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Optimal Solution for a Renewable-Energy-Generation System at a Private Educational Institute in South Korea

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Abstract: Climate change has been turning into a climate crisis. Thus, we live in an era in which it is important to carry out the promise of 2050 carbon neutrality worldwide. South Korea is a country with a very large private education market. As the online education market has also recently expanded rapidly, interest in the electricity consumed by educational institutions is growing. One way to reduce the power consumption of private educational institutions, which is expected to gradually increase, is to replace the existing power system with a hybrid energy system based on renewable energy. This study aims to investigate an optimized renewable-energy-based hybrid system to supply adequate power to private educational institutions in Korea. We propose an optimal system using the HOMER (Hybrid Optimization Model for Electric Renewables) program. The result is that when private educational institutions adopt a hybrid renewable energy system, the renewable fraction is negligible in the grid-connected type, but it is analyzed that the NPC (Net Present Cost) will greatly increase because it exceeds 70% in the stand-alone type. The difference between on-grid and off-grid is significant, so it must be taken into account when devising renewable energy policies.

Keywords: private education institution; hybrid renewable energy system; energy mix; HOMER; photovoltaic; net present cost (NPC); cost of electricity (COE); South Korea

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1. Introduction

Energy consumption levels are now significant due to rapid population growth and industrialization [1–4]. High quality of life is typically dependent on energy consumption, and so energy demand is considered to be an important economic indicator [5,6]. Reserves of conventional resources such as coal, petroleum, and gas are seriously limited [7,8]. To protect the environment and reduce greenhouse gas emissions, the 21st session of the Conference of the Parties (COP) and the 11th session of the COP (a meeting on the Parties to the Kyoto Protocol) convened for 12 days from 30 November 2015 to 11 December 2015 in Paris, France [9–11]. An enhanced climate agreement relative to the 1997 Kyoto Protocol was signed. Parties to the Convention included 195 countries, with the addition of 37 major developed countries. The global average temperature increase brought about an agreement on a 1.5-degree decrease, which is much lower than that of the year prior to industrialization (2 degrees). At the Paris Climate Change Conference, South Korea declared a 37% reduction in greenhouse gas emissions by 2030 [12,13]. In accordance with this trend, the South Korean government set up and announced measures involving commitments to zero-energy building, smart factories, and prosumer (producer and consumer) systems in electric power markets that several developed countries have already implemented [14–16]. Furthermore, to reduce this problem, it is significant to adopt a renewable hybrid energy system which is featured by zero emission [17]. Electricity is one of the most indispensable components in order to strengthen the nation's economy and industry [18]. Electric energy has been generated and saved via renewable-energy generation, energy-storage systems (ESS), and electric vehicles (Evs) [19]. In addition, the Korean government has enhanced the country's energy sector, as new industries in this sector (e.g., renewable-energy generation) can promote existing industries in which growth has slowed. The Korean government's main strategy is to promote an "energy prosumer market". In new energy industry strategies of the "energy prosumer market", anyone can produce and sell generated electric power. This market system also involves a variety of projects (e.g., installing micro-grids into industrial parks, universities, and islands and constructing zero-energy buildings and eco-friendly towns).

High energy consumption, according to academic institutions such as university and research institutes, is a key concern in many countries [20,21], including in South Korea [22]. The enthusiasm for private education in South Korea is recognized worldwide [23,24]. Such institutions consume high levels of electric energy in the summer and winter for indoor cooling and heating, respectively. However, private education institutions have circumvented laws on energy savings via renewable-energy generation, and typically by installing photovoltaic panels onto building roofs. In accordance with "energy prosumer market" strategies, private education institutions constitute large business groups with far-reaching influence.

