improvements that have led to a phenomenal growth of the solar energy market along with public–private partnership. For instance, the overall installed capacity of solar-based electricity generation has risen from only 81 MW in 2007 to more than 5.7 GW in 2017. The cumulative solar power capacity in the last decades is shown in Fig. 7.

Construction of the largest solar power generation plant in South Korea was recently completed in Haenam, South Jeolla Province. The installed system capacity is about 57 MW. Its generated electricity can supply over 20,000 families. Furthermore, by completing construction of the world's largest floating solar power plant by 2020, it will be capable of generating 100 MW which will be supplied to approximately 140,000 residents [14].

The government of South Korea has developed primary and detailed action plans to expand the renewable energy supply and gradually minimize the dependence on non-renewable resources such as coal and fossil fuel [4]. It plans to increase the contribution of renewable energy percentage in the total energy supply mix up to 11% by 2030, as well as promoting solar energy resources as the most important energy source by reducing the role of wasted energy. Hence, the wasted energy proportion of the new and renewable energy will be reduced to 29.2% (from 67.0% in 2014) and the solar energy proportion will be increased to 14.1% (from 4.9% in 2014) by 2035 [4]. In addition to the government strategy to shift the new and renewable energy markets from government-driven deployment to the open market, developing the public–private partnerships improves this market and increases its competitiveness and attractiveness to investors.

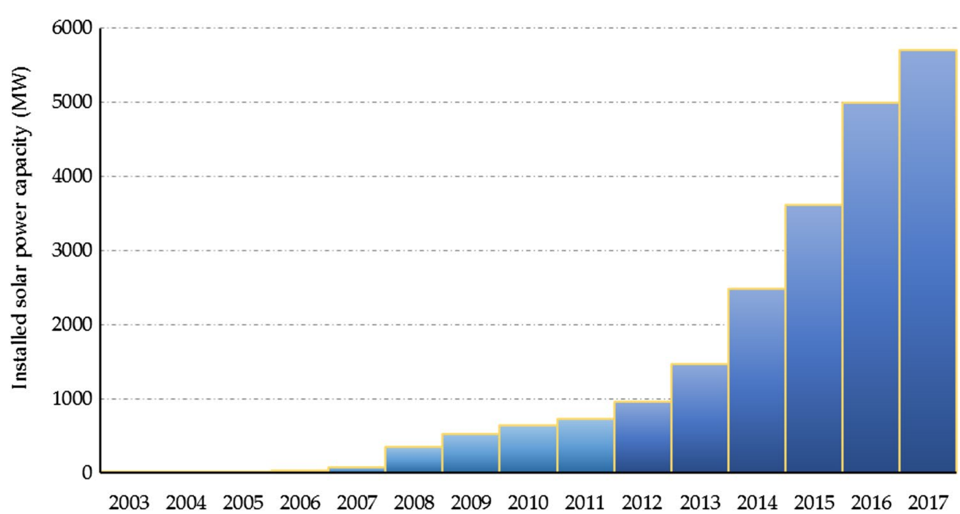

Fig. 7 Cumulative solar power capacity

4 Policy Support to Solar Energy Development

This section presents the key policies and criteria that should be considered in order to increase the contribution of solar energy to the total electricity production in South Korea. It also assesses the implications of these policies in terms of solar capacity growth, cost impact, and market risks of solar energy technology.

After 1 decade of feed-in tariffs (FITs) experience (2002–2011), South Korea replaced FIT, a price regulation tool, with the RPS scheme, a market quantity tool, in 2012 [36]. FIT methodology depends on fixing the electricity market prices for a certain period of time, which guarantees the price of renewable energy sources (electricity from renewable energy sources). Meanwhile, RPS obligates generators and/or electricity suppliers to acquire a specific percentage of electricity from renewable energy sources [37, 38].

Here we implement in-depth analysis for (1) the benefits opportunity, risk and losses of shifting the renewable energy policy, (2) the reasons behind this change, and (3) the impact on the growth of the solar energy market. The following analysis will address these factors.

4.1 FIT Policy (2002–2011)

The FIT scheme was first introduced in 2002. It was based on government guarantees to set fixed tariffs for small-scale power generation from solar, wind, hydropower, biomass, waste, and fuel cells over 15–20 years of project life span. However, the cumulative installed capacity of solar power has soared from 5.9 MW in 2003 to 730 MW in 2011 (see Fig. 7). The number of PV companies also increased from 12 in 2004 to 99 in 2011 [39].

