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ANALYSIS OF KOREA'S ENERGY SELF-RELIANT ISLAND PROJECTS(KESIPS) AND THEIR IMPLICATIONS FOR KOREA'S QUEST FOR SUSTAINABILITY

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A. Background

From climate change to acid rain, contaminated landscapes, mercury pollution, and biodiversity loss, the origins of many of our least tractable environmental problems can be traced to how the modern energy system operates (Byrne and Toly, 2006: 1). The fossil fuel-based economy triggers a variety of problems including economic instability, energy insecurity, social inequity, environmental pollution, and global warming (Wang, Chen, and Park, 2012: 237). Since the world became aware of how the modern energy system makes abundant and cheap energy available beyond limits, demand for realistic solutions to respond to its inequitable socio-economic features has risen in many countries. For example, these efforts led to international agreements such as the 2015 Paris Agreement on climate change.

"The Paris Agreement signals a fundamental shift in technological development, market investment, and policy design with the aim of "holding the increase in the global average temperature to well below 2℃ above preindustrial levels" (Byrne and Lund, 2015: 5). Although the United States announced its intention to withdraw from the

Paris Agreement, other countries have indicated that they will implement the Agreement. Thus, the Paris Agreement remains one of the most important international architecture for climate action to reduce greenhouse gas emissions in the world. There is an urgent need to seek a new energy system based on the concept of sustainability (Wang, Chen, and Park, 2012: 237). Under this current situation, KESIPs has been one of the most applicable solutions to Korea.

The KESIPs represent regional energy planning approaches which limit their boundary on islands. There are two substantial reasons why Korea can have advantages on propelling the KESIPs.

Firstly, there are over three thousand islands in Korea. Among these, about five hundred are inhabited by humans, and only thirteen islands are bigger than 50 km^2 (National Assembly Research Service in Korea, 2016; Research Institute in Gwangju in Korea, 2006). Many of these islands have potential for renewable energy and distributed generation. Before KESIPs were tried, the only feasible generation option for these islands was diesel generators because of cost and existing market demand considerations of renewable energy sources. Although diesel is an expensive fuel, it is easy to handle and store. In addition, diesel generators have relatively cheap installation cost and can vary in capacity from family use to industry use. So most of the islands have used diesel generators to supply electricity to themselves.

Secondly, as Korea Electric Power Corporation (KEPCO) sells electricity to all its customers living in Korea at the same rate, KEPCO has incurred losses from islands due to expensive diesel prices (KEPCO, 2012: 6). Besides, lots of greenhouse gases have been emitted from diesel generators, too. There were no ways to solve these problems in the past.

However, as efficiency of clean energy technologies have been improved and installation costs reduced, Korean government and KEPCO planned to carry forward with the implementation of KESIPs to replace the diesel generators with decentralized energy generation systems which were adequate for remote off-gird regions. In particular, the Ministry of Trade, Industry, and Energy (MOTIE) now view these off-grid energy generation projects as potential business ventures and sources of revenue, to be implemented initially in small villages and islands and later in metropolitan cities (MOTIE, 2015a).

In 2007, when the oil prices skyrocketed, the Korean government and KEPCO designed an approach for the energy self-reliant island and got some results regarding the feasibility of systematic management of renewable energy facilities. After the first trial, additional proposals have been considered with some at different stages of implementation (Chungcheongnam-do Provincial Government in Korea, 2013: 29-32). However, because the high oil prices drove these initial plans, as prices have stayed low, the urgency to implement KESIPs has waned.

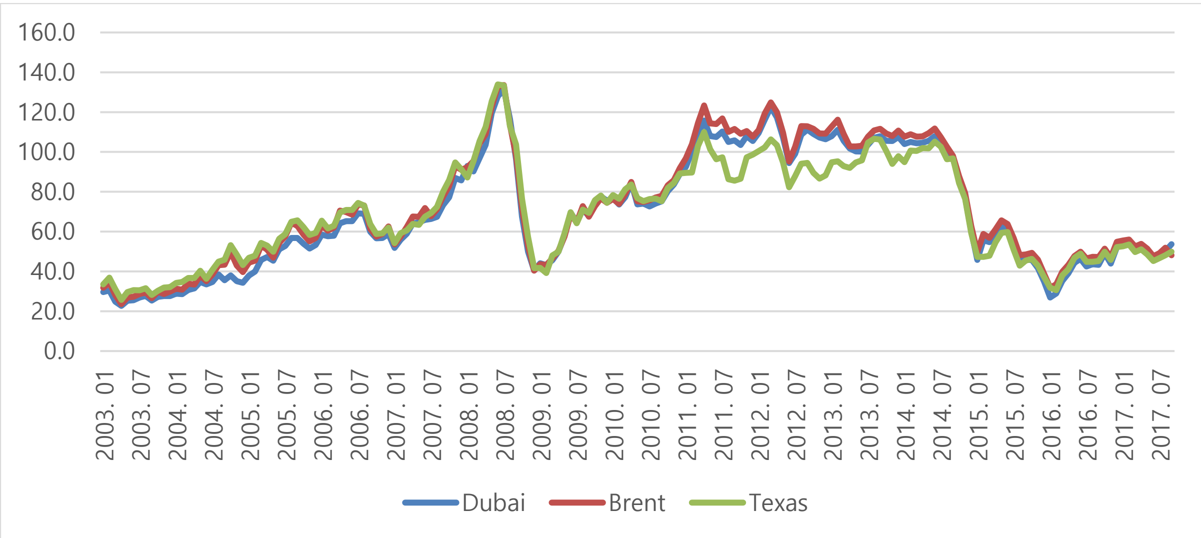

Figure 1. Crude Oil Price Trend (National Statistical Office of Korea)

B. History

Korean government and KEPCO started KESIPs in 2007 and have increased the scale of the projects from a small island with a population of 100 people to a mediumsized island with population of about 10,000 people. Similar projects have also been tried by some Korean local governments.

In the following section, examples of specific projects are discussed. The first project is Yeondaedo project which was implemented during the period of high oil prices, as a clean energy solution. But the generation capacity from these renewable energy technologies could not meet the energy demand at that time because of reliability and cost of installation concerns. Generation mix of Yeondaedo project mainly depends on solar photovoltaic (PV) capacity amounting to 150kW but the rest of energy demand is still supplied by diesel generators. (Chungcheongnam-do Provincial Government Republic of Korea, 2013: 29-32)

However, despite these challenges the partial success of the first project was very encouraging and government tried to experiment KESIPs again. The potential for integration of practical energy storage systems as well as addition of diversified energy mix encouraged the government to improve its original plan, resulting in Gapado project. The aim of Gapado project was to achieve a self-reliant energy island. The project originally had diesel generation units of 450kW capacity. In the proposed plan, new generation mix of Gapado consisted of both wind and solar electricity generation systems (i.e., 500kW and 141kW for wind and solar PV, respectively). In addition, the project had an energy storage unit of 1.86MWh, and a smart grid system was implemented to help in monitoring and controlling the different operations and and functions of the facility. Traditional transportations such as fishing boats and cars were also substituted with electric vehicles. As a result, the initial goal of the government was achieved successfully despite the high installation cost. (Chungcheongnam-do Provincial Government Republic of Korea, 2013: 33-34) (Etnews, 2016)

Through experiences of these projects, the government and KEPCO which managed the legacy projects were successful in piloting KESIPs. Subsequently in 2014, they announced a bigger scale KESIP project on Ulleungdo and the first phase of the project was completed in 2016. The next phase will end in 2020. Additionally, there are ongoing projects in five islands similar to the Ulleungdo project (MOTIE, 2015b) In addition, some Korean local governments have tried projects similar to KESIPs (MOTIE, 2015c) (MOTIE, 2015a). For example, the local government of

Jejudo province declared Carbon-free Island by 2030 in 2012 and this project is ongoing. (Jejudo, 2013a)

Additional projects are listed below:

- 2007, Yeondaedo project in Tongyeong city (0.75km2, about 80 people): Passive (renewable energy about 90%), by Korean government
- 2011, Gapado project in Jeju province (0.84km2, about 180 people): Zero (No fossil fuel), by Korean government
- 2012, Carbon-free Island Jeju by 2030 (1833.2km2, about 635,000 people): Ongoing (goal: No fossil fuel plants and cars by 2030), by local government of Jeju province
- 2014, Ulleungdo project (72.9km2, about 11,000 people): Ongoing (goal: No diesel by 2020), by Korean government
- 2015, 5 Islands projects similar to Ulleungdo project: Ongoing (goal: No diesel by 2020), by Korean government

C. Representative Examples

a. Ulleungdo Project

Ulleundgo is big island among Korean islands. Like most of the islands, Ulleungdo depends on diesel generators to meet its electricity demand for an extended period of time without any connection to the main connection in the mainland due to the long distance. KEPCO proposed a plan for increased capacity of renewable electricity generation in Ulleungdo. The detail of KEPCO's plan is shown in Table 1. It consists of two phases. The first phase was completed in in 2016 and the second phase will end by 2020. As shown in Table 1, the first phase maintains diesel units as back-up generators and the second phase will replace the diesel generators with solar PVs and wind generators. Given Ulleungdo's electricity demand, the capacity of fuel cell and energy storage can outcompete the proposed KEPCO's plan (MOTIE, 2015).

	Total (MW/MWh)	Diesel (MW)	Hydro (MW)	Solar (MW)	Wind (MW)	Geo (MW)	Fuel (MW)	Energy Storage (MWh)
Present	19.2 / 0	18.5	0.7	-	-	-	-	-
1st phase	24.9 / 21.0	15.2	0.7	1.0	8.0	-	-	21.0
2nd phase	20.7 / 22.0	-	0.7	1.0	8.0	4.0	7.0	22.0

Table 1. Ulleungdo project's time and energy source mix plan (source: KEPCO)

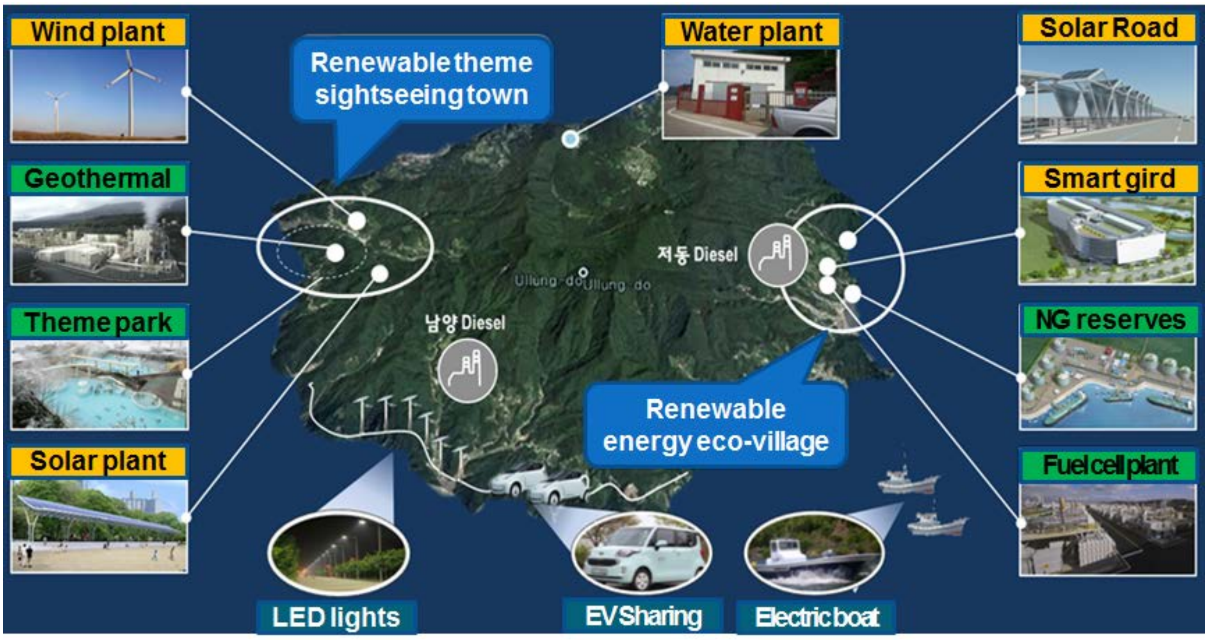

Figure 2. Future of Ulleungdo (Source: KEPCO)

b. Carbon-free Island Jeju by 2030

Jejudo has the largest area and the most population among Korean islands. There are undersea transmission lines between Jejudo and the mainland which are pilot projects on new high voltage direct current transmission line technology. Although Jejudo is on-grid, it generates required electricity from its diesel units.

