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For a Green Stadium: Economic Feasibility of Sustainable Renewable Electricity Generation at the Jeju World Cup Venue

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Abstract: After the 2002 FIFA World Cup in South Korea and Japan, the local governments of South Korea were left in charge of several large-scale soccer stadiums. Although these governments have made significant efforts toward creating profits from the stadiums, it is proving to be too difficult for several administrations to cover their full operational, maintenance, and conservation costs. In order to overcome this problem, one of the governments, Seogwipo City, which owns Jeju World Cup Stadium (JWCS), is attempting to provide an independent renewable electricity generation system for the operation of the stadium. The current study therefore examines potential configurations of an independent renewable electricity generation system for JWCS, using HOMER software. The simulation results yield three optimal system configurations with a renewable fraction of 1.00 and relatively low values for the cost of energy ($0.405, $0.546, and $0.692 per kWh). Through the examination of these three possible optimal configurations, the implications and limitations of the current study are presented.

Keywords: HOMER; green building; green stadium; optimal solutions; Jeju World Cup Stadium

1. Introduction

After the 2002 FIFA World Cup held in South Korea and Japan, the South Korean government owned 10 new stadiums. These stadiums have been operated by the relevant local governments. These local governments have full responsibility for the operation, management, and maintenance of the stadiums. The current operating situations of the stadiums regarding profits differ widely, depending on their locations. More than half of the stadiums have recorded chronic payment deficits. Therefore, the local governments involved have used significant amounts of their budgets in maintaining these stadiums. Table 1 shows the current economic situations of the stadiums.

For example, Daegu World Cup Stadium recorded an accumulated deficit of about four million USD in 2014. In order to cope with this deficit, the local government of Daegu Metropolitan City invited private capital to invest in building the “Color Square Zone”, which was a cultural shopping center. However, the center failed to operate successfully, due to several problems including issues with allocating stores and attracting duty-free shops.

Although in 2006 the local government of Seogwipo City successfully invited one of the country’s professional soccer clubs, Jeju United FC, to base itself at Jeju World Cup Stadium (JWCS), this stadium still brings financial charges to its local government. From 2012 to 2014, JWCS recorded a deficit of about two million USD.

Table 1. Economic situations of 2002 World Cup stadiums in South Korea [1–3].

Location	Annual Earnings and Expenses (Estimated)
Seoul	+9.14 million USD in 2014
Busan	+2.13 million USD in 2013
Incheon	−1.60 million USD in 2014
Daegu	−4.07 million USD in 2014
Gwangju	+3.14 million USD in 2014
Daejeon	−1.26 million USD in 2014
Ulsan	−0.15 million USD in 2012
Suwon	+0.07 million USD in 2014
Jeonju	+0.14 million USD in 2014
Jeju	−0.41 million USD in 2014

Moreover, the conservation and maintenance costs of the stadiums can be expected to increase, because it has been 13 years since they were built. Therefore, the local governments have attempted to implement various remedies to minimize the deficits arising from these stadiums. For example, the local government of Seogwipo City plans to commission the management of JWCS to the SK Group, which owns Jeju United FC under the naming rights of the stadium. Hosting international soccer competitions, attracting soccer teams for their off-season training, and operating a public market have been suggested as short-term innovations. From a long-term perspective, operating communities for sports activities, installing sightseeing facilities, and creating sports-shopping centers are proposed.

Along with these suggestions, significant efforts to minimize the operational costs of JWCS are proposed. The local government of Seogwipo City plans to create renewable energy facilities for JWCS by utilizing the excellent renewable energy resources of Jeju Island.

This study therefore aims to explore an independent renewable electricity generation system for JWCS by analyzing its current electricity consumption. Using the hybrid optimization of multiple energy resources (HOMER) software, potential optimal configurations of renewable energy facilities for JWCS are proposed. The rest of this study is organized as follows. Section 2 presents the status of JWCS. Key economic parameters and detailed economic input data for the simulation are given in Sections 3 and 4, respectively. The optimal configurations of renewable electricity generation systems for JWCS are presented in Section 5. Some discussion points including the shortcomings of the current study are described in Section 6.