Hybrid-energy-generation systems are recognized as highly reliable, efficient, and stable electric power systems characterized by lower capacities for energy storage and lower costs of electricity (COE) because their several optimized sources are mutually complementary [25–29]. However, many experts have argued that if renewable energy is utilized more for electric power generation, it will not be able to provide highly reliable electricity [30]. Alternative and new technologies that can maintain stable power systems are also costly, as they are fully passed on to the public [31–33]. When the proportion of variable renewable energy increases in the power-generation sector, it is likely to make it difficult to maintain a balance between electric power supply and demand in real time. Therefore, before pursuing a supply expansion of variable renewable-energy generation, the stability of the original grid should be determined [34–36].

In many countries, including in South Korea, many studies have been conducted on the techno-economic feasibility and effects of connecting variable renewable energy resources [37–52]. These studies have focused on the following issues. First, while maintaining existing power system stability, how many variable renewable energy systems can South Korea adopt? Similarly, can South Korea achieve variable renewable energy goals that are self-constituted? Second, if South Korea cannot maintain power supply stability, how can technical and operational requirements be satisfied? Third, what is the main role of technological alternatives in stabilizing the power system? Are they economically feasible? Finally, how can variable renewable energy be integrated by adopting technical alternatives to the reliability of existing power systems? Experts have studied the above-listed research questions and have found significant results. However, experts still have doubts about the reliability and feasibility of hybrid energy-systems in the private sector, especially in the downtown area. This is because it is difficult to obtain electric power-consumption data, and research on the private sector is insufficient. In this work, we analyze which hybrid energy-system is the most feasible for a private educational institute's electric power supply. In order to achieve carbon neutrality in 2050, we should focus solely on the private sector, for which renewable-energy adoption has been quite delayed.

2. Materials and Methods

2.1. Review of Economic Feasibility Simulations on Renewable Energy

The technological and economic feasibility test on hybrid systems is necessary for the efficient generation and use of renewable energy resources. As we must consider all configurations to identify energy-mix solutions, techno-economic analyses are quite complex. Several simulation tools have been used to analyze, design, and optimize hybrid energy-generation systems that meet the electricity requirements of urban, rural, and remote areas in overcoming weaknesses of renewable energy sources. Among the software tools used, HOMER and RETScreen are used globally [53]. We used the HOMER program developed by the National Renewable Energy Laboratory (NREL) to design and analyze all hybrid systems that we recommend for satisfying electricity demands. Additionally, HOMER is the most effective tool for analyzing and designing systems which consist of different energy sources and loads [25]. Therefore, it is broadly used by researchers, academics, planners and so on [54].

2.2. Status of Sejong Academy (Load Profile)

Sejong Academy is located in Suwon of the Gyeong-gi province. The academic institute is located close to Seoul, the capital of South Korea. The academic institute's power system is fully powered by the electricity grid, which the Korea Electric Power Corp (KEPCO) operates and manages. Prior to the adoption of the PV centered hybrid energy-system in 2020, the head of the academy approved the use of the power data for economic analysis. According to a load profile that we obtained from the KEPCO, the institute's scaled annual average energy demand amounts to approximately 480 kWh/d, with peak energy demand levels of approximately 123 kW and a load factor of 0.162. Daily and time-step-to-time-step tow random variability values are estimated at 24.1% and 38.4%, respectively, as HOMER default values. In accordance with Figure 1a, Sejong Academy consumes considerable levels of electrical power during the winter vacation period for building heating. As shown in Figure 1b,c, considerable electricity levels are consumed while students study at the facility after school hours.