In 2012, the local government of Jejudo province declared a plan for Carbon-free Island Jeju by 2030. Its goal was no CO_2 emissions in Jejudo province. To meet this target, all power plants and gasoline cars will be replaced by renewable energy facilities and electric vehicles. In addition, integrated smart-grid system will be implemented in the island to improve grid efficiency and reliability at a cost of US$9 billion (Jejudo, 2013a).

The plan consists of four phases (Wang, Chen, Huh, and Park, 2015: 202). The first phase completed in 2012 implemented a test-bed trial on one-tenth area of the province (Jejudo, 2013b). This trial has been completed by the Korean government and the local government of Jejudo. Leading companies such as KEPCO, SKT, KT, and LG electronics participated in this process to ensure a seamless integration of the smart-grid with the renewable energy facilities. The second phase entails replacing half of the current fossil fuel power plants and all gasoline vehicles used for public transportation with offshore wind power plants and electric vehicles, respectively by 2020 (Jejudo, 2013b). In addition, the smart-grid system will be expanded from the test-bed area to cover the entire province. These changes will make renewable share be 20% of primary energy demand. In the third phase, no fossil fuel power plants nor gasoline cars will operate in the island by 2030 (Jejudo, 2013b). The last phase is that renewable share will be 50% of primary energy demand by 2050. This can be achieved by wind power (15%), solar power (5%), geothermal power (7.5%), biogas and biofuels (5%), and hydrogen and fuel cells (17.5%) (Wang, Chen, and Park, 2012).

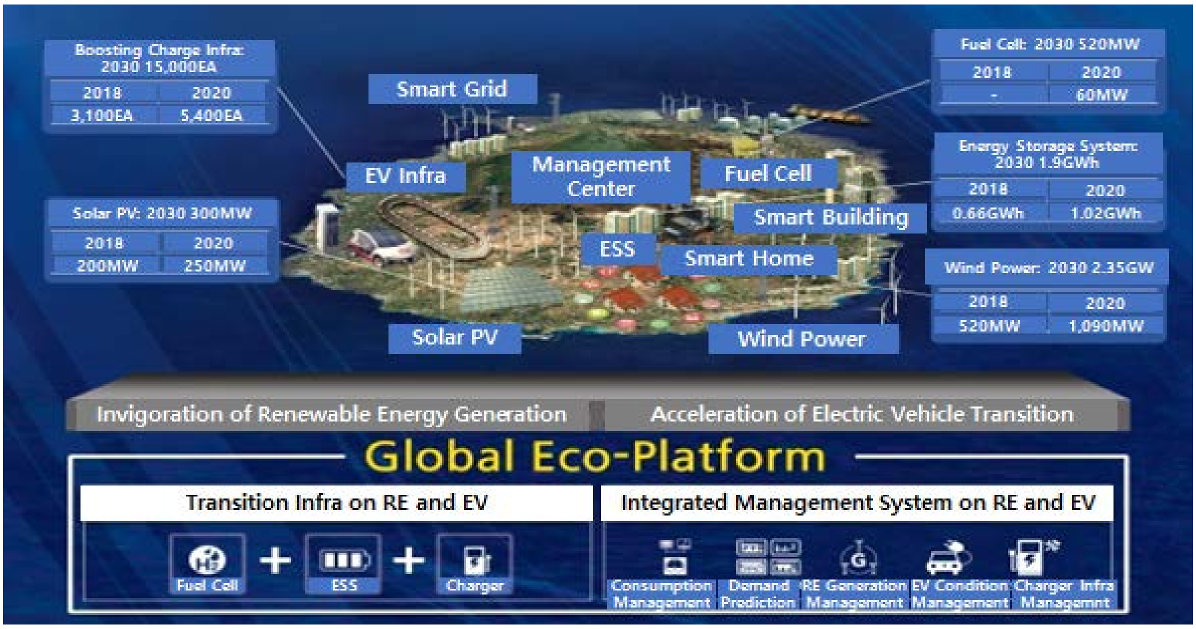

Figure 3. Vision of Carbon Free Island Jeju (Source: KEPCO)

2. Main Issues and Debate of KESIPs

A. Main Issues

Although implementation of KESIPs is still ongoing, there have been many challenges associated with the project. Among these are three main issues, namely, economic feasibility, local conflicts, and environmental destruction.

Because the policy was designed during the oil peak era of “more is better”, the economic feasibility of KESIPs was very high due to operational costs arising from expensive diesel price. In addition, the decisions that guided KESIP was driven by the government and KEPCO. However, because of technological advancements that have enabled production companies to economically extract shale energy resources from previously inaccessible or financially infeasible shale rock formations with breathtaking speeds, oil prices have remained stable in the low range of between $30 and $50. The diesel prices have also also decreased significantly. Although installation cost of renewable energy facilities (REFs) has been on the decline, many policymakers, investors, and industry analysts remain concerned about the economic feasibility of KESIPs. This is mainly because of the intermittency, dispatchability, and cost concerns of REFs. To accomplish a competitive KESIPs market environment for REFs, battery storage or backup generation units are needed many of which are still very expensive. (the Board of Audit and Inspection in Korea, 2016)

Secondly, local conflicts related to siting of REFs units remain a concern. Diesel generators need considerable smaller area than REFs to meet the same amount of demand. In other words, to replace diesel generators with REFs, a huge land area is required which sometimes can lead to conflict with the local landowners. Although

REFs are more environmentally-friendly than diesel generators, generation facilities such as wind have been associated with alteration of the local landscape. In the case of utility scale generation, there are several examples that even solar power can be objected by residents. Wind power also makes a low frequency noise. Due to these negative effects associated with siting of REFs, the price of land near REFs could also be affected. As shown in Figure 4, these factors could lead to serious local conflicts on KESIPs.

Figure 4. Residents Objecting to Installation of Wind Power (Source: Donga Daily News, Newsis, Yangsan Newspaper, Fishing in Marine)

The third is environmental destruction. As explained above, REFs need more land area than the current diesel generators. To meet KESIP's plan, more land might be required to complement generation variability of REFs. These special land use requirements could lead to environmental destruction. For instance, wind electricity generation needs special areas with stable and fast wind speeds. These spots are usually located in a natural mountain or costal hills, often inhabited by endangered species. In addition, wind power is associated with bird deaths. As there are lots of birds in these islands, the unintended consequences of increased expansion of wind electricity generators on bird life could be substantial.

B. Debate

There has been lots of debate from among members of KESIPs. Substantial members are largely the Korea government, utilities, residents, and environmental organizations.

As KESIPs are a result of the Korea government's decisions, the government is based on administrative rationalism. The government has set a goal to reduce its carbon dioxide emission to meet international requirements under the Paris Agreement and see KESIPs as one of the options of achieving this target in the future. These are four main reasons why the Korean government have promoted KESIPs, namely, administrative rationalism, environmental economics, democratic pragmatism, and deep ecology.

Administrative Rationalism (AR)

AR may be defined as the problem-solving discourse which emphasizes the role of experts rather than citizens or producer/consumer in problem solving, and which stresses social relationships of hierarchy rather than equality or competition. (Dryzek, 2013: 5) Basic entities of AR are administrative state, experts, and managers under liberal capitalism. Indeed, under certain circumstances democracy must give way to elite rule. (Ophuls and Boyan Jr., 1992: 209) This is a reason why experts and managers in AR. In addition, as AR assumes that people subordinate to state and experts and managers control state, experts and managers are important for society to be steered in the right direction. They have to be motivated by only public interest.

Utilities including KEPCO tend to follow government's guidelines. This is because the government remains the regulator of the energy industry due to its characteristic that energy is essential to human life. Until the government's guideline gives a proper benefit to utilities, there is no reason why they object to the government. However, in the case of KESIPs there is a huge uncertainty due to oil price concerns. Initially, there was no concern to propel the KESIPs due to high oil price, but these days utilities are anxious about continued period of low oil prices. This position is similar to Environmental Economics (discussed next) because they not only pursue profits in KESIPs, but also pursue environmental-friendly projects for more growth under the government's regulations.

Environmental Economics (EnE)

EnE is mainly based on the economic basis and is similar to economic rationalism (ER) except that it emphasizes the need to incorporate environmental factors into the market. ER may be defined by its commitment to the intelligent deployment of market mechanisms to achieve public ends. (Dryzek, 2013: 122) The environmental economist's view that environmental degradation is caused by a failure to 'value' the environment and a lack of properly defined property rights not only forestalls criticism of the market system, but in fact promotes an extension of markets as the only way to solve the problem. (Beder, 2011: 145) Properly designed and implemented, market-based instruments – regulations that encourage appropriate environmental behavior through price signals rather than through explicit instructions – provide incentives for businesses and individuals to act in ways that further not only their own financial goals but also environmental aims such as reducing waste, cleaning up the air, or reducing water pollution. (Stavins and Whitehead, 2005: 229) In order to prevent the tragedy of the commons, the EnE insists that government should privatize or market property rights related to

environment anyway through internalizing environmental benefits and costs such as the Clean Development Mechanism, green taxes, and so on. These can lead to limitless economic growth. As environment is just a subset of economics and environment can be substituted by human and material capital, economic growth is always possible.

Residents are the most powerful member of KESIPs. Residents' support is necessary and there are largely three types of residents, notably positive, neutral, and negative. Generally, the portion of neutral residents are a majority. Although positive people are cooperative to the government's guideline, they are inactive and want to avoid direct conflicts with negative people. On the other hand, negative people do anything to object the KESIPs. This is related to personal property rights. Most of positive people have most of their property such as land or buildings in the installation area or no effects from KESIPs, but negative people usually have their property near the installation area. This is a reason why local conflicts on KESIPs are serious. Residents' position is related to Democratic Pragmatism.

