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Potentiality of renewable resources: Economic feasibility perspectives in South Korea

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ABSTRACT

Since dependency on fossil fuels and nuclear energy has become a main global concern, the South Korean government has made significant efforts for the diffusion and vitalization of renewable energy generation facilities. One of the notable efforts for renewable energy is the government's and research institutes' provision of natural resource maps. Although these maps are useful for the diffusion of renewable energy generation systems, the economic feasibility of these systems can be affected by various factors (e.g., cost of the components in the systems or the characteristics of national electricity demand). Therefore, the current study investigates the economic feasibility of renewable energy generation systems in 17 selected cities in South Korea using information on the currently considered components and the hybrid optimization of multiple energy resources (HOMER) software. Based on the simulation results, the optimal configurations for the cities are introduced, the potentiality of utilizing renewable energy resources in the cities evaluated, and the renewable energy resources ranked for each city. Among the suggested cities, Jeju and Incheon are nominated as two promising locations for utilizing renewable energy resources. Moreover, this study presents the general economic feasibility maps for South Korean cities, as well as discusses both implications and limitations.

1. Introduction

Since social concerns about using fossil fuels and nuclear energy have arisen based on environmental issues and accidents (e.g., the Fukushima accident) [1,2], several nations have examined their national energy systems from security and economic viewpoints [3,4]. Accordingly, they have attempted to change their mainstream national energy system electricity production from fossil fuels or nuclear energy to renewable energy [5,6].

Although the attempt to change the current energy system is not easy and is accompanied by significant investments in the energy industry, the South Korean government has supported the vitalization of the renewable energy industry and the distribution of renewable energy generation systems in order to minimize dependency on nuclear energy and fossil fuels in its national grid system [7,8]. One of the efforts for vitalization and distribution has been to consistently revise and review "*The Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy*" [9].

Based on this act, the South Korean government aims to reduce the amount of national greenhouse gas emissions by 2020 to 70% of the amount in 2013 through the vitalization of the greenhouse gas emission trading market [10]. Moreover, national institutes in South Korea have provided natural resource maps for solar, wind, and thermal energy resources in the South Korean territory [11].

Although there is a notable positive relationship between the potentiality of renewable energy resources and the economic feasibility of energy generation systems using the resources [12], other information sets, such as the characteristics of national electricity demand (e.g., the patterns of electricity load demand), the cost information of electricity generation facilities (e.g., the installation cost), or the selection of the suggested facilities, can affect the economic feasibility of renewable energy generation systems.

Several studies have investigated the potentiality of renewable energy resources and the feasibility of renewable energy generation systems. Table 1 presents the key findings and results of prior studies conducted in South Korea. Although the prior studies presented some notable findings, the majority of these studies conducted in South Korea employed different electricity demand data sets, which were individually collected. Therefore, the objective of the current study is to present the regional feasibility of renewable energy generation systems with same electricity demand data. It explores the economic feasibility of using renewable electricity generation systems in 17 selected cities in South Korea to respond to the demand pattern of the national electricity load. Moreover, it considers the currently used cost information sets of potential components and renewable energy resources of selected locations in South Korea. The hybrid optimization of multiple

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Table 1
Key findings of prior studies conducted in South Korea.

No.	Region	Location type	Suggested configuration	Renewable fraction (greater than 50%)	Cost of energy ($ per kWh)
1	Ulleung [13]	Island	H, P, W, D, B	97%	0.334
2	Busan [14]	Metropolitan city	P, W, B	100%	0.399
3	Suwon [15]	Education complex	P, W, D, B	99%	0.509
4	Geoje [16]	Island	P, W, B	100%	0.472
5	Gadeok [17]	Island	P, W, B	100%	0.326
6	Jeju [18]	Education complex & island	P, W, B	100%	0.356
7	Jeju [19]	Sports complex & island	P, W, B	100%	0.405
8	Jeju [20]	Government building & island	P, W, B	100%	0.306
9	Daejeon [21]	Charging station	H, P, B	79%	0.180
			H, P, W, B	82%	0.425
			H, P, W, B	100%	0.461
10	Hong-do [22]	Island	W, D, B	84%	0.303

Note: H-hydro turbine, P-PV array, W-wind turbine, D-diesel generator, B-battery unit.

Table 2
Latitude and longitude of the cities in this study (M: metropolitan city, L: local city).

City	Latitude	Longitude
Seoul (M)	37° 33′	126° 56′
Chuncheon (L)	37° 54′	127° 44′
Incheon (M)	37° 28′	126° 37′
Suwon (L)	37° 16′	126° 59′
Hongseong (L)	36° 39′	126° 40′
Cheongju (L)	36° 38′	127° 26′
Daejeon (M)	36° 22′	127° 22′
Andong (L)	36° 20′	128° 25′
Daegu (M)	35° 52′	128° 35′
Busan (M)	35° 10′	129° 04′
Jeonju (L)	35° 49′	127° 09′
Ulsan (M)	35° 33′	129° 19′
Changwon (L)	35° 10′	128° 34′
Gwangju (M)	35° 10′	126° 53′
Jinju (L)	35° 09′	128° 02′
Muan (L)	34° 49′	126° 26′
Jeju (L)	33° 29′	126° 29′

Table 3
Solar resource information for the cities.