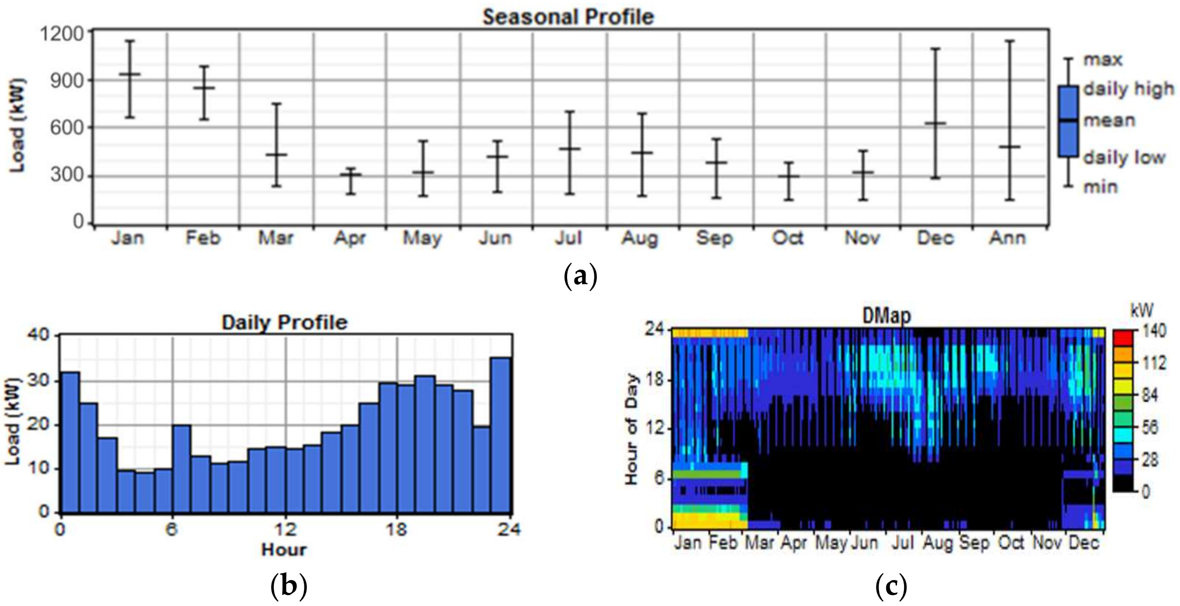

Figure 1. (**a**) Seasonal Load Profile; (**b**) Daily Load Profile; (**c**) Daily Load Map (time step: 1 h).

2.3. Weather Conditions in the Study Area

Solar resource, clearness index, and daily radiation records were gathered from the Korea Meteorological Administration (KMA) which provided a credible database in 201 [55]. The average daily radiation was measured at 3.983 kWh/m^2/d, the average clearness index was measured at 0.491, and the scaled annual average radiation level was measured at 3.98 kWh/m^2/d. The time zone used was Greenwich Mean Time (GMT) +09:00 for South Korea. The global horizontal radiation level is presented in Figure 2. Table 1 shows solar resources and temperatures that can affect electric power levels produced through photovoltaic panels. Korea is a country with four distinct seasons, showing an increasing trend in solar radiation from March to August. However, there is a rainy season mainly in July to August, so the level of radiation tends to be lower than in March to June, as shown in Figure 2.

