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A case study on the implementation environment of Korea's energy-independent island projects

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Abstract

Efforts to build an energy-independent island (EII) have been made in island territories all over the world out of concerns for energy security and the environment. Likewise, EII projects on six islands have been proceeding in Korea since 2014. Korea's EII projects are differentiated from those of other countries in that they have been implemented in a private investment-centric manner. However, it is said that the performance of EII projects over the past years has been inadequate. Hence, this study seeks to identify the problems of Korea's EII projects and to suggest the directions for improvement. This study is primarily based on a literature review. We collected the literature from Science Direct, Google Scholar, and DBpia. In addition, this study draws on a number of other secondary sources. We have identified major challenges such as resolving business uncertainties, enhancing residents' acceptance, and securing advanced microgrid technology. The most important issue for operators is the unit price of electricity per kWh because it is directly linked to profits, but until now it is not easy to accurately calculate it. Efforts to enhance the acceptance by local residents also needs to be pursued in a balanced manner. In order to ensure a stable supply of electricity through renewable energies, it is important to improve the technology for the microgrid system and to make distributed energy resources in the system be connected organically.

Keywords: energy-independent island, renewable energy, project success environment

1. Introduction

Renewable energy generation is rapidly increasing all over the world. The OECD's renewable energy generation increased by about 100% since 2010 (from 624 TWh in 2010 to 1,243 TWh in 2016), and the world's generation increased by 120% (from 782 TWh in 2010 to 1,724 TWh in 2016) [1]. In 2016, renewable energy accounted for 75.8% of the OECD's new power generation facilities and 67.5% of new investments globally [1,2]. Korea's energy industry has adopted a centralized supply system. Of the total energy generation in 2016, coal accounted for 39.6%; nuclear power, 30.0%; Liquefied natural gas (LNG), 22.4%, and renewable energy, just 4.8%. As part of its energy transition policy, the Korean government plans to raise the proportion of renewable energy generation to 20% by 2030. In addition, it has been implementing projects to achieve energy independence in island territories as a means to disseminate renewable energy and to facilitate technology innovation.

Islands can be classified into two categories in terms of power systems. One category includes islands with power system connected with that of the mainland, and the other includes islands with power system that cannot be connected with that of the mainland due to distance and/or due to the costs of submarine transmission cables. In islands with no grid connection with the mainland, oil is transferred from the mainland and stored in oil tanks, and diesel generators are operated to supply electricity. During the winter season, however, the electricity supply costs tend to increase significantly because severe winds frequently prevent oil transportation for one or two months. If electricity is supplied by a stand-alone diesel generator, the average cost of electricity per kWh in Korea is about 44 US cents [3]. Hence,

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residents of the island not only have high fuel costs but also cannot be ensured a stable supply of electricity.

Since 2014, the government has, as one of its national energy projects, initiated energy-independent island (EII) projects, with the intention of replacing diesel generators with microgrid systems and of integrating renewable energy and energy storage systems (ESS) to make the islands self-sufficient in electricity generation. The government has chosen private power producers as the electricity suppliers for the islands instead of Korea Electric Power Corporation (KEPCO), a public corporation, to encourage private investment in EII projects. The government has selected private companies and is helping them to produce and sell electricity for each island. In 2015, six islands were selected for EII projects: Ulleungdo, Jodo, Geomundo, Deokjeokdo, Sapsido, and Chujado. The government plans to spread EII projects to over 60 islands.

However, during the past four years the EII Projects are widely regarded to have achieved little. The project participants have to sign a Power Purchase Agreement (PPA), a contract to sell electricity generated in the islands to KEPCO, an electricity retailer, for the next 20 years. Nevertheless, there are no companies that have signed a PPA, except for Ulleung Enerpia, which was selected as a business operator for the EII project in Ulleungdo. There are a variety of reasons why the EII projects have not gone smoothly. Renewable energy-related projects on islands are being actively conducted all over the world, including Korea. Therefore, if we identify the reasons why the Korea's EII projects are delayed and suggest directions for improvement, this work will contribute to the successful fulfillment of ongoing projects around the world and the establishment of new projects.