Democratic Pragmatism (DP)
DP may be characterized in terms of interactive problem solving within the basic institutional structure of liberal capitalist democracy. (Dryzek, 2013: 99) Basic entities of DP are citizens and civil organizations under liberal capitalism. As DP assumes equality among citizens, interactive political relationships, and mixing competition and cooperation, communications between the government and citizens are important. Citizens who are motivated by a mix of material self-interest and multiple conceptions of public interest are always in the center of discussion on policy decisions. This is because effective decision-making, from an environmental viewpoint, involves both expertise and the views of those who are most affected by the decisions at hand. (Paehlke, 2005: 166)

Environmental organizations are some sort of seasoning to make local conflicts smaller or bigger. They cannot do anything by themselves, but can amplify local conflicts with residents' advocacy easily. Generally, there are two types of environmental organizations which are moderate and radical. Moderate ones want to proceed and expand the KESIPs for the sustainability of the world continuously. However, radical ones hinder the KESIPs to prevent any destruction of the nature.

Deep Ecology (DE)

DE values species, populations, and ecosystems, not just individual creatures. Biocentric equality means that no species, including the human species, is regarded as more valuable or in any sense higher than any other species. Deep ecologists are quite clear on what to do when it comes to wilderness: preserve, expand, and protect it. They have much less to say on other environmental issues, such as air and water pollution in urban areas. This is because unban agglomerations are by definition outside the bounds of defensible human-nature interactions. (Dryzek, 2013: 187-189)

3. Analysis on KESIPs

A. Background on Main Technologies of KESIPs

Improvement in efficiency of renewable energy technologies such as PV and wind electricity systems is ongoing and has become better globally. New technologies will be developed continuously in the future, too. Among them, there are five representative renewable energy source technologies which can be related to KESIPs well. They are solar power, wind power, micro-hydro power, fuel cell, and waste-to-energy.

Solar power and wind power are one of the most economic electricity sources. Generally, islands have good wind potentials. Because water, gas, and trash are the inevitable things of human lives, micro-hydro power, fuel cell, and waste-to-energy can be considered as killing two birds with one stone. In addition, they can help address intermittency of solar power and wind power.

Besides them, there are two inevitable non-renewable energy technologies which can make up for unreliability of above renewable energy technologies. They are battery storage power stations and smart grid. Battery storage power station can save electricity when oversupply and provide electricity when undersupply. Smart grid can help manage variable renewable energy sources efficiently. According to the U.S. Energy Information Administration (EIA), cost specification of each plant is shown in the table below (EIA, 2017b: 2) (EIA, 2017c: 8).

	Lifetime (yrs)	Capital cost ($/kW)	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	Total LCOE ($/MWh)	Area (km2/GW)
Solar PV	20	2,277	21.66	0	85.0	10-50
On-shore Wind	20	1,686	46.71	0	63.7	100
Off-shore Wind	20	6,391	77.30	0	157.4	-
Micro hydro	60	2,220	14.93	2.66	66.2	
Fuel Cell	10	7,221	0.00	44.91	-	
WTE	40	8,623	410.32	9.14	102.4	>=1000
Battery	10	2,813	40.00	8.00	-	

Table 2. Cost of each renewable energy plants (Source: EIA)

a. Solar Power

Solar power is the conversion of energy from sunlight into electricity. There is no need on fossil fuel to generate electricity. Only sunlight is required for generation. It leads to the lowest level of effects on environment compared to other energy sources. However, capacity of solar electricity generation is location specific. Efficiency of typical PV module ranges from 15% to 25% and its capacity factor[1] is around 25%. According to EIA, PV's capacity factor in US is 27.2% in 2016.

Generally, there are largely two forms of solar power generation facilities, photovoltaic (PV) and concentrated solar power (CSP). PVs convert sunlight into an electric current directly through themselves. On the other hand, CSPs have more complex conversion processes, which are sunlight > thermal energy > mechanical energy > electricity. In the case of only heating, above processes can be reduced as sunlight > thermal energy (Hegedus, 2017: 11).

Economic feasibility of solar power has improved drastically. Module prices of PV have also decreased rapidly over the years, from $1.7 per watt in 2010 to around $0.6 per watt in 2017. These days, electricity from solar power makes market price lower than before in some areas. According to EIA, estimated levelized cost of electricity (LCOE)[2] of new PV is similar to advanced combined cycle natural gas plant with

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[1] Capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.

[2] LCOE is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime.

carbon capture storage and about 1.5 times of advanced combined cycle natural gas plant which is one of the most efficient fossil fuel plants (EIA, 2017c: 7).

b. Wind Power

Wind power technology is the conversion of energy from mechanical force of wind into electricity (Hegedus, 2017: 11). There is no need for fossil fuel to generate electricity. Only wind is required for generation. Wind power has low effects on environment except for noise and birds strikes. However, because there are variations on wind speeds, the generation of wind power plants mainly depends on condition of installed regions. Capacity factor of typical wind turbine ranges from 35% to 44%. According to EIA, capacity factor of PV's in the US was 34.7% in 2016.

Generally, there are largely two forms of wind power technologies, notably onshore and offshore. Both have the same conversion processes, which are mechanical energy of wind > electricity. Their difference is installation area. Onshore wind power is installed on land. On the other hand, offshore wind power is placed in water area. As there is no foundation for installation in water area, LCOE of offshore wind power is about 2.5 times as much as onshore despite higher wind potential. Therefore, offshore wind power is not considered in this paper due to its expensiveness.

Economic feasibility of wind power has improved gradually. Enlargement of wind turbine makes wind power more efficient. For example, one 6MW wind turbine is cheaper and makes more electricity than two 3MW wind turbines. The larger the capacity of wind turbine, the longer are the blades. Longer blades can generate electricity even in places with low wind potential. Commercialized wind turbine was 1~2MW in 2000, and now 8MW (MOTIE, 2016: 428). Electricity from wind power makes market price lower than before in some areas. According to EIA, estimated LCOE of new wind power is about 1.16 times of advanced combined cycle natural gas plant which is one of the most efficient fossil fuel plants (EIA, 2017c: 13).

c. Micro Hydro Power

Micro-hydro power is a type of hydro power that typically produces under 5,000kW of electricity using water flow. Unlike large-scale hydro power which makes big ecological changes on environment, micro-hydro power has no direct GHG emissions and little harmful effects on environment. However, because there is limitation on the site such as plenty water flow, it is difficult to find good sites for micro-hydro power in islands (MOTIE, 2016: 460-464). So it seems better to add pumping-up power generation micro-hydro power.

There is always scarce water in small islands because most of the rain drains into sea. This problem occurs on almost of Korea's islands. Korea government has tried to solve it through seawater desalination, (Ministry of Environment, 2017) but micro-hydro power generation could also be a potential solution. In the case of islands with rivers, the streams can provide good locations for siting micro-hydro power facilities. Besides, the potential of streams for siting micro-hydro power can be a source of water for domestic use in the islands. Of course, purification plants have to be added. Micro hydro power can be killing two birds with one stone.

In addition, when pumping-up power generation is added to the micro-hydro power units, it can act as some sort of energy storage. As mentioned earlier, although solar and wind power are intermittent and could exacerbate grid stability challenges, they provide the most reliable energy sources for the island due to their economic feasibility. Micro-hydro power can be supplemental energy source as energy storage.

d. Fuel Cell

Fuel cells convert chemical energy from fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Through this process, only water and heat without air pollution occurs. This heat can be used to supply heating to neighboring areas. Therefore, fuel cell has above 80% efficiency including heat and low harmful effects on environment. Unlike fossil fuel plants, fuel cell has little limitation on the site. Economy of scale is hardly applied to fuel cell. Even small size of fuel cell has similar efficiency to large size. In addition, because fuel cell is made as a module, capacity addition is easy (MOTIE, 2016: 228-231).

However, current fuel cell mainly depends on LNG for hydrogen which is used as primary fuel in electricity generation. It leads to high fuel cost and low economic feasibility. In addition, as installation cost of fuel cell is also high, economic feasibility of fuel cell is lower (EIA, 2016: 8).

Korea government has fulfilled LPG tank projects on rural areas which have no connection to LNG pipelines. The goal of these projects is equity between rural and urban areas. This is because LNG price of urban areas from LNG pipelines is cheaper than LPG price of rural areas (MOTIE, 2014). If these projects are applied to islands, installation cost of fuel cell can be lowered.

e. Waste-to-Energy

Waste-to-energy is the process of generating energy in the form of electricity and heat through waste combustion. Waste is inevitable and is a by-product of human activities as well as bio-chemical processes. Almost all the islands in Korea don't have waste treatment facilities and dump their trash into the sea. Waste treatment and management in the islands is needed to reduce environmental harmful effects. If there is sufficient trash in some islands, waste-to-energy plants can be good choice for them.

Although there are many waste-to-energy technologies, only incineration is considered here due to limitation of area in the islands. Incineration plants can emit fine particulate, heavy metals, dioxin, and acid gas, even if these emissions are relatively low. Through recycling, amount of burning waste should be minimized to prevent environmental harmful effects. (MOTIE, 2016: 588-592)

f. Battery Storage Power Station

Battery storage power station is a form of storage power plant which uses electrochemical batteries. It can be used to cover peak load and improve electric grid stabilization. For example, although renewable electricity generation is intermittent, with battery storage the reliability of the resulting electricity can be improved. Also, capacity generation can be s made as a module, its capacity can be added easily. In addition, as its control times are the shortest among energy storages such as pumping-up, it can play a role in preventing blackout from late response on supply and demand mismatch. However, its price is still in high level due to use of rare metals.

g. Smart Grid

Smart grid is a next generation of intelligent electrical grid which is applied information and communication technologies to current electrical grid to get maximum efficiency. Real time bi-directional communication between consumers and suppliers can make smart grid possible. For example, suppliers can control their generation according to real time demand and consumers can select the cheapest electricity according to real time pricing.

Intermittency of some renewable energy technologies can be solved through smart grid, because smart grid can control demand and supply simultaneously. It can lead to more penetration of renewable energy technologies and make pollution from fossil fuel plants be less. This is because buffer supply preventing blackout can be minimized due to quick response of smart grid.

B. Possible Scenarios of KESIPs

a. Analysis on Korean islands

To induce possible scenarios of KESIPs, it is necessary to analyze the information of Korean islands which are supplied by diesel generation. The KEPCO has published power statistics annually. In 2016 version, I found that there are 54 islands except for Jejudo which is the largest island in Korea. An area and a population of each island is found in Korean National Statistical Office and Korean islands mission. Below table has this information (KEPCO, 2016: 36-38).