City	Solar clearness index (%; standard deviation)	Solar daily radiation (kWh/m^2/d; standard deviation)
Jinju	54.0 (2.45)	4.488 (1.294)
Muan	53.8 (2.44)	4.487 (1.388)
Daegu	53.6 (2.36)	4.419 (1.326)
Changwon	53.1 (2.32)	4.411 (1.273)
Jeonju	53.1 (2.61)	4.379 (1.342)
Ulsan	52.7 (2.17)	4.356 (1.292)
Busan	52.5 (2.29)	4.355 (1.250)
Daejeon	52.1 (2.62)	4.265 (1.331)
Andong	51.8 (2.75)	4.247 (1.248)
Hongseong	51.7 (2.81)	4.221 (1.435)
Gwangju	51.0 (2.72)	4.234 (1.339)
Cheongju	51.3 (2.69)	4.187 (1.386)
Jeju	49.6 (3.33)	4.190 (1.257)
Suwon	50.1 (2.54)	4.062 (1.371)
Seoul	49.6 (2.93)	4.011 (1.326)
Chuncheon	49.3 (2.42)	3.967 (1.327)
Incheon	48.8 (2.56)	3.949 (1.310)

energy resources (HOMER) software is employed to evaluate the suggested configurations of renewable electricity generation systems.

The remainder of the paper is organized as follows. Section 2 presents the locational and environmental information for selected cities. Section 3 reviews the simulation background. Sections 4 and 5 describe the simulation results and several important points. Lastly, Section 6 discusses and concludes.

Table 4
Wind resource information for the cities.

City	Wind speed (m/s; standard deviation)
Busan	5.325 (0.463)
Jeju	4.964 (0.718)
Ulsan	4.788 (0.481)
Daegu	4.436 (0.376)
Incheon	4.320 (0.485)
Muan	4.109 (0.397)
Seoul	4.109 (0.318)
Changwon	4.048 (0.373)
Gwangju	4.001 (0.280)
Suwon	3.784 (0.298)
Andong	3.736 (0.397)
Jinju	3.674 (0.310)
Jeonju	3.574 (0.278)
Hongseong	3.488 (0.328)
Daejeon	3.108 (0.309)
Cheongju	2.971 (0.304)
Chuncheon	2.873 (0.252)

Table 5
Suggested capacities of the components for the cities.

City	PV arrays (kW)	Wind turbines (#; WES 5 Tulipo)	Battery units (#; S6S25P)	Converter (kW)
Andong	130	50	340	55
Busan	150	45	340	55
Changwon	160	45	330	45
Cheongju	170	60	360	60
Chuncheon	145	60	360	70
Daegu	175	55	360	55
Daejeon	150	50	330	45
Gwangju	135	55	350	60
Hongseong	135	60	360	60
Incheon	125	45	290	45
Jeju	120	45	260	50
Jeonju	145	55	350	60
Jinju	140	50	340	50
Muan	120	50	340	55
Seoul	130	60	350	65
Suwon	130	60	360	70
Ulsan	155	45	330	45

2. Cities and environment background

2.1. Location

Eight metropolitan cities and nine local cities (the capital cities of the provinces) in South Korea are selected to test the economic possibility of utilizing renewable resources. Table 2 shows the selected cities in South Korea and their latitudes and longitudes (from local