The FIT subsidies for solar PV had numerous increases in comparison with other renewable energy sources, thereby prompting the government to introduce a capacity cap on FIT for solar PV. The upper limits for the new PV installations were 70 and 80 MW in 2010, and 2011, respectively. If no capacity limit had been set it was expected to have an extensive expansion of solar PV and high budget expenditures [37, 39]. The government's compensation for the difference between the base price of electricity set by MOITE and traded power prices for each type of renewable energy sources are presented in [40]. Overall, the main reason for replacing the FIT in 2012 was a rapid increase in subsidies for solar PV.

4.2 RPS Policy (2012–Present)

Due to rapid budget increments for FIT and the level of renewable energy-based power generation that fell short of expectations, the government of South Korea decided to shift its policy to an RPS scheme in 2012 [36]. RPS requests electricity suppliers to supply a minimally-required percentage (or amount) of their loads through renewable energy sources. RPS is implemented with 13 big electricity suppliers (total generation capacity is greater than 500 MW excluding renewable energy capacity). The government assigned a quota for each electricity supplier; the quota is fixed until 2022. It is calculated by multiplying the supplier total electricity generation capacity (excluding that from renewables) by the annually-required RPS percentage. This percentage was initially set at 2% in 2012 and is expected to reach 10% by 2022 as shown in Fig. 8 [37, 41].

The South Korean government issued a decree that obligates the electricity generator to produce a specific amount of electricity by solar PV sources during the first 5 years of the RPS implementation. Although government subsidies for solar technology were limited under RPS compared with FITs (Fig. 9), the total installed capacity of solar-based electricity generation capacity increased to over 5700 MW by the end of 2017 from a capacity of 959 MW in 2012 under South Korea's RPS (Fig. 7).

RPS strategy succeeded in saving the budget to support solar technology in South Korea while the overall RPS budget allocated to support all other renewable energy technologies was considerably above those under FIT [37]. Consequently, the number of PV companies has shrunk from 99 in 2011 to 83 in 2012. This maybe be due to the considerable risk potential that small and medium companies face

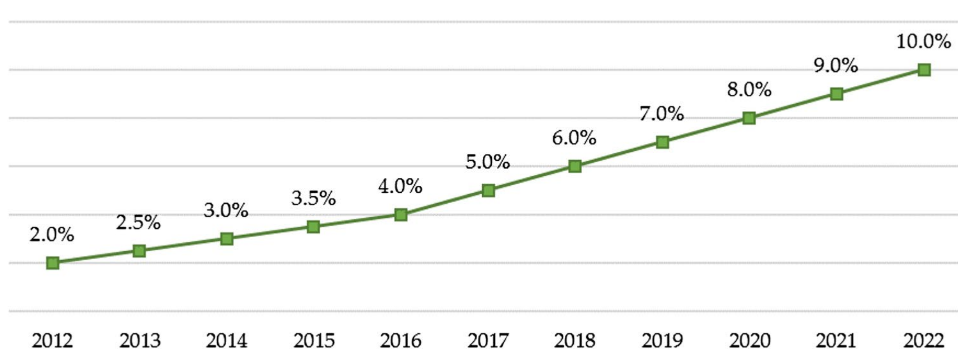

Fig. 8 Annual obligatory percentage under South Korea's RPS [36]

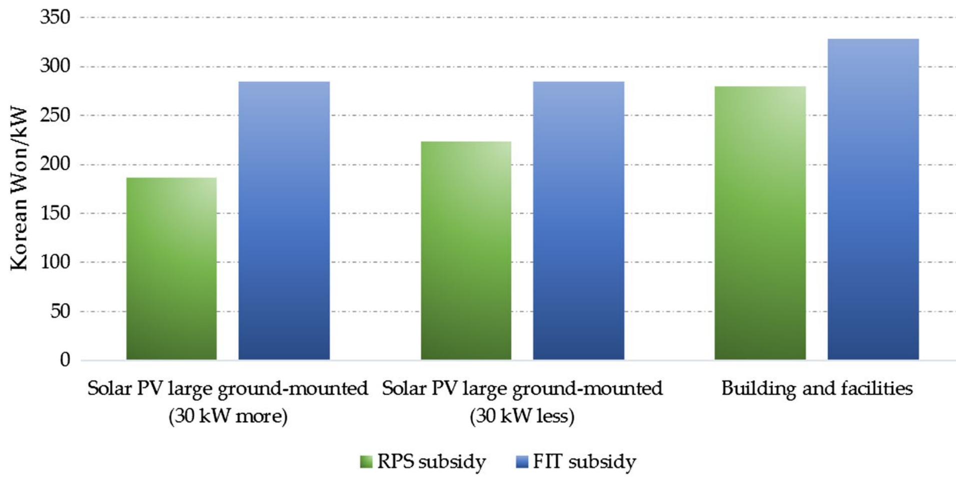

Fig. 9 Comparison of subsidies of RPS with FIT for solar PV [37]

under RPS [37, 39]. Hence, comprehensive policies are in high demand to alleviate market risks for small and medium power suppliers. Furthermore, reconsidering FIT implementation for small increments in capacity will probably play a key role in supporting and stabilizing the market.