Cases of Hybrid Renewable Energy Systems for Particular Areas

There are several prior studies which have investigated the economic feasibility of hybrid renewable electricity systems for particular areas. Sen and Bhattacharyya [4] proposed hybrid renewable energy systems for Palari, one of the villages in India. The proposed systems which were mainly organized by PV arrays, wind turbines and battery units achieved a 90% renewable fraction with $0.420 per kWh of cost of energy (COE). Moreover, Harish Kumar [5] aimed to meet the energy demand of the Geelong area, one of the residential villages in Australia. Based on the results of the simulations generated by HOMER, the systems which mainly included PV arrays and battery units showed $0.283 of per kWh of COE with a 100% renewable fraction.

In South Korea, Park and Kwon [6] used scenario-oriented simulations for presenting optimal configurations of renewable electricity generation systems for one of the large educational institutes. Based on the simulation results of five on-grid and five off-grid scenarios, the proposed configurations achieved $0.509 per kWh of COE with a 100% renewable fraction.

In general, the optimal configurations of hybrid renewable energy systems for responding to the energy demand of isolated areas or multiple complexes in the Asia region showed

$0.181~$1.284 per kWh of COE when the renewable fraction of the configurations was greater than 90% [6]. Table 2 presents the representative results of previous studies conducted in Korea. As presented in Table 2, the majority of the previous studies have introduced hybrid renewable energy systems for isolated areas such as islands or multiple complexes.

Table 2. Summary of previous studies conducted in Korea (PV: PV arrays, WT: Wind turbines, BT: Battery units, DG: Diesel generator, HT: Hydro turbines, GC: Grid connection, COE: Cost of energy, RF: Renewable fraction, IS: Island, MC: Multiple complex).

Location	Type	PV	WT	BT	DG	HT	GC	COE	RF
Kyung-Hee University [6]	MC	√	√	√	√		√	0.509	1.00
Ulleung [7]	IS	√	√	√	√	√		0.334	0.97
Gadeokdo [8]	IS	√	√	√			√	0.326	1.00
Jeju National University [9]	IS & MC	√	√	√			√	0.356	1.00
Geoje [10]	IS	√	√	√			√	0.472	1.00
Deokjeok [11]	IS	√	√	√	√			0.302	1.00
Gasado [12]	IS	√	√	√	√			1.284	0.94
Hongdo [13]	IS		√	√	√		√	0.303	0.84
Chuja [14]	IS	√	√	√	√			0.284	0.52
Geomoon [14]	IS	√	√	√	√			0.241	0.39
Yeongsan [14]	IS		√	√	√			0.376	0.14
Seamangeum [15]	IS		√	√	√		√	0.458	0.63

2. Jeju World Cup Stadium

2.1. Location and Facilities

JWCS is located in the southern part of Seogwipo City, Republic of Korea. This means that this stadium is located in the most southern region of Korea [16]. The coordinates of JWCS are 33°14′ latitude and 126°30′ longitude (Figure 1). JWCS has a total area of 134,122 m^2, with 22,188 m^2 of buildings and a total floor area of 75,957 m^2 across two basement and four ground levels. Initially, 42,778 seats were installed in JWCS; after the FIFA World Cup in 2002, more than 7000 seats were moved to its secondary stadium, Gangchanghak Practice Stadium. Therefore, JWCS currently has 35,657 seats.

Figure 1. The location of JWCS.

The design of JWCS originated in the shape of the crater in Hallasan, one of the shield dormant volcanoes on Jeju Island. The design of JWCS's roof mainly depicts images of fishing nets and "Taewoo", which is the formation of traditional ships in Jeju (Figure 2).

Since the location of JWCS is close to the southern coast of South Korea and the stadium needs to be built to withstand strong winds from the sea, the roof of JWCS has a multiple suspension structure with cable trusses. With this structure, the roof can endure winds of greater than 65 m/s [17].

Moreover, in order to minimize wind effects, the playing pitch of JWCS is built about 14 m below ground level. The lighting capacity of JWCS is more than 2000 lux.

Given the top world-class structure of JWCS, Jeju United FC—one of the participants in the K-League Classic, which is the premier professional soccer league in South Korea—has used JWCS as its home ground since 2006 [18].