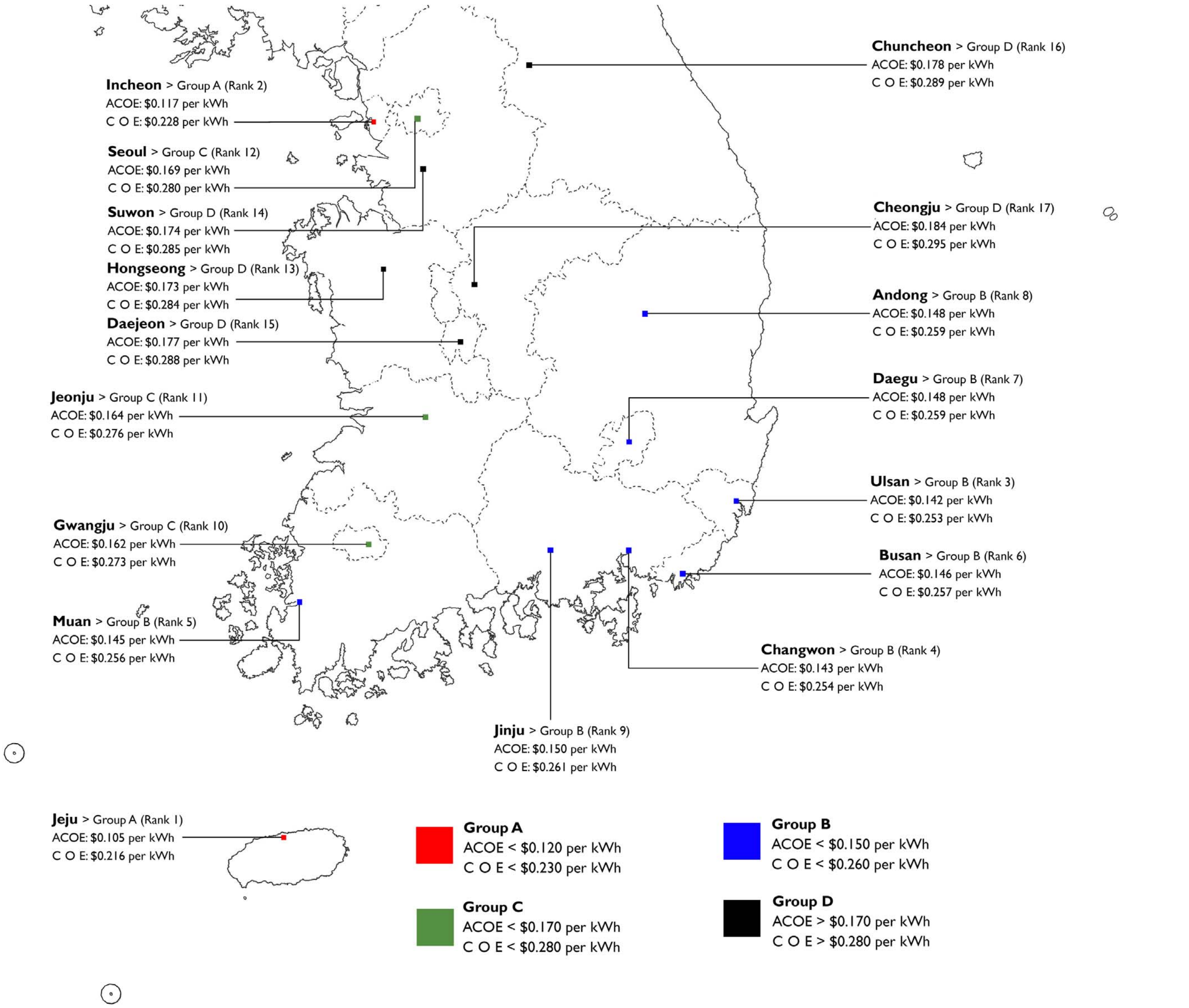

Fig. 1. Summary of the simulation results.

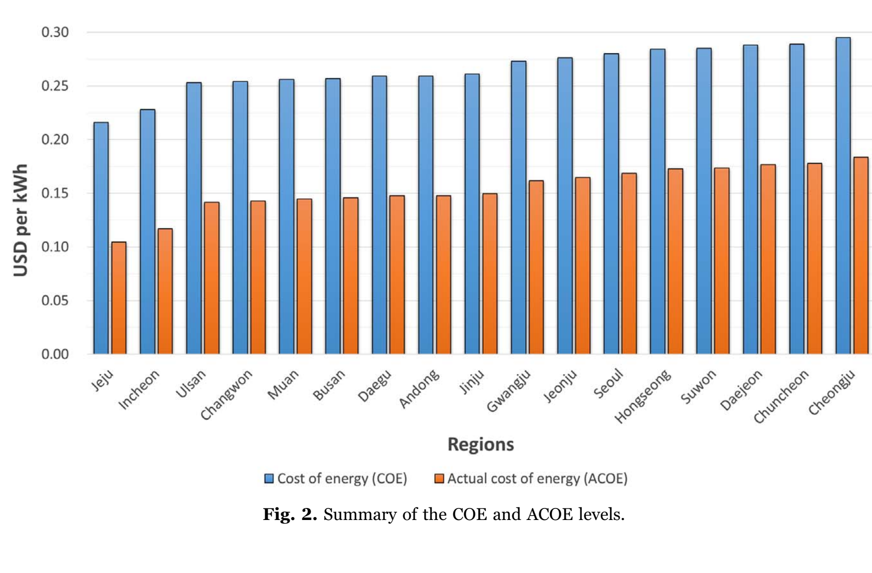

Fig. 2. Summary of the COE and ACOE levels.

Table 6
Economic results of independent renewable electricity generation systems for the cities in South Korea (Group A: ACOE < \$0.120 per kWh, COE < \$0.230 per kWh; Group B: ACOE < \$0.150 per kWh, COE < \$0.260 per kWh; Group C: ACOE < \$0.170 per kWh, COE < \$0.280 per kWh; Group D: ACOE > \$0.170 per kWh, COE > \$0.280 per kWh).

City	Total NPC ($)	Capital cost ($)	Operating cost ($)	Cost of energy (COE; $ per kWh)	Actual cost of energy (ACOE; $ per kWh)	Group
Jeju	1,131,786	672,000	26,405	0.216	0.10472	A
Incheon	1,194,632	706,750	28,018	0.228	0.11672	A
Ulsan	1,323,923	782,250	31,107	0.253	0.14172	B
Changwon	1,331,941	787,500	31,266	0.254	0.14272	B
Muan	1,339,223	788,500	31,627	0.256	0.14472	B
Busan	1,348,322	795,000	31,776	0.257	0.14572	B
Andong	1,355,258	799,000	31,945	0.259	0.14772	B
Daegu	1,354,912	802,000	31,753	0.259	0.14772	B
Jinju	1,365,233	806,000	32,116	0.261	0.14972	B
Gwangju	1,428,639	843,750	33,589	0.273	0.16172	C
Jeonju	1,444,674	854,250	33,907	0.276	0.16472	C
Seoul	1,465,688	867,000	34,381	0.280	0.16872	C
Hongseong	1,487,942	879,750	34,927	0.284	0.17272	D
Suwon	1,492,044	881,500	35,062	0.285	0.17372	D
Daejeon	1,507,015	893,250	35,247	0.288	0.17672	D
Chuncheon	1,516,097	897,250	35,539	0.289	0.17772	D
Cheongju	1,544,064	916,500	36,040	0.295	0.18372	D

governmental offices). The natural geographic information is computed based on the locations of the local governmental offices in the cities.

2.2. Sample electricity load information

This study uses 365,000 kW h-scaled annual load information with the same daily and hourly demand patterns as the electricity load demand of the national grid systems in South Korea. The average electricity load of the data is 825 kW h/d and 34.4 kW, while the peak load is 39.4 kW. Therefore, the load factor is calculated as 0.871.

2.3. Solar resource information of the locations

The data sets for solar resources used in the simulations were gathered by the Korea Meteorological Administration (KMA) and the National Aeronautics and Space Administration (NASA). Table 3 presents summarized solar information.

2.4. Wind resource information of the locations

The data sets for wind resources used in the simulations were collected by the KMA and NASA. Because the hub height of wind turbines in the current study was estimated at 25 m, the average wind speed degrees between ground and 50-m levels are employed. Table 4 introduces the information on the wind resources of the selected cities.

3. The simulation background

3.1. Annual real interest rate and project lifetime

As presented in prior studies on the economic feasibility of utilizing renewable resources [15], the annual real interest rate should be inserted into the HOMER software. Following the methods presented by Dursun [23], an annual real interest rate of 3.02% was used. In addition, the project period is required.