The desirable direction of EII projects all over the world is that business operators voluntarily participate in the projects without substantial government investment. The case of the EII projects in Korea is noteworthy in that participants are not solely dependent on government funding. Private companies estimate the economic feasibility of the projects and decide whether to invest or not. As for Ulleungdo's EII project, a PPA has been signed between the operator and KEPCO to sell and buy electricity produced in the island through a microgrid system. Therefore, this study will provide important implications for project planners or managers who are responsible for the construction of microgrid systems on islands.

The structure of this study is as follows. Section 2 looks at the project's environment for success. There will be various aspects such as politics, economy, society, and technology in the environment for a successful project. Based on existing research, we look more specifically at the success environment related to energy projects in island territories. Section 3 briefly describes the research methodology. Section 4 explores the background and trends of Korea's EII projects. In Section 5, we examine the situation in Korea in more detail based on the theoretical framework examined in Section 2. In this section, we discuss one of the main research questions of this study, "Why are the EII projects in Korea not proceeding well despite the government's significant promotion?". In Section 6, we conclude by discussing another important research question, "How should we deal with the problems of Korea's EII projects?"

2. Literature Review

2.1. Project success environment

A project's success environment can be defined as any circumstances that can affect the success or failure of a project, or as an environment that contributes to a successful project outcome [4]. Various studies have been conducted on environments in which a project can be successfully implemented.

Belassi and Tukel [5], and Ofori [6] emphasize the political, economic and social environment as the external environment factors that are prerequisites for project success, besides the internal factors associated with a project and its management. The political environment is determined by political stability and government support; the government plays a very important role in business success, through such things as infrastructure development and the development of business-friendly institutions [7]. The economic environment refers to the environment that affects the flow of funds, which refers to a stable macroeconomic environment, financial resources through credit agencies, and low interest rates [8]. The social environment is directly related to cultural aspects and the acceptability of local residents in which the project is carried out [9].

Technological advances are also a major factor in the environment for project success [10]. It is necessary to view technological advances as a separate aspect of the environment because it directly affects project performance; although some studies have looked at technological development as part of the economic environment [11]. For example, Information and Communications Technologies (ICTs) play an important role in driving better project processes [10] and driving better ways to improve project performance [12]. Jo and Barry [13] suggested that the technological environment such as technology maturity and expert infrastructure, as well as the political environment and the social environment, is also an important factor in the project success. In addition, technological advances enable various companies to enter the business and to compete with each other by lowering barriers to entry, leading to further innovations [14].

Although the focus on the project's success environment differs from study to study, studies on the project's success environment have considered political, economic, social and technological environments as major determinants of project success. More specifically, in the case studies on energy issues in island territories, we review a project's success environment as follows.

2.2. Energy project success environment in island territories

2.2.1. Political environment

The island of Samsø in Denmark has been attracting attention as a successful example of energy self-sufficiency in an island. Since 1997, Samsø has focused on the development of renewable energy and has achieved energy self-sufficiency within ten years, making the maximum use of Danish climate conditions [15]. Sperling [15] emphasized governmental technology support and governmental process support as reasons for the successful transition of the island to EII. The government’s clear guidelines for regional participation also contributed to the success. In addition, various funding sources for local renewable energy projects and the establishment of local energy organizations have helped to push the Samsø project smoothly.

Dornan [16] argued that the government's funding support and guidelines should be more specific to expand access to electricity in the Small Island Developing States (SIDS) of the Pacific. He emphasized that governmental subsidization is generally required to cover the high initial costs associated with expanding the grid, and that an appropriate policy framework to guide business investment is also important. If impractical business goals are made and there are insufficient specifics on how to achieve them, the performance of the business is hard to guarantee. In particular, the budget allocation should be done appropriately according to the business goal, so that the business can be smoothly implemented. Dornan [17] also stressed that the power companies on Pacific SIDS should be provided with sufficient incentives and resources to expand the grid.

2.2.2. Economic environment

In island territories where the power system is isolated, the energy supply cost is high because the fuel supply cost is generally higher than in other regions. For example, in Pacific SIDS, sometimes the cost of oil supply is 200 to 300% higher [18]. Pacific SIDS residents usually consume up to 20% of their disposable income for energy costs [19]. Therefore, the inflow of renewable energy technology can reduce the energy production cost of the island area. Renewable energy can have competitiveness compared to diesel power generation if fixed cost is low because variable cost is very low [20]. However, in general, the market size of the island region is small, making it difficult to achieve economies of scale when the project is implemented [19].