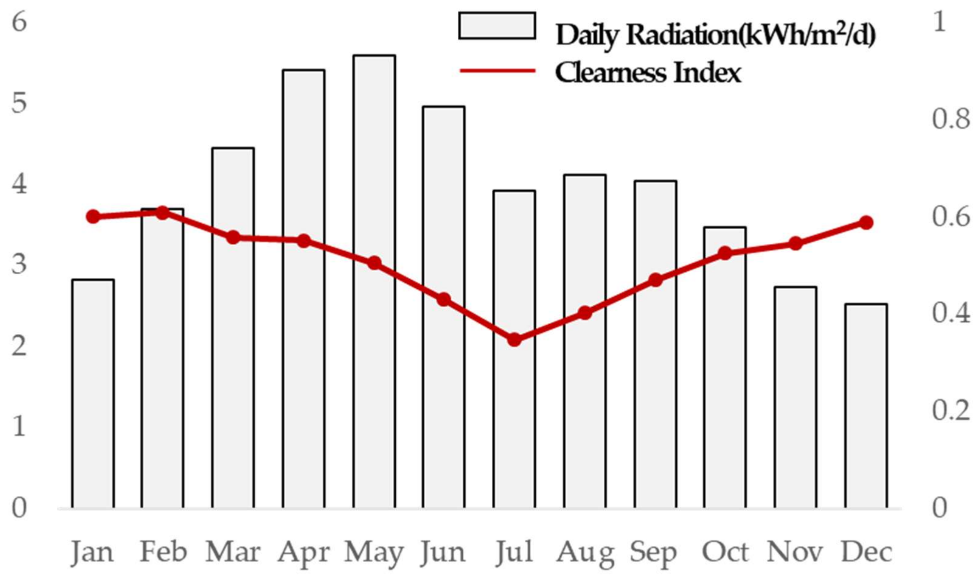

Figure 2. Global Horizontal Radiation (solar radiation and clearness index).

Table 1. Solar Resource and Temperature Inputs (2014).

Month	Clearness Index	Daily Radiation ($kWh/m^2/d$)	Temperature (Celsius)
January	0.601	2.83	−0.5
February	0.61	3.7	1.3
March	0.559	4.45	6
April	0.552	5.42	13.1
May	0.506	5.6	18.2
June	0.43	4.97	23.1
July	0.348	3.93	25.5
August	0.403	4.13	26.2
September	0.471	4.04	22.1
October	0.526	3.48	15.3
November	0.546	2.73	9.5
December	0.59	2.53	2.4

2.4. South Korea's Annual Real Interest Rate

The annual rate that we calculated in this study was considered to examine efficiency levels. In accordance with the official interest rate announced by the Bank of Korea (BOK), the annual real interest rate is 3.9%, which is the input used in this study for optimization [37,56,57].

2.5. Diesel Price

Diesel prices must be considered to accurately optimize hybrid energy-systems when simulations include diesel generators in configurations. The price per liter is assumed to be 1.8 based on the Korea National Oil Corporation' (KNOC) report [22,58]. This study assumed that diesel has a lower heating value of 43.2 MJ/kg, a density level of 820 kg/m^3, a carbon content level of 88%, and a 0.33% sulfur content level.

2.6. Renewable-Energy-Generation Systems: Specification

We examine several scenarios for the private educational institute based on various factors such as batteries, diesel generators, photovoltaic (PV) panels, converters, and grids to enhance the predictability and applicability of the HOMER simulation.

In accordance with previous studies that have designed hybrid power systems using PV panels as a component, we assume an initial installation cost of USD 1800, a replacement cost of USD 1800, and operating and maintenance (O&M) costs of USD 25 per year [22,59].

We use a 20-year lifetime period for PV panels with no tracking systems. In addition, we assume a derating factor of 80%, a slope of 37.23 degrees, and a ground-reflectance level of 20%. We also consider the effects of temperature (i.e., a temperature coefficient of power of −0.5%/°C; for each degree Celsius increases, the efficiency of the system decreases by 0.5%). Finally, the size of PV inputs (from 0 to 430 kW) was considered in the optimization.

While the simulation required the use of numerous diesel generators, it was difficult to determine criteria for sustainable energy generation. In previous studies, the diesel generator size, initial capital cost, replacement cost, and O&M cost have been estimated at 1000 kW, USD 1521, USD 1521, and USD 0.012 per hour, respectively (Park & Kwon, 2016; Rehman et al., 2012). A lifetime is considered to be 15,000 h of operation based on a minimum load ratio of 30%. In addition, we assumed that the fuel curve has an intercept coefficient of 0.08 L/hour/kW rated and a slope of 0.25 L/hour/kW output as given values [25,26].

Batteries are the most expensive modules of hybrid energy-systems. We used the Surrette-6CS25P battery model (S6CS25P; Rolls/Surrette) with 6 V, 1156 Ah (6.94 kWh), 9645 kWh, and batteries per string of 1 (6 V bus) to optimize the hybrid energy-generation system. In regard to battery specifications, capital, replacement and O&M costs are estimated at USD 1229, USD 1229, and USD 10 per year, respectively [47]. Regarding the scale of the energy storage system, 0 to 680 batteries are considered in the simulation.