	Capa-City (kW)	Diesel (kl)[3]	Gener-ation (MWh)[4]	Average Load (kW)[5]	Peak load (kW)[6]	Popul-Ation	Area (km2)
Ulleungdo	18,500	15,277	59,331	6,773	11,904	10,001	72.861
Huksando	4,000	3,957	14,795	1,689	2,562	4,365	19.700
Chujado	5,500	3,324	13,221	1,509	2,232	1,906	7.050
Gumundo	3,500	2,563	9,722	1,110	1,848	1,900	12.000
Duckgeukdo	2,900	2,760	10,356	1,182	1,875	1,413	21.000
Wedo	2,850	1,472	5,299	605	1,155	1,268	14.280
Jodo	2,000	2,190	8,134	929	1,818	3,181	57.110
Backryungdo	9,000	12,448	48,800	5,571	8,352	5,443	51.086
Daechungdo	3,550	2,342	9,450	1,079	1,593	1,392	12.623
Sochungdo	2,650	1,053	3,868	442	648	266	2.910
Yeonpeongdo	7,700	5,042	19,299	2,203	3,366	2,182	6.140
Jawaldo	1,650	869	3,281	375	819	651	7.040
Hongdo	2,350	1,121	4,076	465	1,404	400	6.470
Biyangdo	240	111	295	34	65	100	0.580
Yeoseodo	240	134	388	44	83	74	2.510
Gapado	450	348	1,207	138	230	245	0.900
Duckwoodo	390	116	334	38	75	128	1.200
Whado	240	111	317	36	80	175	1.207
Biando	240	220	559	64	122	358	1.630
Yeondo	260	148	446	51	156	234	0.873
Eochungdo	1,250	834	3,069	350	580	412	2.070
Gaeyado	1,500	723	2,684	306	697	948	1.270
oiyeondo	750	398	1,335	152	280	451	0.528
Soyeonpeongdo	300	287	836	95	265	106	0.241
Sapsido	900	592	2,140	244	762	464	3.780

[3] Diesel means an annual consumption of diesel plants of each islands.

[4] Generation means an annual generation by diesel plants of each islands.

[5] Average load is an annual average demand supplied by diesel plants of each islands.

[6] Peak load is an annual maximum demand supplied by diesel plants of each islands.

Seungbongdo	1,950	1,208	4,444	507	1,143	158	2.216
Phungdo	240	289	931	106	180	169	1.843
Gaeudo	240	96	242	28	52	68	2.190
Gagudo	1,050	795	2,790	319	575	469	9.180
Yeojado	450	187	645	74	150	219	0.474
Chudo	240	172	438	50	104	141	2.500
Eoeudo	160	48	123	14	36	105	1.600
Suwoodo	160	50	136	15	28	40	1.284
Maemuldo	240	251	593	68	153	133	1.810
MunGapdo	240	116	336	38	64	109	3.490
Janggodo	240	302	962	110	267	307	1.500
Godaedo	300	189	611	70	149	220	0.875
Seungnamdo	160	60	155	18	52	36	1.330
Dockgudo	160	51	128	15	38	46	1.689
Gujado	240	93	229	26	51	30	0.371
Suldo	240	71	109	12	76	19	0.270
Songido	260	123	360	41	107	90	4.440
Nackwaldo	750	247	750	86	155	615	12.130
Hodo	300	194	582	66	176	223	1.301
Nockdo	260	113	322	37	64	195	0.895
Sisando	750	265	836	95	188	247	3.650
Duckryangdo	300	116	328	37	68	104	1.750
Eoryongdo	240	77	147	17	42	28	0.369
Wangdungdo	240	74	130	15	42	47	0.420
Uldo	240	83	238	27	50	27	1.760
Sonjuckdo	300	213	651	74	132	187	2.919
Peongdo	240	63	118	13	44	29	0.410
Chodo	750	341	1,189	136	248	464	7.705
Sangwhado	240	79	178	20	38	38	0.030
Average	**1,557**	**1,193**	**4,480**	**511**	**879**	**789**	**6.990**

Table 3. Status of Korean islands which are supplied by diesel plants. (Source: KEPCO, Korean National Statistical Office, and Korean Islands mission)

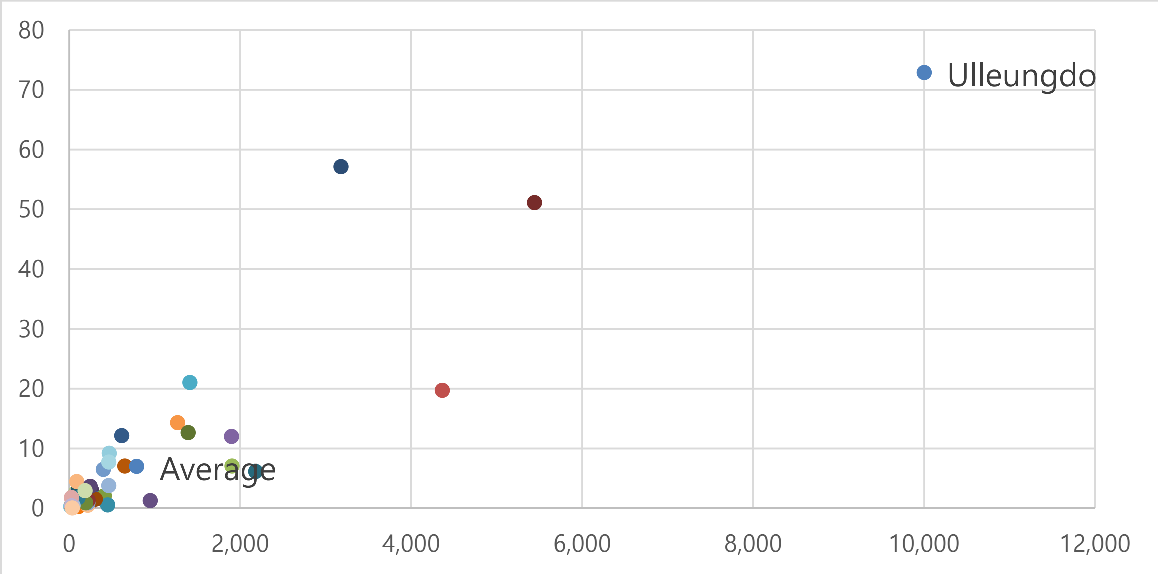

Figure 5. Population and Area of diesel generated Korean Islands (Source: Kepco, Korean National Statistical Office, and Korean Islands mission)

As you can see in the above table, there are two statistical tendency. The first is that generation facilities of islands generally have enough spare capacity compared to average load and peak load. This is because Korea has a low birthrate problem and urban area concentration problem which are the most serious in the world. These have made population of islands decrease gradually and these days more than half of people living in islands are seniors. It is difficult to hear even infants' cries in small islands. The second is that their population is proportional to their area. There are only ten islands which have more than thousand population and most of islands are near the average. Therefore, my target on KESIPs is the average island which has 789 residents, 6.990 km2, annual demand 4,480 MWh, average load 511 kW, and peak load 879 kW.

No. of residents	789
Area (km2)	6.99
Annual demand (MWh)	4480
Average load (kW)	511
Peak load (kW)	879

Figure 6. The information of the target (Picture source: http://www.travelro.co.kr/repository/d01/route/2011/04/14/1302751723465.jpg

b. Assumptions for simplicity

Thiis research used an integrated regional energy policy and planning framework (IREPP) which is a comprehensive conceptual framework designed to assist policy makers and planners at regional levels in developing and evaluating sustainable energy programs and policies (Wang, Chen, and Park, 2012: 237). IREPP identifies energy issues and targets integrates resources, considers other dimensions, and evaluates the result. However, this process is so complicated that many prerequisites are required to do the analysis on the KESIPs.

For simplicity of estimation, I make eight prerequisites. The first is that annual demand of the target is stable business period of KESIPs. If annual demand is changed, scale of needed REFs will be also changed. It means that calculation will be more complex. Fortunately, it can be assumed that annual demand of the target is stable. This is because decrease of population can offset increase of average personal electricity consumption. electricity consumption per capita has increased due to convenience gradually. In addition, electric vehicles have been more popular than before. In other words, annual demand of the target which decide required capacity of REFs can be suggested as a constant throughout business period of KESIPs.

The second is that capacity of solar and wind power is decided by peak day demand. There are two reasons. The first is that REFs of islands can supply peak day demand. The second is that proper mix of solar and wind power is the most economic and realistic option among the above explained REFs due to their cheapest capital cost and capacity expandability. Of course, their generation depends on weather condition. In other words, as they are variable sources, they cannot supply variable demand properly. So supplementations on this prerequisite are added like next three prerequisites.

The third is that battery storage power station plays a role to solve mismatch between demand and supply of solar and wind power. As earlier explanation, there is mismatch between demand and supply of solar and wind power due to their variance of generation. However, battery storage power station can store spare electricity and supply it at required time. In other words, sufficient battery storage power station can make solar and wind power to act like conventional power plants. However, because it is very expensive, its size should be decided properly.

The fourth is that capacity sum of micro-hydro power, fuel cell, and waste-to-energy is decided by 15% of peak load. Micro hydro power can play a role storing spare electricity from solar and wind plants and supplying it at required time. Waste-to-energy can also supply heat as well as electricity at required time. Due to their limited storage, however, their role is also limited to hourly and daily mismatch between demand and supply of solar and wind. 15% reserves are come from the Korean government. For supply stability of electricity, the Korean government has tried to maintain 15% reserves of predicted annual peak load due to irregular demand increase. This value is come from experiences of relevant expertise. The more reserves lead to the more costs and the less reserves lead to high possibility for blackout. In other words, micro-hydro power, fuel cell, and waste-to-energy cope with hourly, daily demand of the target for an efficient role allocation among REFs.

The fifth is that especially bad weathers such as continuous cloudy or breezeless days are not considered. This is because it is difficult to estimate capacity of REFs under these conditions. They can be five days or more. The more are they, the more expensive is their LCOE. In these cases, I assume that free demand response programs such as sequential blackout cover overdemand.

The sixth is that capacity factors of solar and wind power are 18.2% and 34.7% respectively. There are no exact data of each island, but annual sunshine duration of each country is 2065.9 hours for Korea and 2000~4000 hours for US cities. So I assume that capacity factor of solar power in Korea is two thirds of US average which is 27.2% in 2016 and capacity factor of wind power is same to US average which is 34.7% in 2016.

The seventh is that the efficiency of energy storage systems is 80%. There are two sorts of Energy storage systems which are battery storage power station and micro-hydro power. They can store spare generation of solar and wind power and supply it at required time. when a spare energy is stored in energy storage system and stored energy is used, its efficiency is usually 70~90%.

The eighth is that loss rate of transmission and distribution is 5%. Some REFs have a limit on their position unlike diesel plants due to their potential. For example, as wind power needs steadily windy places such as hillsides, a distance between plants and villages is longer than diesel generators. There is a need for considering additional loss of transmission and distribution. I assume that it is 5%.

c. Consideration on mix of REFs

Let's consider a scale of required REFs of the target. The scale of required REFs depends on peak load absolutely. As generation of solar and wind power is variable, their average hourly generation and hourly demand of peak load day have to be considered together for the better economic feasibility. However, I cannot find relevant data of any island in Korea. So I try to guess hourly demand of peak load day through estimation.

The monthly demand of the target can be estimated from whole demand data of Korea. There are largely six sorts of electricity rate in Korea which are house, industry, education, agriculture, lighting, and the others. As there is an insignificant demand of industry in normal islands, real demand of islands can be similar to the power which is whole demand minus industry in Korea. Monthly demands of Korea except for industry use are in below figure.