Harrison and Popke [21] described the difficulty of achieving project economics in islands with the example of geothermal energy development in the Eastern Caribbean islands. In the early 1970s, feasibility studies and surface exploration confirmed significant geothermal potentials in the eastern Caribbean region. However, underground exploration and the drilling of test wells required significant costs. As a result of the initial cost of the project, which did not guarantee the success of geothermal development, it was possible to receive international funding only when the project size was over 12 MW. However, when the large-scale project was carried out, the problem of exceeding the local electricity demand arose.

In order for a project to be carried out, related businesses must participate, and the economic efficiency of the project must be supported first. For renewable energy technology to be more economical than conventional diesel power generation, the price competitiveness of renewable energy should increase as oil prices rise, or the cost of production should decrease due to the improvement of renewable energy technology. In order for energy projects to be successful in island areas, where the economy and population size are small and the logistics facilities are limited, projects should be able to attract enough funds to deal with the problem of economies of scale.

2.2.3. Social environment

From the social environment point of view, the most important thing for the success of island energy projects is ensuring the acceptance of residents. Previous research has shown that there is a gap between acceptance by the society as a whole and acceptance by the local community, which often leads to disruption in the deployment of renewable energy [22]. Van Erck [23] categorized the opposing motives at the local level into three categories: environment, Not In My Backyard (NIMBY), and opportunism. Island energy projects can be opposed due to fears of the destruction of the local environment, due to potential economic losses caused by the destruction of local tourism resources, or due to noise. Residents may not object to a project itself, but they can oppose it for the sake of maximizing additional benefits. To improve the acceptance of residents for renewable energy projects, it is necessary to give objective information about the projects and make the residents understand benefits that can be obtained at the local level, which can offset opposition motives, and consequently encourage the active engagement of the residents.

According to the German Wind Association, residents have a tendency to reduce their opposition and learn more about renewable energy if they can have some of the ownership of the new power plants. This approach was also used in the case of Samsø island [24].

2.2.4. Technological environment

Island territories that are not connected to the mainland's power grid are usually powered by a diesel generator, which requires that the fuel be brought from outside the island meaning that the generators cannot be reliably refueled. A diesel generator is vulnerable to global fuel price fluctuations and has an environmental pollution problem [20].

As a solution to this problem, efforts are being made to make the island regions energy-independent through the development of renewable energy using microgrid technology. Until now, pilot microgrid projects have been carried out in many islands around the world, and at the same time, research on related technologies has been actively carried out to increase the penetration rate of renewable energy [25]. Williams et al. [25] analyzed the technological aspects of microgrid monitoring, measurement, energy conversion and control, as well as related organizational structures and developments. Zhao et al. [25] also proposed a design optimization approach to operating a microgrid on East Fukuyama Island to reduce dependence on imported fossil fuels and reduce energy service costs.

The microgrid is a community-based small-scale grid consisting of a large number of distributed energy resources (DERs). Microgrid technology is used for power control, power quality compensation, remote control and surveillance, controlling grid connection, and stand-alone operation. The energy management system (EMS) of the microgrid controls the production and economical supply of energy. Microgrid technology can compensate for the volatility and intermittency of renewable energy and reduce power losses in local power generation and consumption. Two-way communication between suppliers and consumers is possible, making efficient energy operation possible. The microgrid technology can reduce the variability and intermittency of renewable energy and decrease power losses in local power generation and consumption [26].

3. Methodology

This study is primarily based on a literature review. We collected the literature from Science Direct, Google Scholar, and DBpia, which is a database for Korean academic papers. However, there is a problem that it is difficult to reflect the vivid voices of the field when the research method relies solely on the literature review. In addition to a survey of the relevant literature, this study also draws on a number of other secondary sources. We collected and analyzed materials from all media related to conferences, forums, seminars and interviews regarding Korea's EII. We carried out the complete enumeration survey of those materials through Naver which is the biggest web portal in Korea. We try to reflect the voices of various stakeholders such as the government, KEPCO, power generation operators, and residents of the EII. We also discuss research questions from a balanced perspective by reviewing government press releases, government policy assessments, relevant laws, and professional research reports.