3. Results

3.1. On-Grid Scenario: Generating System

Hybrid energy-systems that combine main grid and electric power sources based on renewable energy are some of the most stable hybrid systems that increase the reliability of private education institution energy consumption. Five devices (diesel generators, PV panels, the grid, converters, and batteries) and primary load 1, that has 480 kWh/d and 123 kW peak, were considered in the on-grid scenario, as shown in Figure 3.

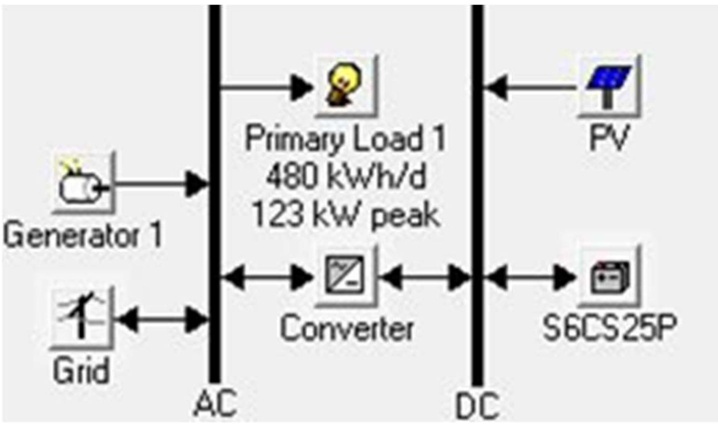

Figure 3. On-grid Scenario: generating system.

The optimization results show that 7374 solutions were simulated; 6600 were feasible and 774 were infeasible due to the capacity shortage constraint. In total, 9258 cases were omitted (8330 due to infeasibility, 784 due to the absence of a converter, and 144 due to the presence of an unnecessary converter). In the case of the on-grid hybrid system, as shown in Table 2, four optimized results are arranged in order of NPC. The first and second COEs are the same, and the third and fourth COEs are also the same, respectively. We used a calculation time of 2:14 and a processing speed of 55 simulations per second.

Table 2. Optimized On-grid hybrid energy systems as a measure of the lowest NPC.

	Grid	**PV**	**Label**	**Surrette 6CS25P**	**Converter**	**Total Capital Cost**	**Operating Cost**	**Total NPC**	**COE**	**Ren. Fraction**	**Diesel**	**Label Hours**
Rank	kW	kW	kW		kW	$	$/year	$	$/kWh	%	L/year	h/year
1	49	0	60	12	15	118,008	23,452	439,278	0.183	0	5948	411
2	49	3	60	12	15	123,408	23,121	440,149	0.183	2	5896	406
3	49	5	80	0	2	132,280	32,017	570,883	0.238	4	10,798	740
4	49	0	80	0	0	121,680	32,889	572,231	0.238	0	11,071	762

3.1.1. Grid Diesel Generator Battery Converter Hybrid Energy System (Rank 1)

This hybrid energy system was modeled using four components, excluding photovoltaic renewable energy sources. Because the rank was determined by economic feasibility, grid and diesel generators are more feasible than photovoltaic panels, which require considerable initial capital costs. This system shows a renewable fraction of 0% and the lowest NPC and COE values.

3.1.2. Grid Photovoltaic Diesel Generator Battery Converter Hybrid Energy-System (Rank 2)

This hybrid energy-system was designed using five components, including photovoltaic panels. Because the rank was determined by economic feasibility (by total NPC levels) though this hybrid energy-system has the same COE (USD 0.183) with a 3.1.1 system, this hybrid energy system is the second most economical among the grid cases. This system shows a renewable fraction of 2% and the lowest COE.

3.1.3. Grid Photovoltaic Diesel Generator Converter Hybrid Energy-System (Rank 3)

This hybrid energy system was designed using three components, excluding batteries. Because batteries are necessary for variable renewable energy generation with a stable electric power supply, this system is not sustainable for use in private education institutions and in the main grid. Though this hybrid energy system has the highest renewable fraction among the grid scenarios, its use of diesel is also significant due to the absence of ESS batteries. This system presents a renewable fraction of 4%, the highest level among the grid optimization results.