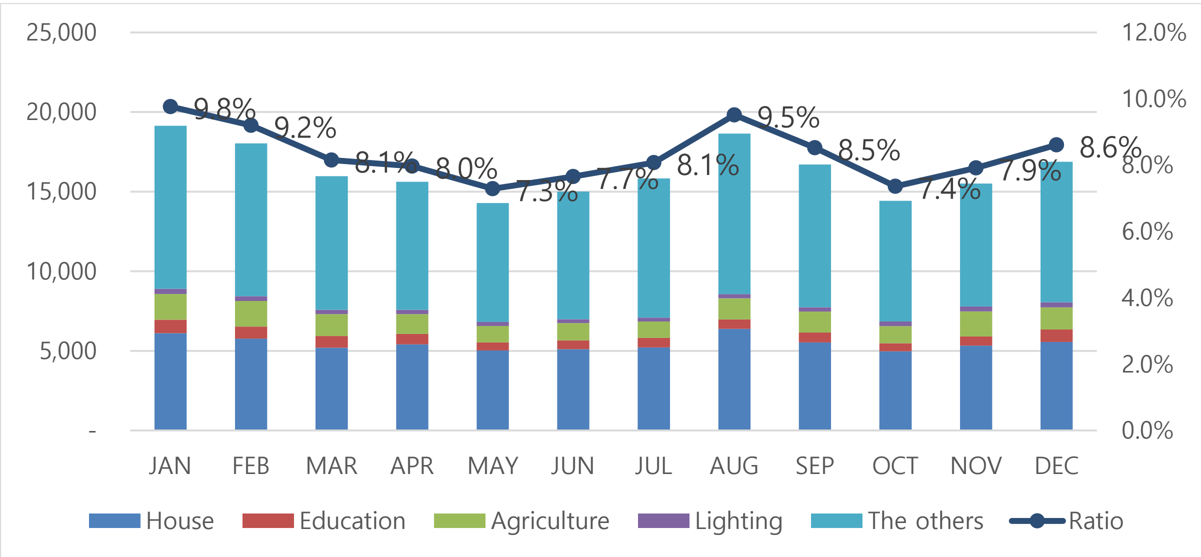

Figure 7. Monthly demands of Korea except for industry use (Source: KEPCO)

This leads to estimated monthly and average daily demand of the target in below table. Estimated monthly demand of the target is the product of monthly ratio of the above figure and annual demand of the target. Estimated average daily demand of the target is estimated monthly demand of the target divided by each month day. As a result, average daily demand of FEB is the highest among them. This is reasonable to KESIPs because personal heating needs such as an electric blanket are increased dramatically during winter in Korea. When it is assumed that demand of the peak day is 1.2 times as many as average daily demand, daily demand of the peak day would be 17.6 MWh.

	1	2	3	4	5	6	7	8	9	10	11	12
Ratio (%)	9.8	9.2	8.1	8.0	7.3	7.7	8.1	9.5	8.5	7.4	7.9	8.6
Monthly Demand (MWh)	437	412	365	357	327	343	362	426	381	330	355	386
Daily Demand (MWh)	14.1	**14.7**	11.8	11.9	**10.5**	11.4	11.7	13.7	12.7	10.6	11.8	12.4

Table 4. Estimated monthly and daily average demand of the target

The only thing we know the information of the target related to the peak day is peak load of the target which is 879 kW. In addition, we already estimate daily demand of the peak day which is 17.6 MWh. From these information, demand curve of the peak day can be estimated as below figure. I assume the peak day is weekday because peak load of weekend is usually less than weekday due to low industrial demand. If capacity of solar and wind power were adjusted according to the peak day demand, there might be no shortage anytime except for especially bad weathers.

In case of the least day, similar analysis can be done like the peak day. The average daily demand of MAY is the lowest among them. When it is assumed that demand of the least day is 0.8 times as many as average daily demand, daily demand of the least day would be 8.4 MWh. There is no data related to the peak load of the least day. So I make virtual demand curve like below figure with reference to the demand curve of the peak day and daily demand of the least day. Unlike the peak day, heating demand is not considered for the least day because it is May.

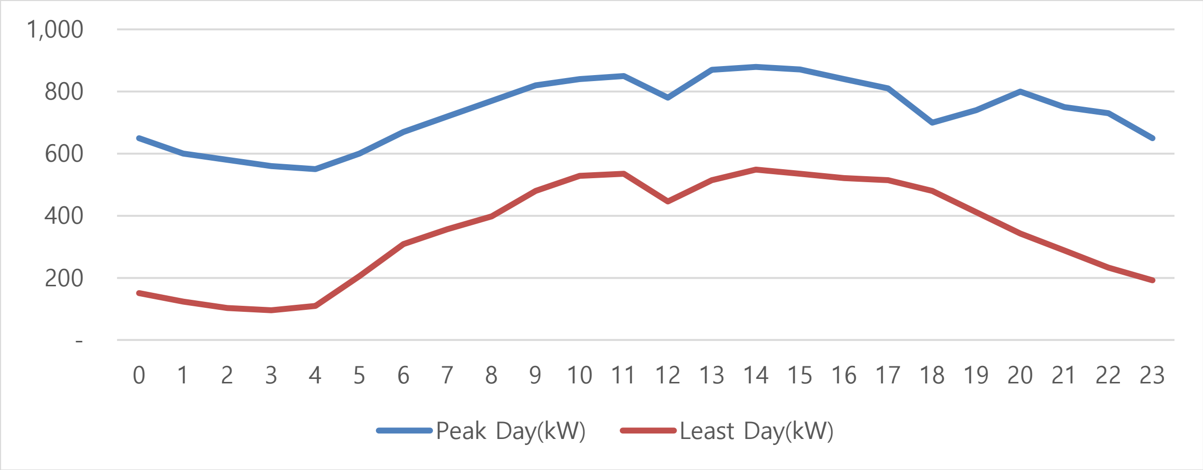

Table 5. Figure 8. Estimated hourly demand curves of the target

Let’s consider general generation curve of solar and wind power which is the most economic among lots of REFs. Below figure is normal average hourly generation of solar and wind power. As you can see, correlation between solar power generation and demand is higher than wind power. Variation of solar power is also higher than wind power because solar power cannot generate electricity during night and bad weather. So mixture of solar and wind power is necessary for stability of supply.

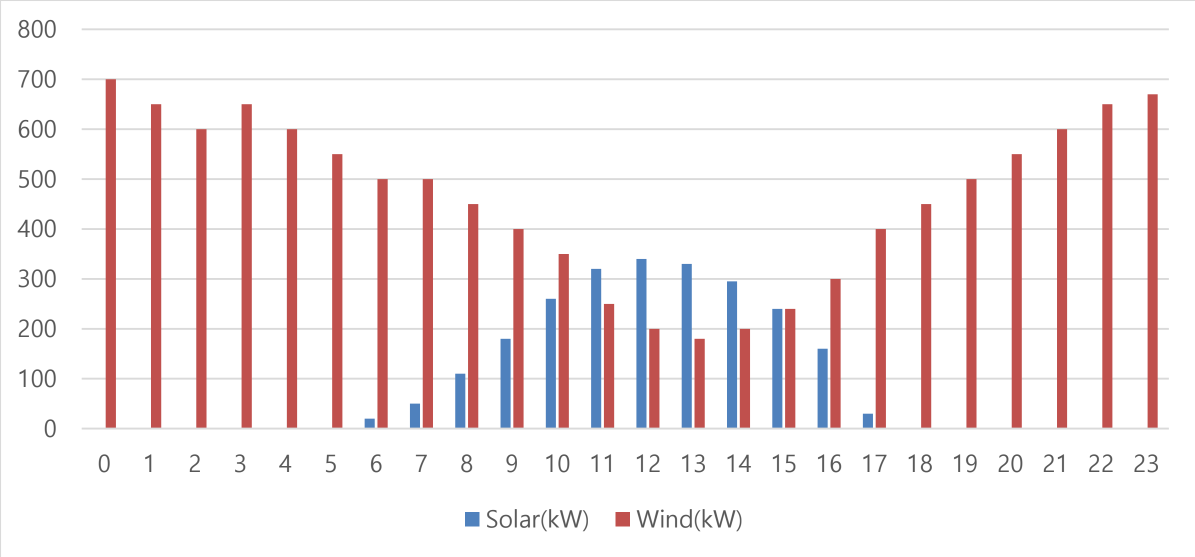

Figure 8. Normal generation curves of solar and wind power

Paul Denholm and Maureen Hand wrote an article which subject was Grid flexibility and storage required to achieve very high penetration of variable renewable electricity. In this article, an efficient mix rate of solar and wind power is three options which are solar 20% / wind 80%, solar 30% / wind 70%, and solar 40% and wind 60%. The other options curtailed electricity from solar and wind much more due to mismatch of supply and demand. (Denholm, 2011: 1823-1827) Therefore, there are three reasonable options for mix of solar and wind power which are solar 20% / wind 80%, solar 30% / wind 70%, and solar 40% and wind 60%.

Let's consider comparisons of each mix to each demand to look for proper capacity of energy storage system. The conditions to consider are the peak day demand 17.63

MWh, capacity factor of solar power 18.2%, capacity factor of wind power 34.7%, and the loss rate of transmission 5%. Capacity is calculated as $\frac{the\ peak\ day\ demand * mix\ rate}{8760\ hr * capacity\ factor}$.

In case of solar 20% / wind 80%, capacity of solar and wind power is 848 kW and 1,778 kW respectively. Demand and supply curves in the peak day can be estimated like below figure. Required minimum capacity of energy storage systems is 1,509 MWh which is 2.95 times as many as average load. I don't consider charge loss of energy storage systems, because there is a sufficient remaining balance in energy storage systems. As the peak day has the highest demand in the year, there would have been spare power before the peak day continuously.

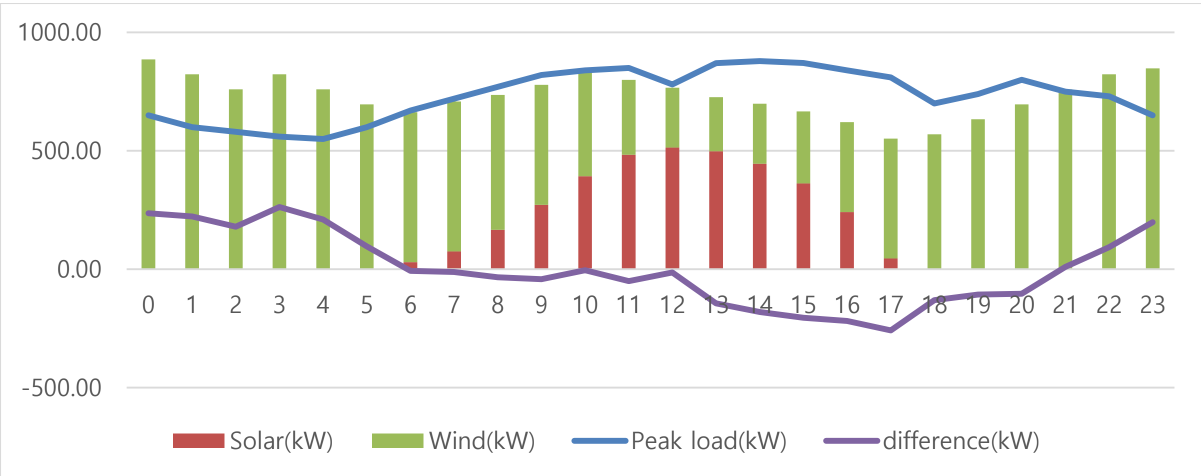

Figure 9. Demand & Supply curves of the peak day in mix of solar 20% & wind 80%

In case of solar 30% / wind 70%, capacity of solar and wind power is 1,271 kW and 1,556 kW respectively. Demand and supply curves in the peak day can be estimated like below figure. Required minimum capacity of energy storage systems is 1,325 MWh which is 2.59 times as many as average load.