Figure 2. A view of JWCS.

2.2. Load Information

The energy system of JWCS is currently maintained and operated by the electricity grid that comprises the island's energy system. The total amount of electricity used by JWCS was calculated as 1.617 GWh in 2014. The average and peak energy demand amounts of the stadium are 157 kW and 321 kW, respectively. Therefore, the load factor of the stadium is 0.489. Figure 3 shows the seasonal profile of the electricity demand of the stadium.

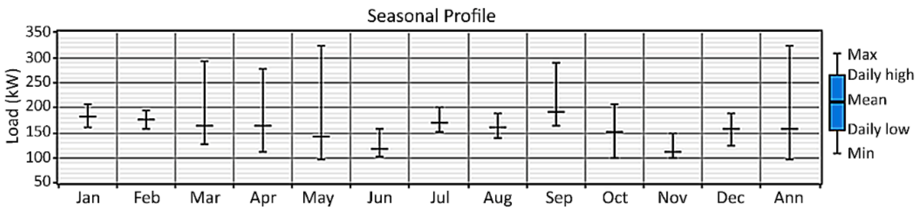

Figure 3. Seasonal profile of the electricity demand in JWCS.

2.3. Solar Energy Information

This study uses data from the National Aeronautics and Space Administration. The annual solar clearness index and average daily radiation are calculated as 0.503 and 4.165 kWh/m^2/day, respectively. The profile of the average monthly solar resource is presented in Figure 4.

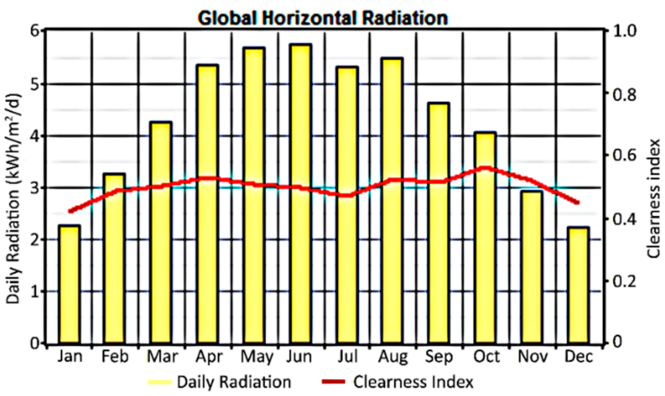

Figure 4. The monthly solar resources available at JWCS.

2.4. Wind Energy Information

The details of JWCS's wind speed data are provided by the National Aeronautics and Space Administration and the Korea Meteorological Administration (KMA). Since the operational height of the wind turbines currently in use is 25 m above the ground, the data used are the averages of the wind speeds at 50 m and ground level. The annual average wind speed is calculated as 6.701 m/s, while Figure 5 shows the monthly wind speed profile of JWCS.

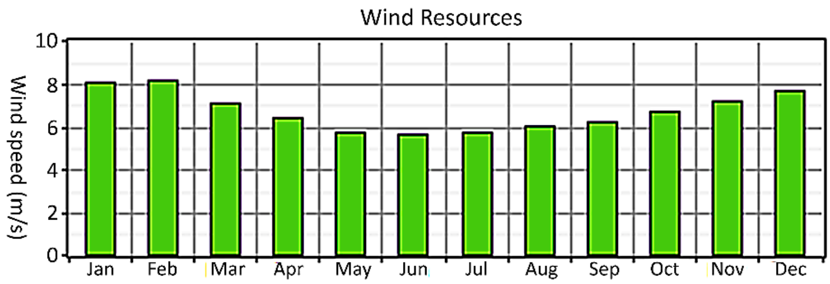

Figure 5. The monthly wind speed profile of JWCS.

3. Key Parameters for the Simulation

3.1. Annual Real Interest Rate

In order to calculate more accurate economic outputs, the real annual interest rate was computed using the mathematical methods introduced by Dursun [19]. The basic information for the parameters is provided by the Bank of Korea. From this, the annual real interest rate used for the simulation is 3.018%.