The research framework is based on the political, economic, social and technological environment discussed in Section 2. In this framework, we analyze in depth the project environment of Korea's EII. Success factors or circumstances of a project can be viewed from various perspectives. This study examines various aspects of the EII projects at the national level by analyzing various conditions surrounding the EII projects, rather than taking organizational leadership or corporate management perspectives. Through this approach, the results of this study can be utilized in future comparative analyses of EII projects between countries and can provide useful information in terms of public policy making (Fig. 1).

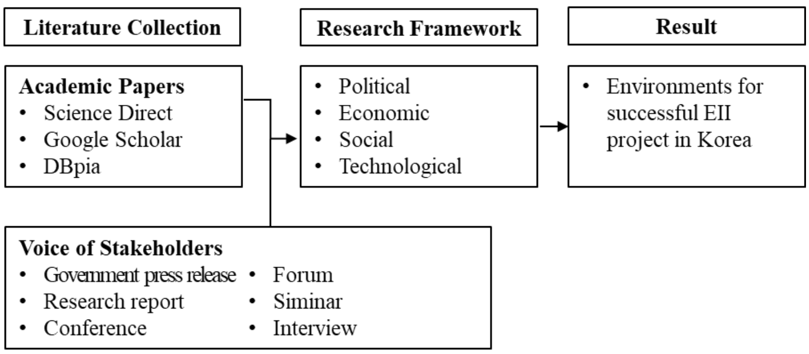

Fig. 1. Research Design

4. Overview of EII Projects in Korea

4.1. Purpose of EII projects and overview of pilot projects

There is a total of 63 island areas in Korea under the management of KEPCO. Since these islands are not connected to the mainland grid, they have installed diesel generators themselves. However, diesel generators have the disadvantage of producing CO_2 and of generating noise. Also, the cost of electricity supply is considerably higher than that of the mainland. However, the cost recovery rate of KEPCO for these islands is considerably low because the electricity retail price is the same as on the mainland. In 2015, the electricity retail price for the island area was 11.1 US cents per kWh, while the electricity supply cost is 45.6 US cents per kWh, which is about four times higher than the retail unit price [27].

In order to compensate for these problems, the primary purpose of the EII project is to convert the power supply method from diesel to renewable energy. This means minimizing diesel power generation on the islands and applying the components of the future microgrid. For example, the EII project produces electricity through renewable energy such as solar and wind power, stores electricity in an ESS, and performs integrated and efficient energy management through EMS. It is possible to maximize the benefits of EII by introducing AMI or electric vehicles. This system can be more eco-friendly and economical than the existing system. The EII project places private companies in charge of electricity generation instead of KEPCO to make the energy transition from diesel generation to renewable energy generation through only private capital. The business operators can retrieve their investment costs through the sale of electricity. In this regard, it differs from energy self-sufficient island development projects that have been implemented through government funding.

Prior to the EII project, a pilot project was conducted on two islands, Gapado and Gasado, for three years from February 2010. The Gapado project was the first stand-alone microgrid system construction in Korea. It was implemented by local government bodies, public corporations and private companies together for two years from 2011 to 2013. It aimed to replace existing diesel generation with wind power generation, solar power generation, and ESS, and convert diesel generation to a backup power source. In addition, an intelligent power grid was installed that included distribution intelligence and integrated monitoring and control. Starting in October 2012, the Gasado Research Project was conducted under the leadership of the KEPCO Research Institute with the aim of developing a renewable energy-based hybrid energy system and grid linkage technology through demonstration of an EMS-based microgrid operation. An EMS for the microgrid was installed, along with four wind turbines with a 100 KW permanent magnet synchronous generator, 314 KW solar power generators, 3 MWh lithium-ion batteries, and two inverters capable of 500 KW class bi-directional charging. The government verified the microgrid engineering technology through the pilot project, and applied the developed EMS to carry out the long-term demonstration.

4.2. EII projects in Korea

After the termination of the pilot projects in 2013, the government has implemented further EII projects. The government decided to promote Ulleungdo first and then select other islands. Ulleungdo was selected as an energy-independent island in 2014, and in July 2015, another five islands were selected as energy-independent islands. The government will continue to expand EII projects for the remaining 57 islands (Table 1).