5 Barriers to the Development and Deployment of Solar Energy Technology

Despite the huge potential and numerous benefits of solar energy, there are still challenges to the development and deployment of solar energy technologies that must be considered. This section discusses the technical, economic, and institutional barriers that constrain the large-scale deployment of solar energy technologies for electricity generation purposes.

5.1 Performance Limitations

The efficiency of PV panels varies depending on their type. It ranges from 4 to 12% and under 22% for thin film and crystalline panels, respectively [13, 17]. However, PV panel performance is sensitive to dust, tree debris, moss, sap, water spots, and snow, and thus may cause further reduction in the power generation efficiency. Using a dual-axis tracking system improves the efficiency by enhancing solar radiation collecting and enabling wind, rain, and gravity to sweep most of the debris and dust. It may likely increase the total amount of energy generation by approximately 20–30% [24, 42].

5.2 Source of Energy

The main limitation of implementing solar energy more widely is its intermittent and unpredictable nature. Moreover, solar energy is vulnerable to changes in weather such as sudden occurrence of cloudy or rainy weather [43]. However, comprehensive short- and long-term forecasting and planning and analysis significantly enhance optimizing and handling these limitations. Additionally, to ensure an uninterrupted power supply during the night or cloudy weather, a solar system should be interfaced with a storage system or other energy sources. In particular, batteries are one of the main elements and are considered the heart of any standalone solar system. During hours of sunshine, a PV system is directly fed to the load and the excess electrical energy is stored in the batteries for later implementation. At nighttime or during a period of low solar irradiance the stored energy in the battery is utilized by the implemented load.

5.3 Initial Construction Cost

Solar technology cost is decreasing annually due to recent technical achievements, but the relatively high cost of PV modules remains the main impediment to its wide adoption, particularly for residential consumption (i.e., private use). Moreover, the inverters required to transform the generated DC into AC power increase the overall cost of PV technology, thereby further resulting in the emergence of other barriers, such as high payback period.

Also, the desire of banks or financial institutions to recover their funds immediately raises the interest rate and impacts the investments in solar technologies. Hence, it is urgently required to develop a special financing infrastructure to motivate the PV industry and enhance the consumption of its products. Such infrastructure should be developed in cooperation among governmental organizations, non-governmental organizations (NGOs) and private sectors.

5.4 Ecological and Social Impacts

Disposal of PV panels and remaining solar system parts after completing their life cycle, usually requires 20–30 years. It is a major challenge for the plant operator and/or owner. This is due to safety, health, and environmental issues [44, 45]. The reported estimation of CO_2 emissions from PV using life cycle assessment is between 0.07 and 0.18 lb of CO_2 per kWh [13]. Consequently, disposing large quantities of PV modules in a single landfill may cause potential risks to human health, flora and fauna. The main concern is related to seeping the harmful chemicals into the surrounding environment and contaminating the soil and both surface and ground water. Since solar energy will play a main role in the power market in the future, now is the best time to assess and analyze the solar energy system impacts and establish plans for their waste management. Accordingly, it is desirable to avoid the tedious task of attending to tons of waste that may result from the delay of management of PV systems and their waste.

Manufacturing solar panels involves various toxic materials, particularly extracting the solar cells. For instance, Cadmium (Cd) is a toxic material used in the thin film of PV cells as a semiconductor that converts solar energy into electrical energy. It is reported that Cd dust and vapors may cause serious health problems such as cancer. There are other harmful solvents that are used to clean dust and dirt from PV modules. As our realization of the harmful effects of the chemicals used in manufacturing PV modules is enhanced, the use of Cd, Pb, Hg, and other hazardous compounds is prohibited by the European Union regulations of the Restriction of Hazardous Substances Directive [44]. This prohibition provides motivation to search for a new material for developing this industry.

Solar power plants require relatively large areas that should be reserved for a period of 20–30 years. This prevents any other usage for any other purpose. The utility-scale PV system commonly requires approximately 3.5–10 acres per megawatt [13]. This area requirement is high and is a serious concern. Several current issues are connected to this problem. One is the population explosion which has already resulted in the occupation of useful lands. Land alteration by tree and bush removal, slope treatment, and land preparation for optimizing the solar plant site may adversely affect wildlife. Addressing these problems, the South Korean government has established floating solar power plants since 2014. Establishing such power plants enables the government to avoid the social costs, particularly those relating to land requisition.