3.2. COE and NPC

The average cost of producing 1 kWh from a particular electricity generation system is defined as the COE. The COE is the first optimization criterion for the simulation. The net present cost (NPC) is the total cost incurred by the system, including the installation costs of its components and maintenance and management costs. If two optimal suggestions show the same COE levels, the NPC is used as the second optimization criterion for the simulation [7]. The estimated lifetime is 25 years, while all calculation steps of the simulation follow the guidelines of Dursun [19].

4. Renewable Electricity Generation Systems

The goal of this study is to identify the optimal renewable electricity generation system for JWCS by comparing renewable energy resources. For the analysis, photovoltaic (PV) arrays, wind turbines, a converter, and batteries are considered. In order to examine the economic feasibility of a given system, initial (installation and replacement) and O&M (operation and management) costs of each component must be entered into the HOMER software. The installation, replacement, and O&M costs of PV arrays per kW are $1800, $1800, and $25 per year, respectively. The current study assumes a PV array lifetime of 20 years with no tracking system. This study considers capacities of 0 kW to 15,000 kW in 5 kW steps [4,6,7,19].

A 10-kW-capacity generic turbine model is considered for the use of wind energy. The installation, replacement, and O&M costs for two wind turbines are $29,000, $25,000 and $400 per year, respectively. A 15-year lifetime and 25 m turbine heights are used in the simulation. This study considers the use of 0 to 2400 wind turbines in steps of two turbines in the simulation [4,6,7,19].

In suggesting an independent renewable electricity generation system, batteries are an essential component. The Surretts-6CS25P model battery, with a nominal voltage of 6 V, a nominal capacity of 1156 Ah, an 80% round-trip efficiency, a minimum charge state of 40%, and a lifetime throughput of

9645 kWh, is considered. The O&M, installation, and replacement costs of each battery are $10, $1229, and $1229 per year, respectively. This study considers 0 to 15,000 units in steps of 10 units. In order to provide connections between AC and DC components, a converter is used. The O&M, installation, and replacement costs per kW are $10 per year, $800, and $800, respectively. A converter has an estimated lifetime of 15 years, 90% inverter efficiency, 100% rectifier capacity relative to the inverter, and 85% rectifier efficiency. This study considers 0 to 3000 kW as converter capacity in steps of 5 kW.

5. Results

This study suggests three optimal simulated configurations: wind turbines–PV arrays–batteries-converter, wind turbines–batteries-converter, and PV arrays–batteries-converter. Figure 6 and Table 3 present the optimal configurations (OCs). Figure 7 shows the cost summary of the OCs. Table 4 shows the estimated annualized costs of each configuration. Table 5 presents the annual electricity-related parameters of the system, while Table 6 shows detailed information on each component in the system.