3.1.4. Grid Diesel Generator Hybrid Energy System (Rank 4)

This hybrid energy system was designed from a diesel generator. This system can serve as a comparative standard, as it presents the highest total capital costs, operating costs, and total NPC, and a renewable fraction of 0%, the lowest value among the grid optimization results.

3.2. Off-Grid Scenario: Generating System

Off-grid scenarios exclude the grid and use renewable energy-sources only (especially photovoltaic sources, as shown in this paper). Although Sejong Academy's power system is now connected to the grid, the off-grid power system was considered as a future solution related to energy trends (an energy-zero building). Four devices—diesel generators, PV panels, converters and batteries—were included in the off-grid scenario, as shown in Figure 4.

The optimization results show that 24,976 solutions were simulated, and 24,138 were feasible, while 838 were infeasible due to the capacity shortage constraint. In total, 18,584 cases were omitted (15,424 due to infeasibility, 2840 due to the absence of a converter, and 320 due to the presence of an unnecessary converter). In the case of the off-grid hybrid system, as shown in Table 3, five optimized results are arranged in order of total NPC. The table shows that the COE values gradually increased along with the NPC values as the rank decreased. This means that the economic feasibility of the off-grid system declined more significantly than that of the on-grid system. We used a calculation time of 4:00 and a processing speed of 104 simulations per second.

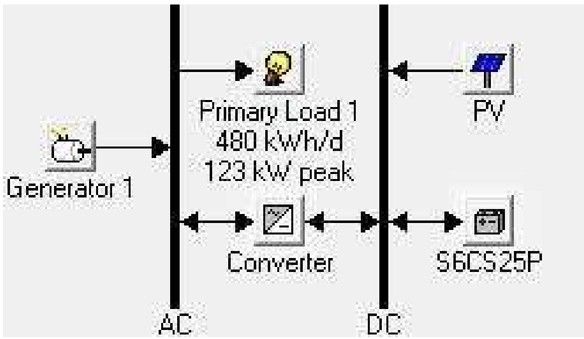

Figure 4. Off-grid Scenario: generating system.

Table 3. Optimized on-grid hybrid energy-systems as the measure of the lowest NPC.

	PV	Label	Surrette 6CS25P	Converter	Total Capital Cost	Operating Cost	Total NPC	COE	Ren. Fraction	Diesel	Label Hours
Rank	kW	kW		kW	$	$/year	$	$/kWh		L/year	h/year
1	170	80	200	55	717,480	65,524	1,615,112	0.673	76	25,164	1106
2	400	0	680	130	1,659,720	48,829	2,328,641	0.971	100	0	0
3	0	60	190	65	376,770	165,470	2,643,589	1.102	0	73,800	3750
4	300	130	0	60	785,730	284,647	4,685,188	1.952	64	113,999	5402
5	0	130	0	0	197,730	449,033	6,349,153	2.645	0	182,293	8760

3.2.1. Photovoltaic Diesel Generator Battery Converter Hybrid Energy-System (Rank 1)

This hybrid energy-system was modeled with four main components: photovoltaic panels, diesel generators, batteries, and inverter/converters. Because off-grid scenarios exclude the grid, diesel and photovoltaic generators should satisfy Sejong Academy's power requirements. The rank was determined based on the NPC using the HOMER simulation. This system shows a renewable fraction of 76% and the lowest NPC and COE values. However, the COE in this case is five times the value of the COE of case 3.1.1.