3.2. Evaluation guidelines

The current study used four evaluation guidelines—one configuration evaluation and three economic evaluations—to investigate the economic feasibility of the simulations. As the first evaluation guideline, the ratio of the renewable fraction (configuration evaluation) from the simulation should be 100%. Second, the cost of energy (COE; economic evaluation), which is defined as "*the cost consumption of producing 1 kW h-electricity from a suggested configuration,*" is employed [15]. Third, the actual cost of energy, which is "*the gap between the cost of energy resulting from the potential configuration and the purchasing cost for the grid connection.*" Fourth, the net present cost (NPC), which is "*the total consumed cost of installing, operating, managing, and replacing a suggested configuration*" is employed [15].

3.3. Other simulation conditions

Because the majority of official reports introduced by the South Korean government have planned to use a 20- to 30-year timeline for the national energy plan [7,9,11,24], the current study used 25 years as the project lifetime in the simulation.

3.4. Component information

The cost information of the potential components considered in the simulations should be employed to present the economic feasibility of the suggested configurations. Based on the official announcements by South Korean research institutes and previous economic feasibility studies conducted in South Korea [7,13,25–27], the following information was used for the components.

For PV arrays, the installation, replacement, and operation and management (O & M) costs are assumed to be \$1050 per kW, \$1050 per kW, and \$20 per year per kW, respectively. Moreover, the average lifetime, ground reflectance, and derating factor of PV arrays are estimated at 20 years, 20%, and 80%, respectively. No tracking system is considered. The current study considered the range from 0 to 500 kW as the potential capacity of PV arrays (in 5-kW increments).

Two turbine models are used as potential components in the simulation: the WES 5 Tulipo and generic 10 kW wind turbine models. The WES 5 Tulipo had 2.5 kW AC-rated power, \$5000 capital cost, \$4000 replacement cost, and \$50 per year of O & M cost to use one unit. The capital, replacement, and O & M costs of two units of generic 10 kW wind turbines (10 kW DC-rated power) are \$29,000, \$25,000, and \$400 per year, respectively. For both turbines, the hub height and lifetime are 25 m and 15 years, respectively. Moreover, the range from 0 to 200 turbines is regarded as the potential capacity of both turbines (in 2-turbine increments).

The Surrette 6CS25P is selected as a potential battery model. This model had \$1100 capital cost, \$1000 replacement cost, and \$10 per year O & M cost to use one unit. This model presented 9645 kW h of lifetime throughput with 6 V of nominal voltage. The nominal capacity of the battery is 1156 A h with 6.94 kW h. The considered capacity of the battery units is 0–1000 with 5-unit increments.

In order to maintain the connection between DC and AC, an electrical converter should be included in the simulations. The capital, replacement, and O & M costs are assumed to be \$700 per kW, \$700 per kW, and \$10 per year, respectively. The lifetime and efficiency of inverter inputs are assumed to be 15 years and 90%, respectively. The current study considered 0–750 kW (in 5-kW increments) as the potential considered range.

The purchasing cost of the grid connection is essential for calculating the actual cost of energy. Based on the information officially introduced by KEPCO [28], \$0.11128 is used.

Table 7
Detailed cost information of the optimal configurations of the cities in this study (O & M: Operation & Management; Wind turbine: WES 5 Tulipo).

City (COE, Group)	Period	Component	Capital ($)	Replacement ($)	O & M ($)	Salvage ($)	Total ($)
Jeju (0.216, A)	Total period	PV array	126,000	69,763	41,792	−45,134	192,421
		Wind turbine	225,000	115,535	39,180	−28,656	351,058
		Battery	286,000	310,262	45,274	−113,829	527,707
		Converter	35,000	22,465	8707	−5572	60,600
		System	672,000	518,025	134,952	−193,192	1,131,786
	Annual period	PV array	7236	4006	2400	−2592	11,050
		Wind turbine	12,921	6635	2250	−1646	20,161
		Battery	16,424	17,818	2600	−6537	30,305
		Converter	2010	1290	500	−320	3480
		System	38,592	29,749	7750	−11,095	64,996
Incheon (0.228; A)	Total period	PV array	131,250	72,670	43,533	−47,014	200,439
		Wind turbine	225,000	115,535	39,180	−28,656	351,058
		Battery	319,000	346,061	50,498	−126,964	588,596
		Converter	31,500	20,219	7836	−5015	54,540
		System	706,750	554,485	141,047	−207,649	1,194,632
	Annual period	PV array	7537	4173	2500	−2700	11,511
		Wind turbine	12,921	6635	2250	−1646	20,161
		Battery	18,319	19,874	2900	−7291	33,802
		Converter	1809	1161	450	−288	3132
		System	40,587	31,843	8100	−11,925	68,605
Ulsan (0.253; B)	Total period	PV array	162,750	90,111	53,981	−58,298	248,544
		Wind turbine	225,000	115,535	39,180	−28,656	351,058
		Battery	363,000	393,794	57,463	−144,476	669,781
		Converter	31,500	20,219	7836	−5015	54,540
		System	782,250	619,658	158,460	−236,445	1,323,923
	Annual period	PV array	9346	5175	3100	−3348	14,273
		Wind turbine	12,921	6635	2250	−1646	20,161
		Battery	20,846	22,615	3300	−8297	38,464
		Converter	1809	1161	450	−288	3132
		System	44,923	35,586	9100	−13,579	76,030
Changwon (0.254; B)	Total period	PV array	168,000	93,018	55,722	−60,178	256,561
		Wind turbine	225,000	115,535	39,180	−28,656	351,058
		Battery	363,000	393,794	57,463	−144,476	669,781
		Converter	31,500	20,219	7836	−5015	54,540
		System	787,500	622,565	160,201	−238,325	1,331,941
	Annual period	PV array	9648	5342	3200	−3456	14,734
		Wind turbine	12,921	6635	2250	−1646	20,161
		Battery	20,846	22,615	3300	−8297	38,464
		Converter	1809	1161	450	−288	3132
		System	45,224	35,753	9200	−13,687	76,491
Muan (0.256; B)	Total period	PV array	126,000	69,763	41,792	−45,134	192,421
		Wind turbine	250,000	128,372	43,533	−31,840	390,065
		Battery	374,000	405,727	59,205	−148,854	690,078
		Converter	38,500	24,712	9577	−6129	66,660
		System	788,500	628,574	154,106	−231,957	1,339,223
	Annual period	PV array	7236	4006	2400	−2592	11,050
		Wind turbine	14,357	7372	2500	−1829	22,401
		Battery	21,478	23,300	3400	−8548	39,630
		Converter	2211	1419	550	−352	3828
		System	45,282	36,098	8850	−13,321	76,909
Busan (0.257; B)	Total period	PV array	157,500	87,204	52,239	−56,417	240,526
		Wind turbine	225,000	115,535	39,180	−28,656	351,058
		Battery	374,000	405,727	59,205	−148,854	690,078
		Converter	38,500	24,712	9577	−6129	66,660
		System	795,000	633,178	160,201	−240,057	1,348,322
	Annual period	PV array	9045	5008	3000	−3240	13,813
		Wind turbine	12,921	6635	2250	−1646	20,161
		Battery	21,478	23,300	3400	−8548	39,630
		Converter	2211	1419	550	−352	3828
		System	45,655	36,362	9200	−13,786	77,431
Andong (0.259; B)	Total period	PV array	136,500	75,577	45,274	−48,895	208,456
		Wind turbine	250,000	128,372	43,533	−31,840	390,065
		Battery	374,000	405,727	59,205	−148,854	690,078
		Converter	38,500	24,712	9577	−6129	66,660
		System	799,000	634,388	157,589	−235,718	1,355,259
	Annual period	PV array	7839	4340	2600	−2808	11,971
		Wind turbine	14,357	7372	2500	−1829	22,401
		Battery	21,478	23,300	3400	−8548	39,630