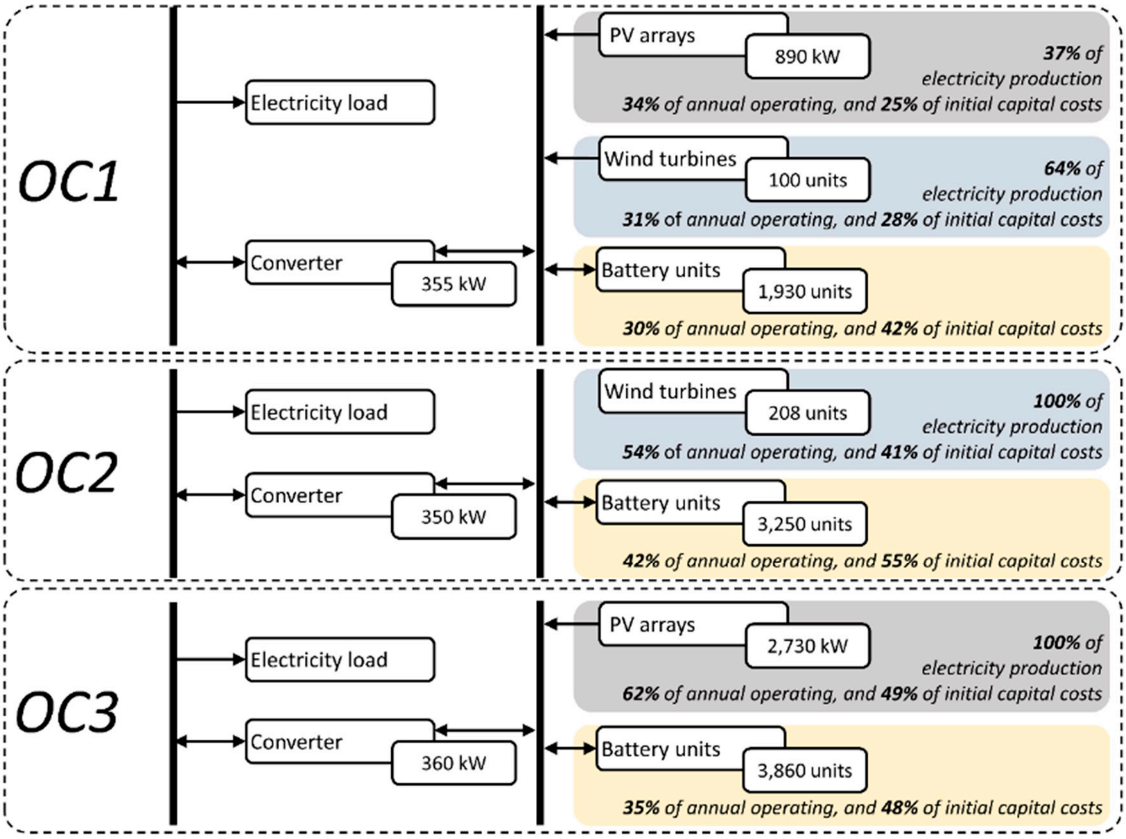

Figure 6. Summary of the optimal configurations for JWCS.

Table 3. Optimal configurations for JWCS.

Components	OC1	OC2	OC3
Wind turbines (#)	100	208	-
PV arrays (kW)	890	-	2730
Batteries (#)	1930	3250	3860
Operating cost ($/year)	228,516	330,728	379,422
Initial capital ($)	5,707,970	7,290,250	9,945,940
Total NPC ($)	9,687,156	13,049,261	16,552,863
COE ($/kWh)	0.405	0.546	0.692
Renewable fraction	1	1	1

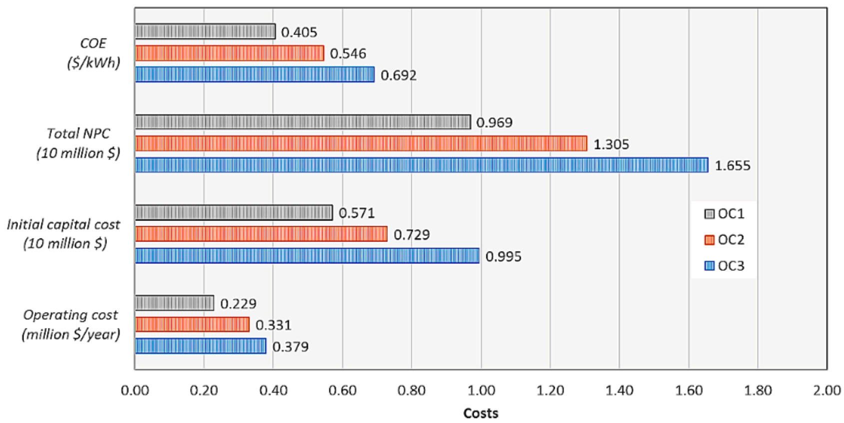

Figure 7. Cost summary of OCs for JWCS.

Table 4. Estimated annual costs of the optimal configurations.

Optimal Configurations	Components	Capital ($/Year)	Replacement ($/Year)	O&M ($/Year)	Salvage ($/Year)	Total ($/Year)
OC1	Wind turbines	83,270	46,076	20,000	−11,428	137,918
	PV arrays	91,999	50,938	22,250	−32,955	132,233
	Battery	136,217	162,550	19,300	−59,637	258,430
	Converter	16,310	10,468	3550	−2597	27,731
	System	327,797	270,032	65,100	−106,616	556,313
OC2	Wind turbines	173,202	95,838	41,600	−23,771	286,870
	PV arrays	-	-	-	-	-
	Battery	229,381	273,724	32,500	−100,424	435,181
	Converter	16,080	10,321	3500	−2560	27,341
	System	418,664	379,883	77,600	−126,755	749,391
OC3	Wind turbines	-	-	-	-	
	PV arrays	282,201	156,248	68,250	−101,085	405,613
	Battery	272,434	325,100	38,600	−119,273	516,861
	Converter	16,539	10,616	3600	−2633	28,122
	System	571,174	491,963	110,450	−222,992	950,596

Table 5. Annual electricity production, load and quantity of the system.