- Ulleungdo: Ulleungdo's EII project is to generate revenue by replacing the existing diesel based electricity supply system with a microgrid system based on renewable energy. The first phase of the project was scheduled to be completed by 2017, and 30% of Ulleungdo's total power was to be supplied through solar power, wind power, and hydropower generations with ESS and EMS. By the end of the second phase of the project, to be completed by 2020, geothermal and fuel cell power plants will be introduced. Ultimately, the aim is for Ulleungdo to become the world's largest energy self-sufficient island with the help of renewable energy and ICTs. A special purpose corporation (SPC) 'Ulleung Enerpia' was established for this project.
- Deokjeokdo: Deokjeokdo is an island with a population of 2,000 and currently operates a diesel power plant with a capacity of 2.9 MW. The EII project of Deokjeokdo has been carried out under the supervision of the KT Consortium. A 500 KW solar power plant and two 750 KW wind power plants will be installed, aiming to supply 39% of electricity demand through renewable energy and ESS.
- Jodo: Jodo has more than 2,000 people, and the LG CNS consortium will organize a project to build an island for energy independence. Jodo is currently supplying electricity to the island through an internal combustion power plant with a capacity of 3.6 MW. A 294 KW solar power plant and two 750 KW wind power plants will be installed, with the aim of supplying 45% of electricity demand through renewable energy and ESS.
- Geomundo: Geomundo has a population of 2,000, and the project will be under the supervision of the LG CNS consortium. Electricity is being supplied to Geomundo through a 4.5 MW internal

combustion power plant. A 1,164 KW solar power plant and two 750 KW wind power plants will be installed, with the aim of supplying 50% of the electricity demand of the island through renewable energy and ESS.

- Sapsido: Sapsido is an island of fewer than 500 people and is the smallest island among the EIIs. Sapsido currently supplies electricity to the island through a 900 KW internal combustion power plant. A 1.6 MW solar power plant will be installed, with the aim of supplying 83% of electricity demand through renewable energy.
- Chujado: Chujado has a population of 2,300, and the project will be carried out through the POSCO ICT Consortium. A 1.3 MW solar power plant and four 800 KW wind power plants will be installed, with the aim of supplying 46.2% of electricity demand through renewable energy and ESS.

Table 1. EII Projects in Korea

			Ulleungdo	Deokjeokdo	Jodo	Geomundo	Sapsido	Chujado
Gener-al infor-mation	Administrative district		Ulleung-gun, Gyeongsangbuk-do	Ongjin-gun, Incheon	Jindo-gun, Jeollanam-do	Yeosu, Jeollanam-do	Boryong-si, Chungcheongnam-do	Jeju Special Self-Governing Province
	Area [km^2]		72.6	38.3	35.7	41.8	12.8	42.5
	Route distance [km]		130	77.9	12	114.7	22.8	85
	Population/ household (2015)		10,316/5,429	1,947/1,072	2,351/905	1,922/741	435/386	2,311/1,501
	2015 Power generation [MWh]		63,043	10,487	8,300	9,904	2,179	13,435
	2015 Generating cost [$/MWh]		223	318	399	311	617	284
	Deficit [1,000$] (2015)		8,237	2,660	3,226	2,307	1,175	2,696
Power mix	existing	Diesel [MW]	18.5 (10.5MW, 8MW)	2.9 (0.3MW*3, 0.5MW*4)	3.6 (0.5MW*2, 2.6MW*1)	4.5 (0.5MW*1, 1MW*4)	0.9 (0.3MW*2,v0.15MW*2)	5.5 (1MW*4, 0.5MW*3)
		Renewable [MW]	0.7(hydro) 0.2(PV)	-	-	-	-	-
	to be built	wind	6 (2MW*3)	1.5 (750KW*2)	1.5 (750KW*2)	1.5 (750KW*2)	-	3.2
		PV [MW]	0.6	0.5	0.294	1.164	1.6	1.3
		geothermal [MW]	12	-	-	-	-	-
		Battery [MWh]	28	6	8.12	9.97	6.1	12
		PCS [MW]	36	2	4.25	4.75	1.5	10
Operator			Ulleung Enerpia	KT Consortium	LG CNS Consortium	LG CNS Consortium	Woojin Industrial Systems	POSCO Consortium
Investment [million$] (2016)			336	21	43	56	21	43