5.5 Technical Hindrances

Power plant projects need large areas, thus they are located far from developed and urban areas. This means that increasing distance between solar power plants and consumption points makes the budget and risk management of the transmission system substantially complex to the solar power industry. Hence, a systematic approach to maximize the utilization of current network assets should be established. Managing the link between the (high voltage) transmission network and (lower voltage) local networks should be prioritized in areas where solar power generation plants are small and dispersed over the low voltage grid (for example, rooftop solar panels). Proper planning and analysis would likewise facilitate development of optimal solutions. Intra-industry cooperation should be enhanced to expand the PV supply chain and to increase knowledge sharing through conferences, regular meetings and workshops.

To successfully implement PV systems, it is essential to build an adequate workforce. The availability of a trained workforce is necessary to achieve technological leadership in the PV industry. A focused, collaborative, and goal-oriented workforce is highly desired. Consequently, cooperation between the government and NGOs is required to develop a program to train those who intend to use the home solar system regarding its basic operation, maintenance, and management.

6 Recommendations

This section provides recommendations for policymakers, in which various environmental, social, economic and geographical factors are considered.

6.1 Optimal Sites of Solar Power Projects

It is important to conduct comprehensive assessments of social, environmental, and geographical aspects and cost analysis to properly select the best solar power project sites. Moreover, a complete understanding of available solar resources in the prospective area is essential since these factors significantly affect the stability of a power system and thus the ease of its transmission, project feasibility and sustainability. Southeastern coastal areas of South Korea and Jeju Island have high solar radiation rates, hence they are considered suitable places for establishing solar power projects. Using dual-axis tracking system for the PV array will increase the total amount of collected solar energy, and the energy production from the PV system will increase by approximately 20–30%. It also enables wind, rain, and gravity to sweep away most debris and dust. In addition, the presence of the East China Sea in the south and East Sea/Sea of Japan in the east enables the government to establish floating solar power plants in these locations. The establishment of floating solar power plants reduces social costs, particularly those relating to the land requisition, thereby reducing the potential conflicts due to land acquisition, and saving the land for residential purposes to accommodate population growth.

6.2 Policy Implications

Despite the subsidies for solar technology, the growth of solar PV has been substantial under the RPS policy compared with FIT. The RPS policy led to savings in its support for solar technology in South Korea. However, high variations in the solar energy market are a major concern, particularly for small suppliers despite the growth of PV capacity under the RPS policy. Consequently, the number of PV companies has decreased. Also, the project costs seem to be higher under the RPS policy in comparison with the previous costs under the FIT policy (apart from solar PV and fuel cells) because of the limited supply of new capacity. Thus, the demand for a comprehensive policy is necessary to alleviate the market risks especially for small power plant projects. An additional FIT for small increases in capacity might be a possible policy option. Strengthening the cooperation between the government and NGOs by devising an improved financing infrastructure is essential for boosting solar energy technology and its products.

6.3 Net Energy Metering

Domestically, the surplus energy of an installed solar power system in a residential house can be transferred into the public electrical grid. The customer is compensated for excess electricity that is exported to the grid by the utility company on a per kilowatt-hour (kWh) basis. Thus the net energy metering (NEM) policy may affect the rapid growth of the distributed solar industry in South Korea. A fair compensation to the customers of NEM is necessary for developing the solar energy market and supporting micro power generation (at household level). Currently, advancements in communications and smart grid technologies have provided the capability to present substantially refined calculations of distributed generation value. The NEM customer charges for energy imported and credits for energy exported are netted against each other. If the amount of electricity that a customer imports exceeds the amount exported from the solar system, then the difference is billed to the customer. If exports exceed imports during a billing cycle, then the NEM customer can carry over the balance into future billing cycles.

7 Conclusions

Various issues related to solar energy are addressed in this study. It includes an economic analysis for examining the competitiveness of solar energy compared with fossil energy counterparts. Principle findings show that despite a substantial decrease in capital cost and an increase in fossil fuel price, solar energy technology is still not as competitive as conventional technologies that depend on fossil fuel for electricity production. Several technical, economic, and institutional barriers currently constrain large-scale deployment of PV systems.

On the policy and regulation level, FIT, capital subsidies, RPS specified for solar energy, public investments, and other financial incentives are addressed. In these policies, government reports indicate that the share of solar energy in the energy supply mix will be improved up to 14.2% by 2035. However, the increasing energy cost poses a major impediment in replacing nuclear power and fossil fuels with renewable energy. Nevertheless, it is vital to consider externalities, such as climate change, air pollution, and GHG emissions, when comparing solar energy technology with fossil fuel technologies.

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