(continued on next page)

Table 7 *(continued)*

City (COE, Group)	Period	Component	Capital ($)	Replacement ($)	O & M ($)	Salvage ($)	Total ($)
		Converter	2211	1419	550	−352	3828
		System	45,885	36,432	9050	−13,537	77,830
Daegu (0.259; B)	Total period	PV array	157,500	87,204	52,239	−56,417	240,526
		Wind turbine	250,000	128,372	43,533	−31,840	390,065
		Battery	363,000	393,794	57,463	−144,476	669,781
		Converter	31,500	20,219	7836	−5015	54,540
		System	802,000	629,589	161,072	−237,748	1,354,912
	Annual period	PV array	9045	5008	3000	−3240	13,813
		Wind turbine	14,357	7372	2500	−1829	22,401
		Battery	20,846	22,615	3300	−8297	38,464
		Converter	1809	1161	450	−288	3132
		System	46,057	36,156	9250	−13,653	77,810
Jinju (0.261; B)	Total period	PV array	147,000	81,390	48,757	−52,656	224,491
		Wind turbine	250,000	128,372	43,533	−31,840	390,065
		Battery	374,000	405,727	59,205	−148,854	690,078
		Converter	35,000	22,465	8707	−5572	60,600
		System	806,000	637,955	160,201	−238,922	1,365,234
	Annual period	PV array	8442	4674	2800	−3024	12,892
		Wind turbine	14,357	7372	2500	−1829	22,401
		Battery	21,478	23,300	3400	−8548	39,630
		Converter	2010	1290	500	−320	3480
		System	46,287	36,636	9200	−13,721	78,402
Gwangju (0.273; C)	Total period	PV array	141,750	78,484	47,016	−50,775	216,474
		Wind turbine	275,000	141,210	47,886	−35,024	429,071
		Battery	385,000	417,660	60,946	−153,232	710,374
		Converter	42,000	26,958	10,448	−6686	72,720
		System	843,750	664,311	166,296	−245,718	1,428,639
	Annual period	PV array	8140	4507	2700	−2916	12,432
		Wind turbine	15,793	8109	2750	−2011	24,641
		Battery	22,110	23,985	3500	−8800	40,795
		Converter	2412	1548	600	−384	4176
		System	48,455	38,150	9550	−14,111	82,044
Jeonju (0.276; C)	Total period	PV array	152,250	84,297	50,498	−54,537	232,509
		Wind turbine	275,000	141,210	47,886	−35,024	429,071
		Battery	385,000	417,660	60,946	−153,232	710,374
		Converter	42,000	26,958	10,448	−6686	72,720
		System	854,250	670,125	169,778	−249,479	1,444,674
	Annual period	PV array	8743	4841	2900	−3132	13,352
		Wind turbine	15,793	8109	2750	−2011	24,641
		Battery	22,110	23,985	3500	−8800	40,795
		Converter	2412	1548	600	−384	4176
		System	49,058	38,484	9750	−14,327	82,965
Seoul (0.280; C)	Total period	PV array	136,500	75,577	45,274	−48,895	208,456
		Wind turbine	300,000	154,047	52,239	−38,208	468,078
		Battery	385,000	417,660	60,946	−153,232	710,374
		Converter	45,500	29,205	11,319	−7244	78,780
		System	867,000	676,488	169,778	−247,579	1,465,688
	Annual period	PV array	7839	4340	2600	−2808	11,971
		Wind turbine	17,228	8847	3000	−2194	26,881
		Battery	22,110	23,985	3500	−8800	40,795
		Converter	2613	1677	650	−416	4524
		System	49,790	38,849	9750	−14,218	84,171
Hongseong (0.284; D)	Total period	PV array	141,750	78,484	47,016	−50,775	216,474
		Wind turbine	300,000	154,047	52,239	−38,208	468,078
		Battery	396,000	429,593	62,687	−157,610	730,670
		Converter	42,000	26,958	10,448	−6686	72,720
		System	879,750	689,082	172,390	−253,280	1,487,942
	Annual period	PV array	8140	4507	2700	−2916	12,432
		Wind turbine	17,228	8847	3000	−2194	26,881
		Battery	22,741	24,671	3600	−9051	41,961
		Converter	2412	1548	600	−384	4176
		System	50,522	39,573	9900	−14,545	85,449
Suwon (0.285; D)	Total period	PV array	136,500	75,577	45,274	−48,895	208,456
		Wind turbine	300,000	154,047	52,239	−38,208	468,078
		Battery	396,000	429,593	62,687	−157,610	730,670
		Converter	49,000	31,451	12,189	−7801	84,840
		System	881,500	690,668	172,390	−252,514	1,492,044
	Annual period	PV array	7839	4340	2600	−2808	11,971