Sources: Lee et al. [28]; The Korea Electric Times [29,30]

5. Korea's EII Project Environment

5.1. Political environment

The Ministry of Trade, Industry and Energy (MOTIE) formed a public and private joint task force in August 2014 to establish detailed plans for the optimal power mix, the establishment of special purpose corporations (SPC), and investments. The SPC was established in September 2015 through an agreement between the participating institutions [31]. The MOTIE announced that the EII project could result in about 1.50 billion US dollars in revenue through prevention of power outages, the reduction of capital investment costs and an improvement in the utilization rate of renewable energy and result in about 1.24 billion US dollars in revenue through a reduction of energy consumption, employment creation, carbon emission reduction, and microgrid export. There are however a number of challenges to overcome.

Especially, the cost of constructing EIIs is enormous. According to the business plan, the SPC will invest 344.4 million US dollars. As the investment costs are huge, institutional support is needed to improve business performance [32].

The MOTIE decided to make the islands' power generation and utilization information transparent so as to build a successful business model for the EII project. In addition, for institutional support, the "Electricity Transaction Guidelines for the Development of New and Renewable Energy in the Island Regions" was enacted in April 2015. Moreover, KEPCO, private operators and experts will form a consultative body to optimize the detailed business plan and to conclude a power purchase contract (PPA) for new and renewable energy production [31]. The MOTIE also plans to make a support plan that includes, for example, differentiation of renewable energy certificate (REC) weights.

However, the PPA contract has been signed only on the Ulleungdo project among the six islands so far. The delay of the PPA contract is due not only to the delay of the establishment of the Electricity Transaction Guidelines for the Development of New and Renewable Energy in the Island Regions, which is the basis of the PPA, but to the PPA contract method that does not remove the project uncertainty.

In the case of Ulleungdo, the PPA contracted with KEPCO is only about the unit price of the transaction, so there is a problem in that the amount of money may change when actual settlement is made. The settlement unit cost is calculated after the capacity of generator unit is determined and the actual operation starts. However, the power generation facilities to be installed on Ulleungdo still remain in the design stage, so the calculation of the unit cost is not possible at present. This problem is caused by the fact that the electricity sales company, KEPCO, can change or revise the contents of a business plan submitted by a power generation company based on the Electricity Transaction Guidelines for the Development of New and Renewable Energy in the Island Regions. The guidelines also stipulate 20 years as the basis for contracts for electricity trading, but it is stipulated that it can be flexibly settled in consideration of fuel price fluctuations and stability of power supply and demand. In Appendix 1 of the guideline, the unit price of electricity trading in the new renewable energy generation business area is divided into contract time and settlement time, and the unit price at the time of the contract is required to include the forecasted amount of electricity trading [33].

PPA is usually done with fixed electricity prices. If power unit prices change depending on facility capacity, profit, and oil price, it is difficult to mobilize investors because the feasibility study is difficult. The MOTIE is striving to make long-term profits by leaving a good precedent rather than pursuing profits in the short term because it wants to make Ulleungdo's EII business a model for overseas export [34].

The direction of differentiation of RECs in the areas of the islands has yet to be established. First of all, it is necessary to identify the cause of the cost difference related to the construction and operation of the facilities between the land and the island operators. Therefore, it is necessary to recognize the specificity of the island area and to reflect the gap in the REC weighting by analyzing the increase and decrease factor of the operating cost, the construction cost increase, and the transportation cost for the transportation of equipment, etc. [28].

5.2. Economic environment

The EII projects have differentiated from the pilot projects in Gapado and Gasado. The pilot projects were supported by the government in terms of research and development, and thus, the operators did not have to worry about the economic feasibility. Since the EII projects are inevitably costly, economic prospects become a problem when the projects are to be extended to all the island regions in Korea. Revenues from the EII projects are the result of sales revenue generated by PPA from KEPCO and additional revenue from sales of REC for the sales of renewable energy. Operators can choose whether or not to participate in the projects, considering revenues and costs. In other words, an operator who concludes that they can make profits even under such conditions will participate in the projects [35].