3.2.2. Photovoltaic Battery Converter Hybrid Energy-System (Rank 2)

This hybrid energy system was modeled using three components: photovoltaic panels, batteries, and converters. The analyzed NPC and COE of this system are even higher than those of system 3.2.1. Though the system shows the highest renewable fraction value of 100% among all of the cases examined in this study and the second lowest NPC value of the off-grid scenarios, this system presents too high an NPC value for the private education institution to adopt. Because almost of all institutions are located in inner-city areas, they are free to connect to the grid and do not need to replace current power systems with stand-alone hybrid systems. However, it is significant to note that the zero-energy building system is the second most economically feasible of the off grid scenarios.

3.2.3. Diesel Generator Battery Converter Hybrid Energy-System (Rank 3)

This power system was designed from three components excluding photovoltaic panels. When the grid was connected to the power system, the configuration was found to be the most economically feasible. However, after the grid was removed from the original model, the NPC and COE values increased. This system presents a renewable fraction of 0%.

3.2.4. Photovoltaic Diesel Generator Converter Hybrid Energy-System (Rank 4)

This hybrid energy-system was designed from three components excluding an ESS. Because batteries help the power system supply stable electricity to the load, batteries can reduce hybrid-system variability. However, because this system does not use an ESS, this system requires several more generators than system 3.2.3. The COE of this system is the most economically feasible by roughly three times.

3.2.5. Diesel Generator Only (Rank 5)

This power system was designed from diesel generators only. This system may be used as a comparative standard among off-grid scenarios, as the system presents the lowest initial installation cost while its operating cost, total NPC, and COE are the highest. In addition, its renewable fraction of 0% is also the lowest of the off-grid simulation results.

4. Discussion

South Korea's wind resources are not sufficient to generate a profit. However, they can be used to resolve technical and economic problems related to other forms of renewable-energy generation (e.g., unstable supplies of electricity due to efficiency decline, land purchases when adding new sites, increased expenses, and maintenance problems). Integrated energy-generation systems including small wind turbines are currently under development. Small wind systems can generate electric power 24 h a day. In addition, such systems can prove beneficial when an area that depends heavily on fossil-fuel energy requires considerable levels of power. Such systems can also supply electricity to cities and buildings (e.g., for street light replacement, disaster monitoring, meteorological systems, and communications).

Renewable energy sources (e.g., photovoltaic panel, wind turbine, solar thermal, small hydro sources) are affected by weather and climatic conditions. Accordingly, electricity generation from hybrid energy-systems remains intermittent. These renewable energy sources present relatively high levels of variability due to their fluctuating energy outputs. The renewable fraction (2035) in total energy consumption will be 13.7%. Additionally, that in total energy production will be 25.8% and 84.4 GW. So renewable energy consumption/production will be more valuable (fifth energy master plan, Korea) [60]. Hybrid systems generally use several technical devices to respond to output fluctuations. One such system is the energy storage system (ESS). However, initial costs of ESS are higher than those of back-up systems that use gas turbines or diesel generators.

5. Conclusions

The levels of renewable energy generated are not important, as the share of photovoltaic generation is growing in Japan, and the instability of the power systems is now considered a very serious issue. By reducing fluctuations in variable renewable energy ESS outputs, hybrid energy-systems can benefit main electric power systems. However, as developers cannot internalize these external benefits, there are no other incentives to invest in an ESS. To mitigate this gap between total costs and benefits, the government must decrease ESS costs. Rapid declines in renewable energy prices have been caused by economies of scale due to the expansion and dissemination of technological advances.

Since operators consider electricity consumption a business secret, it is very hard to access the datasets. Thus, previous studies on the economics of the hybrid energy system in Korea have focused on the public sector. This study is different in that it has been expanded into the private sector. Based on the results of this study, it will provide an opportunity to research hybrid energy-systems that are adapted to private areas such as department stores and amusement parks. The South Korean government should reinforce policies, including incentives to improve private facilities adoption. In addition, the government must strive to develop eco-friendly conditions that promote the use of renewable energy-systems. Reputable expert groups can promote and support institutions that lack expertise in the renewable-energy sector to make informed decisions based on accurate information. In turn, the South Korean government will not exclude private education institutions from renewable-energy policies.

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