(continued on next page)

Table 7 *(continued)*

City (COE, Group)	Period	Component	Capital ($)	Replacement ($)	O & M ($)	Salvage ($)	Total ($)
		Wind turbine	17,228	8847	3000	−2194	26,881
		Battery	22,741	24,671	3600	−9051	41,961
		Converter	2814	1806	700	−448	4872
		System	50,623	39,664	9900	−14,501	85,685
Daejeon (0.288; D)	Total period	PV array	183,750	101,738	60,946	−65,820	280,614
		Wind turbine	275,000	141,210	47,886	−35,024	429,071
		Battery	396,000	429,593	62,687	−157,610	730,670
		Converter	38,500	24,712	9577	−6129	66,660
		System	893,250	697,252	181,097	−264,584	1,507,016
	Annual period	PV array	10,552	5843	3500	−3780	16,115
		Wind turbine	15,793	8109	2750	−2011	24,641
		Battery	22,741	24,671	3600	−9051	41,961
		Converter	2211	1419	550	−352	3828
		System	51,297	40,042	10,400	−15,194	86,545
Chuncheon (0.289; D)	Total period	PV array	152,250	84,297	50,498	−54,537	232,509
		Wind turbine	300,000	154,047	52,239	−38,208	468,078
		Battery	396,000	429,593	62,687	−157,610	730,670
		Converter	49,000	31,451	12,189	−7801	84,840
		System	897,250	699,389	177,614	−258,156	1,516,096
	Annual period	PV array	8743	4841	2900	−3132	13,352
		Wind turbine	17,228	8847	3000	−2194	26,881
		Battery	22,741	24,671	3600	−9051	41,961
		Converter	2814	1806	700	−448	4872
		System	51,527	40,164	10,200	−14,825	87,066
Cheongju (0.295; D)	Total period	PV array	178,500	98,831	59,205	−63,939	272,596
		Wind turbine	300,000	154,047	52,239	−38,208	468,078
		Battery	396,000	429,593	62,687	−157,610	730,670
		Converter	42,000	26,958	10,448	−6686	72,720
		System	916,500	709,429	184,579	−266,444	1,544,064
	Annual period	PV array	10,251	5676	3400	−3672	15,655
		Wind turbine	17,228	8847	3000	−2194	26,881
		Battery	22,741	24,671	3600	−9051	41,961
		Converter	2412	1548	600	−384	4176
		System	52,633	40,741	10,600	−15,301	88,672

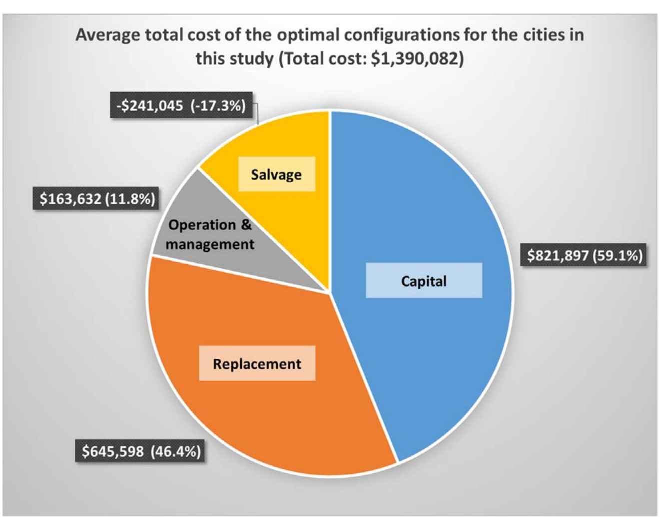

Fig. 3. Summary of the average total cost.

4. Renewable electricity generation systems

The HOMER software is used to test the economic potentiality of renewable resources in South Korea. Because it is essential to test the electricity load data, 365,000 kW h-scaled annual electricity load data with the same pattern as the national electricity consumption of South Korea are simulated and used [29]. Moreover, the current study followed the simulation procedure proposed by previously validated studies [23].

5. Simulation results

Potential configurations of renewable electricity generation systems are proposed for 17 cities in South Korea. All configurations are organized as the combination of wind turbines (type 2: WES 5 Tulipo), PV arrays, and converter batteries. Table 5 presents the optimal configurations of independent renewable electricity generation systems for the cities in South Korea. Fig. 1 presents a summary of the simulations, while Fig. 2 and Table 6 present the economic indicators of the systems. Based on the COE and ACOE levels, the cities are categorized by the economic feasibility of the systems in the cities.

The results of the simulations indicate that all cases achieve 100% of the renewable fraction, $0.216–$0.295 per kWh of COE levels, and $0.10472–$0.18372 per kWh of ACOE levels.