The energy charge paid by the electricity sales company KEPCO to power generation companies can be assisted by a support fund that KEPCO receives from the Electric Power Industry Basis Fund (EPIBF). This follows the electricity trading contract under Article 19 (2) of the Electricity Transaction Guidelines for the Development of New and Renewable Energy in the Island Regions [33]. The supply of electricity to the islands has mainly been carried out by KEPCO. The fuel cost exceeding electricity sales income has been compensated by the EPIBF. However, oil prices have fallen sharply during the EII project. Oil prices continued to decline from $109.07 a barrel in 2012 to $96.78 in 2014 and to $50.77 in 2015. The government and operators did not predict the drop in oil prices at the time of the project plan. Because fuel cost is linked to the oil price, the price difference between electricity production cost and electricity sales income was reduced as oil prices fell, and KEPCO received less support. This again has caused a situation in which the charges that power generation companies received from KEPCO decreased. To estimate the construction cost and operation cost of the EII project from the viewpoint of the power generation companies, the diesel fuel cost has to be calculated. But the volatility of the fuel cost has become too large. When the government announced its plans for EII, profitability seemed to be guaranteed. However, as the situation changed a few years later, operators are making hard and careful calculations to reflect oil price volatility in PPA contracts.

However, if the basic principle of the government’s EII project is to be carried out by private power generation companies, the government should encourage the expectation that the private companies will be able to make a profit. Because of the nature of the energy industry, large-scale investment and long-term operation and management are required, so companies’ confidence in entering the new energy industry is very important [36].

A delay in a decision to raise REC weights for renewable energy development in the islands is increasing the uncertainty of business economic feasibility. It is constantly being argued that higher REC weights are needed compared to land because the investment in renewable energy is usually higher on islands than on the land. The Korea Electrotechnology Research Institute analyzed the economic efficiency of renewable energy technology in island regions. The institute conducted a technical and economic analysis of solar, onshore wind, fuel cells, small hydropower, and geothermal power, which are expected to be supplied to EIIs. To do this, the institute collected the available domestic and foreign data, set the standard facility size, developed the indicators such as facility utilization rate, installation cost, operation cost, and linkage cost, and conducted the technical and economic analysis for each alternative. The study identified the existing economic feasibilities of each energy sources and the costs that are expected to be added or reduced for the islands, and then calculated the cost difference between them. There is no significant difference in facility costs of renewable energy between land and island areas, but the construction cost of solar energy and wind power was 43.7% and 33.7% higher than land, respectively. As a result of the total economic analysis, the estimated costs of renewable energy on the island were as follows: Solar power was 14.2~17.1 US cents per kWh, onshore wind was 13.7~18.2 US cents per kWh, fuel cell was 20.3~21.8 US cents per kWh, geothermal power was 17.5~20.9 US cents per kWh, and the small hydropower was 12.1~14.4 US cents per kWh. The difference in costs of renewable energy sources between land and island areas is estimated to vary by 10 ~ 42% [28].

5.3. Social environment

In the case of Korea's EII project, although it is initiated by the rising social acceptance of the expansion of renewable energies, it seems that the Korean government is not paying attention to securing the acceptance of residents in the community. The Korean government is focusing on the development of technologies and encouraging the participation of business operators, considering the EII project as a new growth engine. According to the MOTIE, the way to secure the acceptance of residents is one of the evaluation criteria when selecting operators for the project. However, it is stated that the degree of reduction in electricity production costs is the top priority for the project applicants. As for Ulleungdo, it is necessary to install a large capacity geothermal power plant, and thus conflicts are likely to emerge when securing land necessary for power plant installation [37]. Resolving the lack of technologies and economic feasibility would be the first priority for the government and business operators, but they should make an effort to understand the cultures, environments, and characteristics of each island and to secure the acceptance of the residents in the long term.