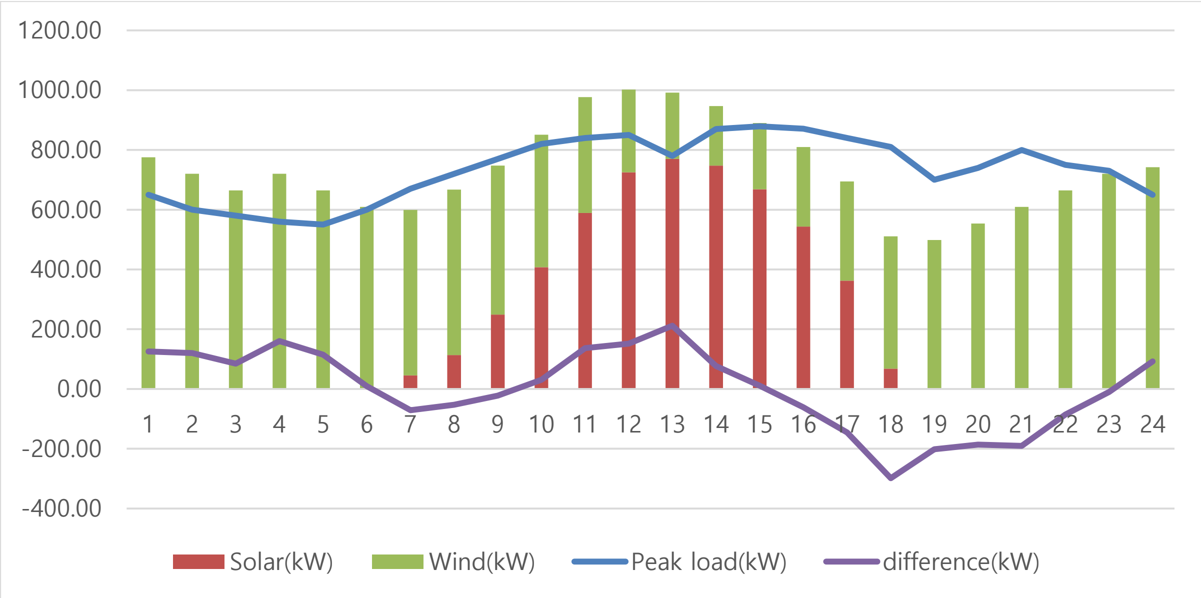

Figure 10. Demand & Supply curves of the peak day in mix of solar 30% & wind 70%

In case of solar 40% / wind 60%, capacity of solar and wind power is 1,695 kW and 1,334 kW respectively. Demand and supply curves in the peak day can be estimated like below figure. Required minimum capacity of energy storage systems is 1,862 MWh which is 3.64 times as many as average load.

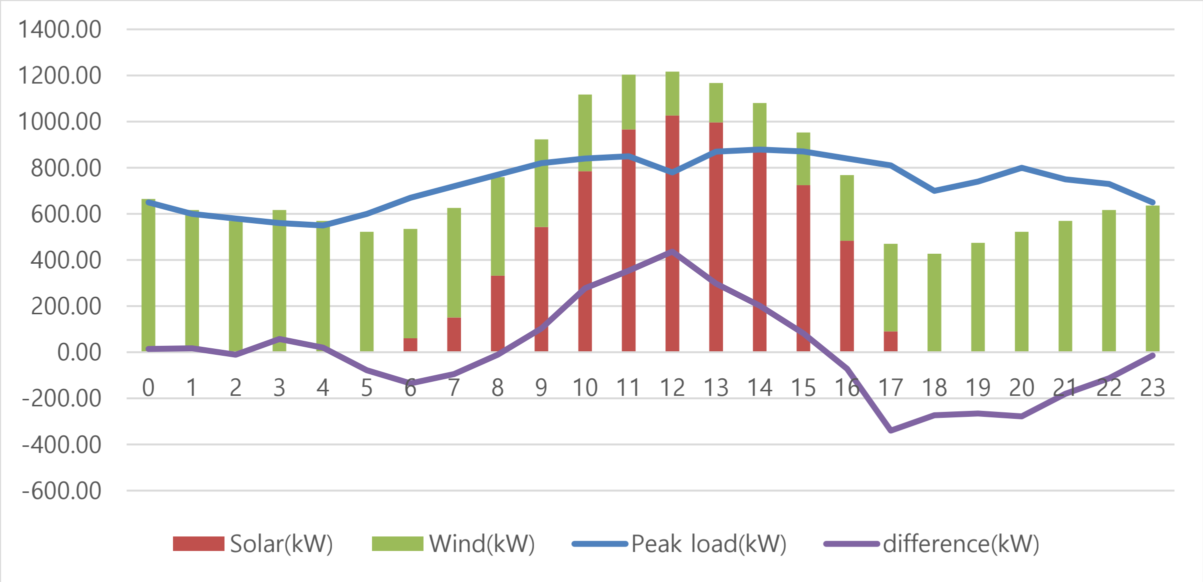

Figure 11. Demand & Supply curves of the peak day in mix of solar 40% & wind 60%

Let's consider capacity of the other REFs except for solar and wind power. There are four sort of REFs which are micro-hydro power, fuel cell, waste-to-energy, and battery storage power station. As you can see in above table 2, fuel cell is too expensive at this time. So I consider micro-hydro power, waste-to-energy, and battery storage power station.

The first is micro-hydro power. I consider a present plant as a reference. Sincheon sewage treatment plant in Daegu has 139kW micro-hydro power which has four meters head of water. (Daegu Gyeongbuk Development Institute, 2002)

Per capita average daily water consumption in Korea is 332 liters. This water is inevitable to people of each island. In order to supply and treat this amount of water, water supply facility and sewage treatment plant should exist in the target and these can have micro-hydro power like the above practice.

In order to calculate its capacity, I assume four conditions. The first is that head of water of every micro-hydro plant is 5 meter. The second is that an efficiency of the plants is 90%. The third is that capacity of pumped storage is island's required water of 120 days which is 31.45 Ml. The fourth is that pumped plant can generate electricity during four hours using full tank.

In base of above conditions, micro-hydro power plant can supply maximum limit 96.32 kW[7] during four hours using its full tank. It is same to 11.0% of peak load. In addition, it can generate electricity repeatedly during a day. After water is moved from lower tank to upper tank using spare electricity, generation can be done at required time. Its annual generation can be changed according to mismatch between demand

[7] Maximum limit of micro-hydro power plant = potential energy of full tank * plant efficiency * conversion factor between jule and Wh / operation hour = 31.45 Ml * 9.8 m/s2 * 5 m * 90 % * 0.0002778 J/Wh / 4 h = 96.32 kW

and supply. When micro-hydro power plants generate electricity using full tank once a day, the annual generation of micro-hydro power is 140.63 MWh. The ratio of annual generation of micro-hydro power to the whole annual demand is about 3.1%.

Figure 12. Shincheon sewage treatment plant and micro-hydro plant in Daegu (Source: Daegu Environmental Corporation)

The second is waste-to-energy. Per capita average annual waste emission in Korea is 310 kg and conversion factor of municipal solid waste plants in US is 0.481 MWh/ton. When it is assumed that waste-to-energy plant works four hours a day, capacity of waste-to-energy plant is 80.68 kW. It is same to 9.2% of peak load. Because an annual waste emission is limited, the annual generation of micro-hydro power is 117.80 MWh. The ratio of annual waste-to-energy generation to the whole annual demand is about 2.6%.

Capacity sum of micro-hydro power and waste-to-energy is 20.2% of peak load during four hours. This is similar to the Korean government's guideline for stability which is 22% reserves of peak load. The government has tried to maintain 22% reserves of predicted annual peak load due to possibility of unpredicted demand increase and facilities malfunction. This value is come from experiences of relevant expertise. The more reserves lead to the more costs and the less reserves lead to high possibility for blackout. It seems like that the above pumped micro-hydro plants and waste-to-energy plants can play a role like at least 20.2% reserves during 4 hours.

At last, energy storage systems could reduce fraction of curtailment from solar and wind. The more is a capacity of energy storage system, the less is curtailment from solar and wind. When a fraction of system electricity from solar and wind is 80%, a fraction of generation curtailed from solar and wind is about 33% for no storage, 18% for 4 hours of average demand, 13% for 8 hours, 11% for 12 hours, and 9% for 24 hours. (Denholm, 2011: 1823-1827)

Energy storage systems includes micro-hydro power and battery storage power station. When the above explained micro-hydro power plant is full tank, its generation capacity is 385.28 kWh which is 0.75 times as many as average load. It means that empty micro-hydro power plant is same to battery storage power station which has an output capacity 385.28 kWh. Therefore, Required capacities of battery storage power station are 1658.72 kWh for 4 hours of average demand, 3895.36 kWh for 8 hours, 5939.36 kWh for 12 hours, and 12071.36 kWh for 24 hours.

As battery storage power station has relatively expensive capital cost and short lifetime, its capacity should be minimized for the better economic feasibility. The capacity of solar and wind power is determined by the demand of peak day. It means that there is usually spare electricity except for the peak day when bad weather is not considered.

We already saw the required minimum capacity of energy storage systems for each mix of solar and wind power in the analysis on three mix cases of solar and wind power. They are reasonable values because the peak day is the hardest condition in terms of supply. Therefore, minimized capacities of battery storage power system could be

1,123.33 kWh for solar 20% / wind 80%, 939.87 kWh for solar 30% / wind 70%, and 1,476.29 kWh for solar 40% / wind 60%.

Let's estimate daily usage rate of each case. Daily usage rate is 100% for the peak day. On the other hand, daily usage rate of the least day is 0.0% for solar 20% / wind 80%, 0.7% for solar 30% / wind 70%, and 19.0% for solar 40% / wind 60%. When it is assumed that the average usage rate is an average of the peak day and the least day, it is 50.0% for solar 20% / wind 80%, 50.4% for solar 30% / wind 70%, and 59.5% for solar 40% / wind 60%. Therefore, annual usage of each case is 205.01 MWh for solar 20% / wind 80%, 172.71 MWh for solar 30% / wind 70%, and 320.67 MWh for solar 40% / wind 60%.

Through above explanations, I can make three possible scenarios of KESIPs on the target which are in below table. The difference among them is caused by different mix of solar and wind power in each scenario. As the target of each scenario is same, capacities of micro-hydro power and waste-to-energy plant which depend on population of the target are also same. Capacity of battery storage power station is also influenced by different mix of solar and wind power in each scenario.

Scenario	Solar (kW)	Wind (kW)	Micro hydro (kW)	Waste-to-energy (kW)	Battery storage power station (kWh)
1st	848	1,778	96.32	80.68	1,123.33
2nd	1,271	1,556			939.87
3rd	1,695	1,334			1,476.29

Table 6. Three possible scenarios of KESIPs

C. Specific Analysis on KESIPs

a. Economic Feasibility

From above table of EIA's cost specification of each plant, detailed cost of each scenario can be calculated in a below table. I assume that there are no effects related to interest rate, inflation rate, generation decline rate of PV, and decrease rate of electricity demand for simplicity. In order to calculate total LCOE, lifetime of whole system is 120 years. For example, solar/wind powers are installed 6 times and battery is installed 12 times. And I assume that micro-hydro power plant and battery storage power station work once a day fully for calculation of variable O&M cost.