5.1. Detailed cost information

Table 7 summarizes the cost information for the total period and annual period. As presented in Fig. 3, the capital cost is more than 40% of total costs, while the replacement cost is more than 30% of total costs. This means that major investment should be considered for the configuration.

Table 8 presents the electricity production and consumption information. PV arrays generally contribute 23–34% of electricity production, while wind turbines generate 66–77% of electricity pro-

Table 8
Electricity production and consumption of the optimal configurations of the cities in this study.

City (COE ($ per kWh); Group)	Electricity production (kWh per year)		Electricity consumption (kWh per year)	Excess electricity (kWh per year)
	PV array	Wind turbines		
Jeju (0.216; A)	161,861 (27%)	438,913 (73%)	300,924	261,776
Incheon (0.228; A)	163,789 (27%)	442,851 (73%)	300,980	267,417
Ulsan (0.253; B)	224,132 (34%)	439,874 (66%)	300,931	326,482
Changwon (0.254; B)	234,013 (35%)	440,623 (65%)	300,937	337,354
Muan (0.256; B)	176,838 (27%)	489,230 (73%)	300,944	328,509
Busan (0.257; B)	216,561 (33%)	441,056 (67%)	300,919	319,816
Andong (0.259; B)	184,862 (27%)	488,308 (73%)	300,923	335,570
Daegu (0.259; B)	221,049 (31%)	490,214 (69%)	300,931	374,978
Jinju (0.261; B)	208,716 (30%)	490,257 (70%)	300,923	362,400
Gwangju (0.273; C)	185,745 (26%)	540,457 (74%)	300,923	390,723
Jeonju (0.276; C)	210,882 (28%)	539,924 (72%)	300,929	415,040
Seoul (0.280; C)	173,794 (23%)	589,008 (77%)	300,924	426,908
Hongseong (0.284; D)	187,843 (24%)	587,435 (76%)	300,918	439,751
Suwon (0.285; D)	174,953 (23%)	588,942 (77%)	300,925	427,973
Daejeon (0.288; D)	248,371 (32%)	537,748 (68%)	300,914	450,733
Chuncheon (0.289; D)	191,969 (25%)	588,074 (75%)	300,917	444,395
Cheongju (0.295; D)	235,589 (29%)	586,309 (71%)	300,913	487,106

Table 9
Wind turbine information for each case.

City (COE ($ per kWh); Group)	# of turbines	Total production (kWh per year)	Total rated capacity (kW)	Mean output (Min., Max.)	Wind penetration (%)	Hours of operation (hours per year)	Leverlized cost ($ per kWh)
Jeju (0.216; A)	45	438,913 (73%)	113	50 (0, 118)	146	8100	0.0459
Incheon (0.228; A)	45	442,851 (73%)	113	51 (0, 118)	147	8116	0.0455
Ulsan (0.253; B)	45	439,874 (66%)	113	50 (0, 118)	146	8044	0.0458
Changwon (0.254; B)	45	440,623 (65%)	113	50 (0, 118)	146	8048	0.0458
Muan (0.256; B)	50	489,230 (73%)	125	56 (0, 131)	162	8048	0.0458
Busan (0.257; B)	45	441,056 (67%)	113	50 (0, 118)	146	8048	0.0457
Andong (0.259; B)	50	488,308 (73%)	125	56 (0, 131)	162	8042	0.0459
Daegu (0.259; B)	50	490,214 (69%)	125	56 (0, 131)	163	8055	0.0457
Jinju (0.261; B)	50	490,257 (70%)	125	56 (0, 131)	163	8055	0.0457
Gwangju (0.273; C)	55	540,457 (74%)	138	62 (0, 144)	179	8051	0.0456
Jeonju (0.276; C)	55	539,924 (72%)	138	62 (0, 144)	179	8052	0.0456
Seoul (0.280; C)	60	589,008 (77%)	150	67 (0, 157)	196	8046	0.0456
Hongseong (0.284; D)	60	587,435 (76%)	150	67 (0, 157)	195	8051	0.0458
Suwon (0.285; D)	60	588,942 (77%)	150	67 (0, 157)	196	8047	0.0456
Daejeon (0.288; D)	55	537,748 (68%)	138	61 (0, 144)	179	8045	0.0458
Chuncheon (0.289; D)	60	588,074 (75%)	150	67 (0, 157)	195	8050	0.0457
Cheongju (0.295; D)	60	586,309 (71%)	150	67 (0, 157)	195	8044	0.0458

Table 10
PV array information for each case.

City (COE ($ per kWh); Group)	Total production (kWh per year)	Total rated capacity (kW)	Mean output (kW; Min., Max.)	Mean output (kWh/d)	PV penetration (%)	Hours of operation (hours per year)	Leverlized cost ($ per kWh)
Jeju (0.216; A)	161,861 (27%)	120	18 (0, 124)	443	53.8	4366	0.0683
Incheon (0.228; A)	163,789 (27%)	125	19 (0, 130)	449	54.4	4381	0.0703
Ulsan (0.253; B)	224,132 (34%)	155	26 (0, 160)	614	74.4	4382	0.0637
Changwon (0.254; B)	234,013 (35%)	160	27 (0, 165)	641	77.7	4381	0.0630
Muan (0.256; B)	176,838 (27%)	120	20 (0, 124)	484	58.7	4373	0.0625
Busan (0.257; B)	216,561 (33%)	150	25 (0, 155)	593	71.9	4381	0.0638
Andong (0.259; B)	184,862 (27%)	130	21 (0, 135)	506	61.4	4383	0.0648
Daegu (0.259; B)	221,049 (31%)	150	25 (0, 155)	606	73.4	4381	0.0625
Jinju (0.261; B)	208,716 (30%)	140	24 (0, 145)	572	69.3	4380	0.0618
Gwangju (0.273; C)	185,745 (26%)	135	21 (0, 140)	512	62.0	4378	0.0666
Jeonju (0.276; C)	210,882 (28%)	145	24 (0, 150)	578	70.0	4381	0.0633
Seoul (0.280; C)	173,794 (23%)	130	20 (0, 136)	476	57.7	4381	0.0689
Hongseong (0.284; D)	187,843 (24%)	135	21 (0, 140)	515	62.4	4377	0.0622
Suwon (0.285; D)	174,953 (23%)	130	20 (0, 135)	479	58.1	4380	0.0684
Daejeon (0.288; D)	248,371 (32%)	175	28 (0, 182)	680	82.5	4381	0.0649
Chuncheon (0.289; D)	191,969 (25%)	145	22 (0, 151)	526	63.7	4382	0.0696
Cheongju (0.295; D)	235,589 (29%)	170	27 (0, 177)	645	78.2	4379	0.0664