	Component/Load	OC1 (kWh/Year)	OC2 (kWh/Year)	OC3 (kWh/Year)
Production	PV array	1,179,356 (37%)	-	3,617,575 (100%)
	Wind turbines	2,007,862 (64%)	4,176,345 (100%)	-
Consumption	AC primary load	1,373,551 (100%)	1,373,551 (100%)	1,373,551 (100%)
Quantity	Excess electricity	1,531,579	2,505,224	1,886,374
	Unmet load	1046	1080	1200
	Capacity shortage	1365	1373	1336
	Renewable fraction	100%	100%	100%

As shown in Table 3 and Figure 7, OC1 displays the lowest degrees of COE and NPC. This means that using both wind and solar energy resources achieves greater economic feasibility than using a single renewable energy resource. Figure 8 presents the cash flow of OC1, based on the analysis of the NPC, while Figure 9 shows the monthly electricity production of renewable energy resources from OC1. As shown in Figure 10, the batteries in the system are used extensively, because the suggested system does not have a grid connection.

Table 6. Detailed information of each optimal configuration.

	Factors	OC1	OC2	OC3
PV arrays	Rated capacity (kW)	890	-	2730
	Mean output (kW)	135	-	413
	Mean output (kWh/day)	3231	-	9911
	Capacity factor (%)	15.1	-	15.1
	Total production	1,179,356	-	3,617,575
	Output (min.~max.; kW)	0~890	-	0~2734
	PV penetration (%)	85.8	-	263
	Hours of operation (h/year)	4364	-	4364
	Levelized cost ($/kWh)	0.112	-	0.112
Wind turbines	Total rated capacity (kW)	1000	2080	-
	Mean output (kW)	229	477	-
	Capacity factor (%)	22.9	22.9	-
	Total production (kWh/year)	2,007,862	4,176,345	-
	Output (min.~max.; kW)	0~998	0~2075	-
	Wind penetration (%)	146	304	-
	Hours of operation (h/year)	7325	7325	-
	Levelized cost ($/kWh)	0.0687	0.0687	-
Battery	Nominal capacity (kWh)	13,386	22,542	26,773
	Usable nominal capacity (kWh)	8032	13,525	16,064
	Autonomy (h)	51.2	86.2	102
	Lifetime throughput (kWh)	18,615,236	31,346,900	37,230,472
	Battery wear cost ($/kWh)	0.142	0.142	0.142
	Energy in (kWh/year)	648,429	725,490	1,051,122
	Energy out (kWh/year)	518,950	580,487	845,901
	Storage depletion (kWh/year)	226	105	5541
	Losses (kWh/year)	129,253	144,897	199,680
	Annual throughput (kWh/year)	580,202	649,002	945,751
Converter (Inverter)	Capacity (kW)	355	350	360
	Mean output	157	157	157
	Output (min.~max.; kW)	0~321	0~321	0~321
	Capacity factor (%)	44.2	44.8	43.6
	Hours of operation (h/year)	8759	8758	8755
	Energy in (kWh/year)	1,526,172	1,526,135	1,526,001
	Energy out (kWh/year)	1,373,551	1,373,517	1,373,397
	Losses (kWh/year)	152,621	152,618	152,604

In order to create a "green stadium", this study presents optimal configurations for JWCS in South Korea. To obtain the most economical and optimal configurations, the current study uses the HOMER software package to analyze renewable energy resources. The main results of the simulation are as follows:

First, the simulation results yield three optimal configurations: wind/PV/battery/converter (OC1), wind/battery/converter (OC2), and PV/battery/converter (OC3). Second, OC1, which comprises wind turbines, PV arrays, batteries, and a converter, obtains the lowest degrees of COE ($0.405 per kWh), total NPC ($9,687,156), initial capital ($5,707,970), and operating cost ($228,516 per year), compared with OC2 and OC3. Third, all optimal configurations achieve a renewable fraction of 100%. Fourth, although OC2 and OC3—which depend mainly on wind turbines and PV arrays, respectively—achieve generally acceptable COE levels ($0.546 per kWh and $0.692 per kWh, respectively), using multiple renewable sources is more beneficial in developing independent renewable electricity generation than focusing on just one of the available renewable energy resources.