Scenario		1st	2nd	3rd
Solar (20yrs)	Capital cost($)	1,929,976	2,894,965	3,859,953
	Fixed O&M($/yr)	18,359	27,538	36,718
	Variable O&M($/yr)	-	-	-
	Annual generation(MWh/yr)	1,351	2,027	2,703
Wind (20yrs)	Capital cost($)	2,998,116	2,623,352	2,248,587
	Fixed O&M($/yr)	83,062	72,679 62	62,296
	Variable O&M($/yr)	-	-	-
	Annual generation(MWh/yr)	5,405	4,730	4,054
Micro hydro (60yrs)	Capital cost($)	235,210	235,210	235,210
	Fixed O&M($/yr)	1,438	1,438	1,438
	Variable O&M($/yr)	374	374	374
	Annual generation(MWh/yr)	141	141	141
WTE (40yrs)	Capital cost($)	695,734	695,734	695,734
	Fixed O&M($/yr)	33,106	33,106	33,106
	Variable O&M($/yr)	1,077	1,077	1,077
	Annual generation(MWh/yr)	118	118	118
Battery (10yrs)	Capital cost($)	3,159,932	2,643,866	4,152,814
	Fixed O&M($/yr)	44,933	37,595	59,052
	Variable O&M($/yr)	1,640	1,382	2,565
	Annual usage(MWh/yr)	205	173	321
Total (120yrs)	Capital cost($)	70,045,363	67,393,916	89,042,626
	Fixed O&M($/yr)	180,898	172,356	192,610
	Variable O&M($/yr)	3,091	2,832	4,016
	Sum of all costs ($)	92,124,018	88,416,582	112,637,751
	Annual demand(MWh/yr)	4,480	4,480	4,480
	LCOE($/kWh)	**0.171**	**0.164**	**0.210**

Table 7. Economic analysis of each scenario

Since diesel costs about 1,300 won per liter in Korea and the currency rate is about 1,130 won per $, generation cost of diesel is 0.31 $/kWh. LCOE of each scenario is about 0.56 times for the 1st scenario, 0.54 times for the 2ndscenario, and 0.68 times for 3rd scenario. These costs are less than the fuel cost of diesel generation. In other words, every scenario of KESIPs have an advantage to diesel generators.

If shipping charge of diesel is considered, generation cost of diesel is about 0.35 $/kWh. This is because there is a difference between diesel price of islands and the average due to shipping charge. According to Korea National Oil Corporation, diesel price of Ulleungdo is usually 250 won per liter more expensive than the average, although Ulleungdo has the most population among islands except for Jejudo. Of course, a distance between Ulleungdo and main land is very far, but relatively big ships are used to carry diesel. In case of a small island, its distance is short, but diesel demand is small. These can lead to shipping charges similar to Ulleungdo. I assume average shipping charge is 200 won per liter conservatively. Therefore, LCOE of each scenario is about 0.49 times for 1st, 0.47 times for 2nd, and 0.59 times for 3rd more than generation of diesel. It means that KESIPs have better economic feasibility.

b. Local Conflicts

There can be lots of local conflicts caused by KESIPs. Among them, declined land price is one of the severest causes. According to the Bank of Korea, net assets of Korean family are composed of ninety percent real estates and ten percent financial assets in 2016. In other words, a value of real estates is very important to Koreans. This is a reason why NIMBY is severe in Korea. In case of islands, this problem is more serious because most of residents are senior citizens whose land is the only property to them.

The installation of REFs can decrease land price of their vicinity, as explained earlier. Among REFS, waste-to-energy is the most hateful REFs due to its bad smell and air pollution. Wind power is the next order to waste-to-energy and solar power is the last order. Micro hydro power and battery storage power station have little bad effects on land price. Water scarcity of islands is severe as well as a vicinity of reservoirs is usually more expensive than the others. These can lead to preference on micro-hydro power. In case of battery storage power station, there is no bad effects on a vicinity of installation place, because it can be located in the inside of normal building.

In order to calculate the influence on local conflicts by REFs, additional considerations on solar power are required. Unlike waste-to-energy and wind power, there are largely two methods of installation to solar power which are rooftop and the others. As rooftop solar power is installed in the roof of building, there is little resistance. On the other hand, residents dislike the others such as utility scale PV. Therefore, the portion of rooftop solar power should be removed from calculation.

Let's consider rooftop solar power on the target. Most of buildings in islands are lower than the second floor due to low density of population. Even Ulleungdo which has the most population except for Jejudo has that the tallest building is fifth floor. In addition, most of residents are senior citizens in islands. There is no exact data related to it, but there is a clue. The ratio of senior citizens to population in Korea is 13.2% in 2015. Although most of metropolitan areas are less than the average, the others are higher than the average. (National Statistical Office of Korea, 2016) When high population mobility of young generation from rural areas to urban areas is considered, Korean islands would be much more serious than the average. Commonly, the size of senior citizens' family is one or two because their children already left them. Above two facts can lead to a good condition for rooftop solar power. Since the population of the target is 789, the number of available roofs can be assumed as around 300 which is estimated from that the average size of senior citizens' family is two and the number of roofs is equal to 75% of family number. This number leads to 900 kW of rooftop solar power, when average capacity of rooftop solar power is 3 kW.

There is qualitative difference among above explained REFs. Solar power is the least resistance due to its low bad effects. I assume that waste-to-energy is nine times as hateful as solar power. This is because nine times are the worst number in a nine degree scale. And I assume that wind power is two times as hateful as solar power. Relative resistance of each scenario is in the below table. Although there are small amount of difference among them, 1st scenario is the worst and 3rd scenario is the best in case of relative resistance. In other words, 3rd scenario could be the easiest to propel.

Scenario	Area(km2)			Ratio(%)			Relative Resistance
	Solar[8]	Wind	WTE	Solar	Wind	WTE	
1st	0	0.178	0.081	0	2.54	1.15	1.06
2nd	0.011	0.156	0.081	0.16	2.23	1.15	1.03
3rd	0.024	0.133	0.081	0.34	1.91	1.15	1.00

Table 8. Relative resistance of each scenario in local conflicts

c. Environmental destruction

Although REFs are more environment-friendly than diesel generators, they need more area than diesel generators. Wind power and micro-hydro power can be more destroyable to environment due to their optimal locations. Steadily windy places are the best installation location for wind power. These areas are usually located in hillsides which are surrounded by wildlife. In addition, small stream is required to build micro-hydro power. As there are few streams in islands, its installation locations are also limited. In other words, there are few ways to choose installation areas for micro-hydro power. On the other hand, the others can have more freedom on their locations. Due to low population density of islands, there are few tall buildings which have more than second floor. As explained earlier, most of islands are good places for rooftop

[8] Solar power is the value which excludes rooftop capacity.

solar power. Although waste-to-energy is the most hateful among REFs, there is no limit on its location except for residents' objection. Battery storage power system is free to select its location. Therefore, area of wind and micro-hydro power is a key to calculate environmental destruction quantitatively.

I assume that wind power is 4 times as hateful as micro hybrid power. This is because micro hybrid power is essential to sustain human life. There are lots of local conflicts from installing REFs and penetration of wind power is in a very slow progress due to objections of residents and environmental organizations. On the other hand, there is no proper place for installing large hydro power plants in Korea. This is because they were already constructed in good potential places. So even construction of micro-hydro power plants has been planned. This means that there is considerable relative resistance between wind power and micro hybrid power.

Scenario	Wind		Micro hydro		Relative Resistance
	Area(km2)	ratio to island	Area(km2)	ratio to island	
1st	0.178	2.54%	0.013	0.18%	1.33
2nd	0.156	2.23%	0.013	0.18%	1.16
3rd	0.133	1.91%	0.013	0.18%	1.00

Table 9. Relative resistance of each scenario in environmental destruction

D. Sensitivity Analysis

The purpose of sensitivity analysis is to acknowledge the underling uncertainty which we always face about the magnitude of the impacts we predict and the values we assign to them. In particular, it should convey how sensitive predicted net benefits are to changes in assumption.

There are three more manageable approaches to doing sensitivity analysis. The first is partial sensitivity analysis which is most appropriately applied to what the analyst believes to be the most important and uncertain assumptions. It can be used to find the values of numerical assumptions at which net benefits equal zero, or just break even. The second is worst- and best-case analysis. Analysts are generally most concerned about situations in which their most plausible estimates yield positive net benefits, but they want to know what would happen in a worst case involving the least favorable, or most conservative, assumptions. The third is Monte Carlo sensitivity analysis which includes the mean and variance, or spread, of the distribution of net benefits to convey information about the riskiness of the project.

Although partial sensitivity analysis has some limitations, I will use this method for more consideration on conditions of the KESIPs. Islands need more transportation fee as well as additional labor costs than mainland due to the distance between islands and mainland. I assume they are double in islands. They lead to increase of capital cost, fixed O&M cost, and variable O&M cost. According to NREL, US PV residential system cost is $2.80/W which is composed of labor install cost of $0.30/W, supply chain cost of $0.42/W and so on (NREL, 2017:21). When these ratios are applied to the above total capital costs, they can be about 1.26 times as much as the above values. And I assume that fixed O&M costs will be doubled since labor cost is more important to fixed O&M cost. In this case, LCOE of each scenario is about 0.80 times for 1st scenario, 0.77 times for 2nd, and 0.97 times for 3rd less than the fuel cost of diesel generation. When a shipping charge is considered, LCOE of each scenario is about 0.70 times for 1st, 0.67 times for 2nd, and 0.84 times for 3rd compared to the cost of generation by diesel. It means that all scenarios have better economic feasibility than diesel generators without subsidy from the government, when the uncertainty of the weather is ignored. However, since there is more need in the renewables case for spare capacity for stable supply, the subsidy of the government can reduce the risk of utilities to realize KESIPs sooner than before.

In addition, there is some possibility that the capacity factor of PV in islands is lower than on the mainland due to frequent fog. This leads to a requirement for more capacity. Since there is no public data on it, I assume that islands need 1.5 times more capacity to get same generation. On the other hand, capacity factor of wind power can be similar or higher than the mainland due to fewer obstacles. I assume that capacity factor of wind power is the same as the given value for conservative approach. At the same time, uncertainty of weather influences capacity of REFs. I assume that even if there are several cloudy days, the KESIPs should supply electricity without problems such as blackout. Capacity of wind power should be increased to supply whole daily demand without PV's generation. And battery storage power station should be also increased to solve a mismatch between generation and demand. I assume that the needed capacity battery storage power is 4 hours of average hourly demand which is 2,044 kWh. From these conditions, LCOE of each scenario is about 1.02 times for 1st, 1.08 times for 2nd, and 1.14 times for 3rd higher than diesel generation which includes shipping charge.