Table 11
Rankings of economic feasibility, solar and wind energy resources.

City	Rankings of economic feasibility (based on COE levels)	Rankings of solar energy resource (based on annual average solar daily radiation)	Rankings of wind energy resource (based on annual average wind speed)
Jeju	1 (0.216)	14 (4.190)	2 (4.964)
Incheon	2 (0.228)	19 (3.949)	5 (4.320)
Ulsan	3 (0.253)	6 (4.356)	3 (4.788)
Changwon	4 (0.254)	4 (4.411)	8 (4.048)
Muan	5 (0.256)	2 (4.487)	6 (4.109)
Busan	6 (0.257)	7 (4.355)	1 (5.325)
Andong	7 (0.259)	9 (4.247)	4 (4.436)
Daegu	8 (0.259)	3 (4.419)	11 (3.736)
Jinju	9 (0.261)	1 (4.488)	12 (3.674)
Gwangju	10 (0.273)	11 (4.234)	9 (4.001)
Jeonju	11 (0.276)	5 (4.379)	13 (3.574)
Seoul	12 (0.280)	17 (4.011)	7 (4.109)
Hongseong	13 (0.284)	10 (4.221)	14 (3.488)
Suwon	14 (0.285)	15 (4.062)	10 (3.784)
Daejeon	15 (0.288)	8 (4.265)	17 (3.108)
Chuncheon	16 (0.289)	18 (3.967)	19 (2.873)
Cheongju	17 (0.295)	12 (4.187)	18 (2.971)

duction. Although the ratios of PV arrays and wind turbines in each case vary, reducing the amount of excess electricity generated by each configuration mainly determines the economic feasibility of the configuration.

5.2. Wind turbine information

As shown in Table 9, 45 (Busan, Changwon, Incheon, Jeju, and Ulsan) to 60 (Cheongju, Chuncheon, Hongseong, Seoul, and Suwon) wind turbines are required in the configurations. Table 9 shows the detailed information for the wind turbines used in each case.

5.3. PV array information

As shown in Table 5, 120 (Jeju and Muan) ~170 (Daejeon) kW-capacity PV arrays are employed in the configurations. Table 10 shows the detailed information for the PV arrays used in each case.

5.4. Ranking of the potentiality of economic feasibility and renewable resources

Based on the results of the simulations, the rankings of the results and the potentiality of renewable resources are presented in Table 11. Considering the levels of COE (0.216) and ACOE (0.10472), Jeju is nominated as the most economic city for utilizing renewable energy resources in South Korea.

6. Discussion and conclusion

Since dependency on fossil fuels and nuclear energy has created social and environmental concerns in international society, the majority of developed countries have attempted to reduce dependency on nuclear energy and fossil fuels in their national energy systems. Therefore, as an alternative to nuclear energy and fossil fuels, the South Korean government has implemented several policies and introduced plans to utilize renewable energy resources in its territory.

Although there are many information sets for renewable energy resources in South Korea, including the national solar energy maps and wind resource tables [11], few economic investigations of utilizing renewable energy resources in South Korea have been independently conducted [30]. Moreover, because the majority of these investigations were conducted with the independent electricity load information of particular areas or islands [13,15], no economic investigations responding to the electricity load of the national grid system have been conducted.

Therefore, the current study aims to explore the economic feasibility of renewable energy generation systems in selected cities in South Korea using sample electricity load data that show the same demand pattern as the national grid system. The main findings of the current study can be summarized as follows:

- It examines the economic feasibility results of potential renewable energy generation systems in South Korea, and presents two economic parameters and results after evaluating the potentiality of using renewable energy resources in the regions and cities.
- The simulation results suggest Jeju and Incheon as the two most promising cities to utilize renewable energy resources.

The investigations of the potential economic feasibility of renewable electricity generation systems are conducted in 17 selected cities using the HOMER software; the location information sets of the selected cities; their resource information sets; and the currently considered information on wind turbines, PV arrays, battery units, and converters in South Korea. Consistent with the findings of previous studies [30,31], Jeju is considered to be the best city to utilize renewable electricity generation systems.

In addition, based on the COE ($0.216–$0.295 per kWh) and ACOE ($0.10472–$0.18372 per kWh) levels in the simulations in the current study, the renewable portfolio standard (RPS), renewable fuel standard (RFS) and renewable heat obligation (RHO) policies in South Korea to provide subsidies for installing renewable energy generation facilities should play a key role in reducing the amount of investment required for installation [32].

Nevertheless, there are several shortcomings. First, the current study uses information on renewable energy resources based on the current sites of the local governmental offices in the selected cities. This means that there could be other more promising locations for renewable electricity generation systems in the selected cities. For example, as shown in previous studies conducted in South Korea, several islands in South Korea could be more economic locations for renewable electricity generation systems. Second, there could be more optimal configurations for the cities, because the cost information for the components in the configurations can differ. The current study considers the most widely used cost information in South Korea. These shortcomings can be addressed in future studies by using the findings of the current study as a baseline.

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