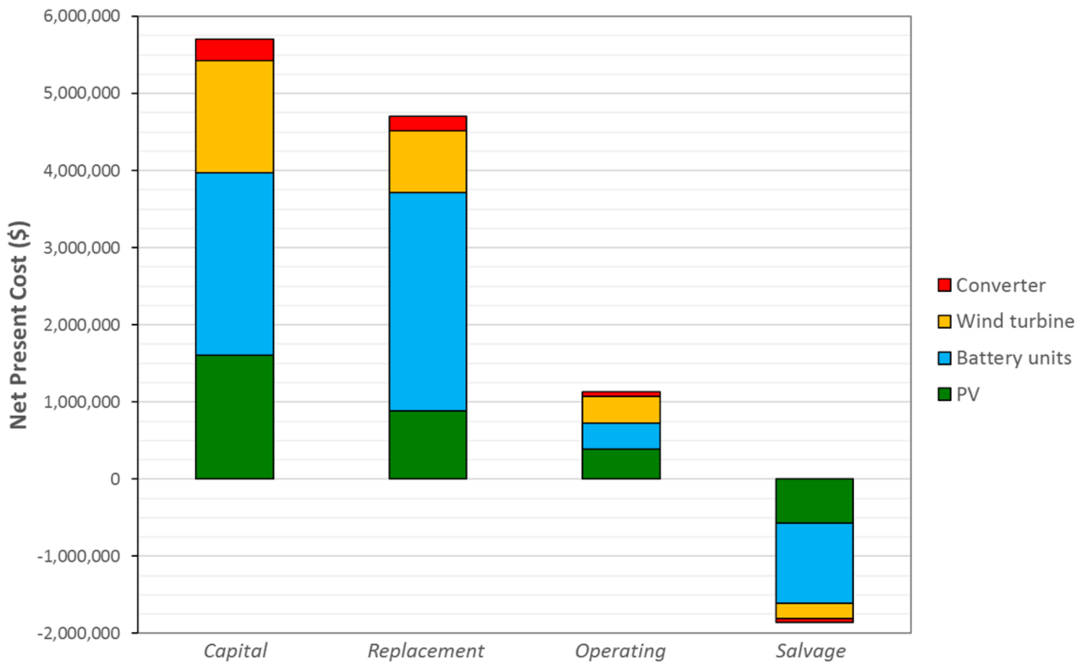

Figure 8. NPC-based cash flow results of optimal configuration 1.

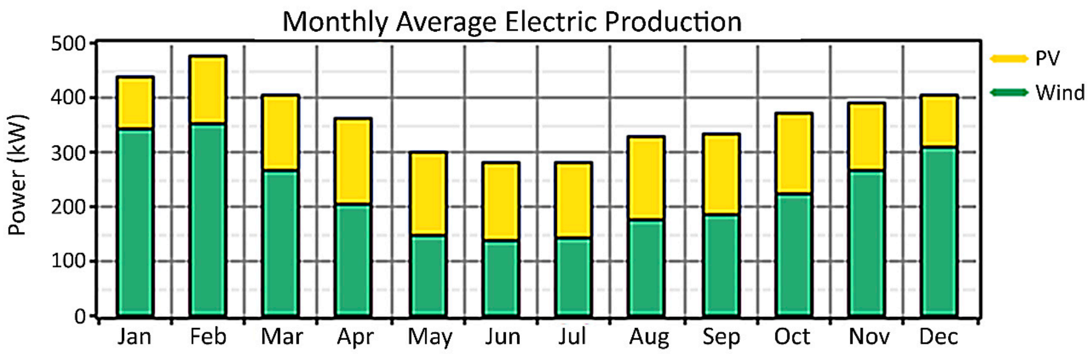

Figure 9. The monthly electricity production of optimal configuration 1.