E. Analytic Hierarchy Process (AHP)

AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It has been used to assist numerous corporate and government decision makers. Problems are decomposed into a hierarchy of criteria and alternatives. What we have to do is three steps which are to state the objective, to define the criteria, and to pick the alternatives. (Haas and Meixner. 2017)

In case of KESIPs, objective is to select the best scenario of KESIPs. The criteria are economic feasibility, local conflicts, and environmental destruction. The alternatives are the three scenarios which are explained in the above.

The information on the criteria is arranged in a hierarchical tree and then synthesized to determine relative rankings of alternatives. In particular, both qualitative and quantitative criteria can be compared using informed judgements to derive weights and priorities. Using pairwise comparisons, the relative importance of one criterion over another can be expressed.

I assume three conditions among criteria to apply AHP to KESIPs which are based on Environmental Economics. This is because the economic value is believed to be more important than environmental one in developing countries such as Korea. Of course, the specified conditions for this analysis cannot be assumed to be absolutely correct. However, the analysis can be meaningful as a means to broadlyt benchmark costs and performance.

After discussions with experts in Korea, I assume that economic feasibility is two times as important as local conflict. This is because KESIPs are also a type of business. If there were no proper profit in KESIPs, utilities would not want to change diesel generators. In addition, in order to reduce local conflicts, money is required to reduce local conflicts because local conflicts are often caused by damages on personal property rights. There are always negative residents, in particular landlords, who dislike REFs due to disadvantages such as noise and damaged landscape without any direct benefits. Proper benefits can be source of compensation to negative residents. A value of the economic feasibility is more important than local conflicts but not absolute.

The second is that local conflicts are three times as important as environmental destruction. The members directly involved KESIPs are utilities and residents. The government and environmental organizations are indirect members. If utilities and residents agreed with KESIPs, it would be difficult for the others to interfere about KESIPs. In particular, KESIPs are not only one of the government's wish list, but also environment-friendly ones among lots of energy projects. It is difficult for environmental organizations to object KESIPs actively. If some environmental organizations resisted KESIPs without residents' support, they would look like notorious crusaders of Earth First!. In other words, opinion of residents is far more important than environmental organizations.

The third is that economic feasibility is four times as important as environmental destruction. KESIPs are environment-friendly because current diesel generators are replaced with REFs. REFs can also destroy environment of installation area, but reduce greenhouse gas emission and air pollution from diesel consumption. If destruction on critical environment such as habitats of endangered species were avoided, REFs installation could be considered as a small problem. So mix of REFs can be decided easily by comparison of the economic feasibility on REFs.

From above conditions, I can make a matrix. This leads to an eigenvector of my criteria. This eigenvector means quantitative relationship among criteria. The matrix and the eigenvector are provided below.

	economic feasibility	local conflicts	environmental destruction		
economic feasibility	1	2	4	economic feasibility	0.558
local conflicts	1/2	1	3	local conflicts	0.320
environmental destruction	1/4	1/3	1	environmental destruction	0.122

Above processes are done in alternatives. My alternatives are three scenarios. Through each analysis done in the above, I can make each matrix of alternatives for each criterion. These lead to eigenvectors.

In case of economic feasibility, its matrix and eigenvector are in the below. Even when the sensitivity analysis is considered, the results are same.

Economic Feasibility

	1st	2nd	3rd		
1st	0.171/0.171	0.164/0.171	0.210/0.171	1st	0.350
2nd	0.171/0.164	0.164/0.164	0.210/0.164	2nd	0.364
3rd	0.171/0.210	0.164/0.210	0.210/0.210	3rd	0.286

In case of local conflicts, its matrix and eigenvector are in the below.

Local Conflicts

	1st	2nd	3rd		
1st	0.155/0.155	0.150/0.155	0.145/0.155	1st	0.323
2nd	0.155/0.150	0.150/0.150	0.145/0.150	2nd	0.333
3rd	0.155/0.145	0.150/0.145	0.145/0.145	3rd	0.344

In case of environmental destruction, its matrix and eigenvector are in the below.

Environmental Destruction

	1st	2nd	3rd		
1st	0.104/0.104	0.091/0.104	0.078/0.104	1st	0.289
2nd	0.104/0.091	0.091/0.091	0.078/0.091	2nd	0.329
3rd	0.104/0.078	0.091/0.078	0.078/0.078	3rd	0.383

The above three eigenvectors on alternatives are merged as a new matrix. Multiplication of the new matrix and eigenvector of criteria is a result of AHP.

$$\begin{vmatrix} 0.350 & 0.323 & 0.289 \\ 0.364 & 0.333 & 0.329 \\ 0.286 & 0.344 & 0.383 \end{vmatrix} \text{ X } \begin{vmatrix} 0.558 \\ 0.320 \\ 0.122 \end{vmatrix} = \begin{vmatrix} 0.334 \\ 0.350 \\ 0.316 \end{vmatrix}$$

Among the three scenarios, the 2nd appears to be the best option due to the best economic feasibility, although its local conflicts and environmental destruction are 2nd in importance. This is because the economic feasibility is weighted as much more important than the others as well as the differences of local conflicts and environmental destruction are too small to change the ranking among the scenarios.

If a deep ecology principle is applied to the above three conditions, the above conditions will be reversed. The matrix and eigenvectors below show this outcome.

	economic feasibility	local conflicts	environmental destruction		
economic feasibility	1	1/2	1/4	economic feasibility	0.136
local conflicts	2	1	1/3	local conflicts	0.238
environmental destruction	4	3	1	environmental destruction	0.625

Since there is no difference on alternatives, the above three eigenvectors of alternatives are same.

The second result of the AHP exercise is presented below by multiplication of the alternatives' matrix and the new criteria' eigenvector.

0.350	0.323	0.289		0.136		0.305
0.364	0.333	0.329	X	0.238	=	0.335
0.286	0.344	0.383		0.625		0.360

The different conditions lead to the different result. Unlike the Environmental Economics case, the 3rd scenario is the best option due to its relatively low resistance on local conflicts and environmental destruction. It means that the result of AHP can be varied dramatically according to the weights given to the different values.

4. Implications

As noted above, as overview of KESIPs was introduced in this analysis to bring out the main issues surrounding KESIPs. In the case of main technologies of KESIPs, three possible scenarios were induced. These three scenarios are analyzed in three sections, namely economic feasibility, local conflicts, and environmental destruction. If the target is changed in substantial conditions, such as population, area, it can be adapted easily through adjusting the ratio of the given new target and the target analyzed in this paper.

The result of AHP is that generation units that blend both solar and wind power is the most influential factor. The second scenario provides the best economic feasibility due to its potential to integrate both solar and wind power. Proper mix rate of solar power and wind power can make mismatch of demand and supply minimized in the peak day. It can lead to minimization of battery storage power station which is the most expensive among REFs due to its short lifetime and high capital cost. Of course, if demand curve changes, a different mix rate of solar and wind power should be considered.

Let's consider sensitivity analysis of KESIPs. In the case of economic feasibility, we can consider subsidies for installation cost of REFs. The U.S. government grants utilities 20% of capital cost on REFs. Through the government's subsidy program, each scenario can have much lower levelized cost of electricity (LCOE) than diesel. When the subsidy rate is 20% of total capital cost, the ratios of each scenario's LCOE to diesel which includes shipping fee are 0.602 for 1st, 0.577 for 2nd, and 0.718 for 3rd. This means that all scenarios get sufficient economic profits from the KESIPs. Even in the above hard condition which includes a high shipment fee, additional labor cost, an assumed lower capacity factor of PV on islands, and uncertainty of weather, 20% of subsidy could make LCOE of all scenarios be lower than diesel. The ratios of each scenario to diesel are 1.024 for 1st, 1.084 for 2nd, and 1.144 for 3rd, but they are changed as 0.880 for 1st, 0.931 for 2nd, and 0.982 for 3rd through 20% of subsidy. It means that the government subsidy can be also an important method for promotion on the KESIPs.

Capacity of battery storage power station directly causes this difference. Because the main energy sources of KESIPs are variable, energy storage systems are inevitable for stability and security of electricity supply. According to the required optimal mix of solar and wind power, the battery storage capacity of the power station also needs to be changed to reflect the above analysis. Solar 30% / wind 70% needs the least capacity of battery storage power station among three options. This is because this option has the highest correlation with estimated demand curve of the peak day. In other words, there is the least mismatch between supply and demand. In the case of solar 20% / wind 80% option, it has more capacity of battery storage power station than solar 30% / wind 70%, but its capital cost on solar and wind power is the least amount due to the biggest ratio of relatively cheap wind power. This leads to 2nd order among three options.

However, there is still a substantial problem on KESIPs which is stability. Solar and wind generation capacity depends on weather which is variable. At worst, solar power may not generate for several days due to heavy rains and snow in monsoon and winter. Capacity of wind power generators can be reduced sharply due to a sudden calmness of wind. In order to complement their weak stabilities, they have more capacity per capita in battery storage power station and micro-hydro power. This could lead to higher capital cost and more expensive LCOE. To solve this problem, there is need to consider expanding transmission and distribution networks to cover the small islands with big islands. Expansion of electric power network can be achieved through undersea transmission connections. Network expansion will ensure that generation from far flung parts of the islands are wheeled into the grid thus improving stability and reliability, under a growing penetration of renewable electricity and distributed generation regime. There is no need for more capacity of battery storage power station and micro-hydro power. It leads to better economic feasibility.

In the case of local conflicts, installation area ratio of solar power, wind power, and waste-to-energy effect the result. Waste-to-energy is the most influential of the technologies. There is no way avoiding their installation to accomplish KESIPs. The only way is to reduce local conflicts through increased participation of more residents.

However, top-down approach of the government can make situation of KESIPs worse. Bottom-up approach is needed. If candidates of KESIPs are proposed to the government through Residents' cross-voting and the expertise verify their possibility, there would be less local conflicts at the initial stage. If utilities give the partial right of management to residents, there would be less local conflicts at process of operation.

In the case of environmental destruction, installation area ratio of wind and micro-hydro power is the main cause. The effect of wind power is the most substantial. Micro hydro power is inevitable, but wind power can be moved from on-shore to off-shore in the future. Off-shore wind power does not destroy wildlife of islands. Instead, the problems are its expensive installation cost and relatively low demand. Off shore wind power has a higher capacity per unit such as 5 MW, but required wind power capacities of the target are 1,778 kW for solar 20% / wind 80%, 1,556 kW for solar 30% / wind 70%, and 1,334 kW for solar 40% / wind 60%. And it is risky to depend one or two wind power plant due to low stability. As the earlier explanation, connection among neighboring islands can be a solution.

The KESIPs can be representative one of feasible projects in a post-Paris Agreement regime. From the above analysis on possible scenarios of KESIPs, it is apparent that Korean utilities can maintain a stable electricity supply regime at a cheaper LCOE than diesel plants. However, this can be changed according to the diesel tax. Unlike most of countries, some countries such as the US levy a low tax on diesel. The KESIPs can be relatively less attractive to them. Despite this, island countries can help the KESIPs to prevail in the world. This is because they can put some pressure on ther countries to cope with the climate change through technological development. (Byrne and Inniss. 2002: 22) The KESIPs can be applied from islands to metropolitan areas in the future, because they are based on the IREPP. The adaptation of the IREPP at the national level is possible because many concepts of the IREPP can also be application to national energy planning (Wang, Chen, and Park, 2012: 253).

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