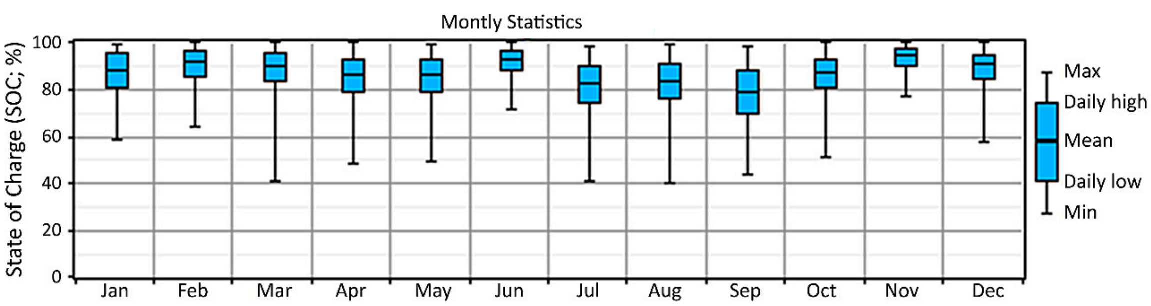

Figure 10. The state of charge of batteries in optimal configuration 1.

6. Discussion and Conclusions

Following the 2002 FIFA World Cup, a major event held partly in South Korea, several local governments that manage the stadiums built for the World Cup have grappled with the efficient utilization of these stadiums. Although all the stadiums have brought in professional soccer clubs, their revenues are inadequate to cover all the stadiums' operational and maintenance costs. Therefore, the local government of Seogwipo City is attempting to build renewable energy facilities for JWCS, including the creation of an independent electricity generation system for the stadium. The current study proposes a hybrid wind/PV/battery/converter system to respond to the electricity demand of JWCS. Using the HOMER software, potential configurations of optimal renewable electricity systems are proposed. Both COE and NPC are used as economic criteria for the configurations.

The three optimal configurations achieved a 100% renewable fraction with COE levels of $0.405, $0.546, and $0.692 per kWh, respectively. Considering the findings of prior simulation studies ($0.420 per kWh for the Palari site in India, $0.409 and $0.422 per kWh for the Binalood region in Iran) [4,20], the suggested systems for JWCS can achieve viable results. The simulation and results of the present study can contribute to a better understanding of the possibilities of renewable energy resources and future planning for JWCS. In addition, the results can form a baseline for turning the venue into a "Green Stadium". Moreover, the configuration which employed multiple energy resources is more economic than the configurations which selected one of the potential energy resources.

Even though there are major costs involved in installing renewable electricity generation facilities for JWCS, these facilities can contribute effectively in maintaining the stadium in the long term. Moreover, considering that this study did not consider a grid connection to facilitate selling of the electricity generated by the suggested system, the stadium could achieve an even better economic performance if such a grid connection were considered.

In addition, because the initial capital costs contribute to more than 58% of the NPC costs in all configurations with the battery units as the most expensive components, the gradual plans should be prepared. One of the possible plans is to preferentially install and operate PV panels and wind turbines before the installation and operation of the battery units. Moreover, the following points can be considered:

- The various supporting plans conducted by the governments can be applied.
- Because the current price of the midnight electricity is significantly low, using PV panels can take priority over installing and operating other suggested components.
- In order to minimize the capacity and costs of an electric converter, other wind turbine models which can be connected to the AC load can be considered.

Several notable limitations remain to be investigated by future studies. First, this study does not consider any supporting policies or plans being developed in South Korea. Such policies can have significant effects on the implementation of renewable power generation systems [21–23]. Second, although the results of the simulation are optimized using mathematical methods, other optimal solutions using different criteria may achieve a better economic performance for JWCS [6]. Third, this study does not consider any natural disasters; because JWCS is close to the sea [9], there may be unexpected consequences from natural disasters. These shortcomings can be addressed in future studies, using the results of the current study as a baseline.

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