For example, there have been a number of failures of energy self-sufficient region projects in Europe caused by residents' opposition, such as the failure to introduce a bio-energy power plant in Umbria, Italy, in Cricklade, UK, and in Lund, Sweden [38]. The central governments' top-down approach leads to a lot of opposition to the projects and conflicts within the regions. Likewise, in Korea, there have been many cases where the progress of the energy self-sufficient region project has stopped due to the opposition from the residents [39,40]. The reasons for the opposition are noise pollution, light pollution, damage to the landscape, destruction of the natural environment, etc. One of the representative cases would be the wind farm construction project on Mt. Hanwoo in Uiryeong, Korea. The project was approved for business in 2012 with the goal of achieving an annual power generation of 41,631 MWh by installing 25 wind power generators totaling 750 KW at the site. It was scheduled to begin construction in May 2015. However, in March 2015, residents started to oppose the construction because of landslides, noise pollution, and low-frequency damage, and held a demonstration against the project. The conflict was extended into a legal battle and the construction was stopped. After several months of negotiation, they agreed to start the construction of the wind farm [41]. As can be seen from the above cases, even if the business operators actively participate in the project because the economic feasibility of the project is sufficient, lack of acceptance by the residents can cause the business itself to be lost. In order for the EII to be maintained and developed continuously, it is necessary not only to obtain consent from local residents, but also to create an atmosphere in which local residents themselves actively participate in maintaining and developing EII. Hence, for the long-term success of EII projects in Korea, further efforts to improve the acceptance by the residents on each island are needed.

On the other hand, the recent earthquake in Pohang in 2017 has made securing the acceptance of Ulleungdo's residents more difficult [42]. This is because that for Ulleungdo's project, geothermal power generation is the dominant source of power generation. Geological experts point out that the pressure of the water injected during the geothermal energy development caused the earthquake, so there are suspicions about causality between geothermal power generation and the earthquake. If it is found that there is an association between earthquakes and geothermal power generation, it is almost impossible to secure the acceptance of residents for EII projects that include geothermal power generation, such as that in Ulleungdo. To sum up, it is necessary to prepare a concrete plan for securing the acceptance of the residents rather than to push ahead with the EII projects forcibly.

5.4. Technological environment

KEPCO not only succeeded in exporting the microgrid operating system in 2015 to Ontario but also signed a memoranda of understanding (MoU) with Maryland that includes cooperation for emerging technologies in the energy industry including a smart grid [43]. Although there are some visible outcomes, the technologies related to microgrid systems in Korea are still in its early stages. Even on Gasado, which aimed to produce its electricity with only renewable energy considering its small population, about 80 percent of the electricity used in the island is covered by solar and wind power, and the rest is supplied through diesel generation. According to the auditor's report by the Board of Audit and Inspection in 2016, in the islands working on EII projects, the amount of electricity produced by diesel generation has exceeded the amount planned at the initiation of the project, allowing for the increase in electricity consumption of each island [44]. The amount of electricity generated through renewable energy was only from 42 to 73 percent of the planned amount. This situation might be attributed to the fact that renewable energy has inherent limitations in producing electricity predictably and stably. If solar or wind power cannot produce electricity due to bad weather conditions, diesel generation is inevitable considering current technological competence. Even though microgrid systems were originally introduced to solve the volatility and intermittency of renewable energy, related technology is not advanced enough to resolve those problems at present.

The first main problem of EII projects in terms of the technological environment is that the storage capacity of the ESS in the microgrid system is not sufficient. In order to resolve the volatility and intermittency of renewable energy, we need to store electricity in the ESS when there is a surplus of electricity and to exploit it in the period when the electricity production is insufficient to cover demands. However, the current technological competence requires a lot of money to increase the storage capacity of the ESS. For example, there are three ESSs installed on Gapado and their total capacity is 3.86 MWh, making it difficult to store sufficient electricity for use in case of shortages [45]. Although ESS installation costs have been reduced, it still costs about 700 thousand US dollars to expand 1MWh of ESS. In addition, the capacity of the power conversion system (PCS), which converts the voltage or electric current in an ESS to store electricity in a battery or to release it into a grid, is 450 KW, which is very small, resulting in unstable power supply in Gapado.

The principal objective of the microgrid system is to manage loads and distributed energy resources within the system through the EMS [46]. In order to achieve optimal operation of the microgrid system, various information from within and without the system, such as the real-time status of each DER and changing electricity rates, should be collected in real time, and optimal operating schedules of DERs should be derived through optimization calculations and predictions by EMS [47]. It is necessary for the microgrid system to determine the charge rates of the ESS depending on the weather and to decide how much to drive the generators. However, some islands under the EII projects do not have an EMS in their microgrid system. Moreover, even if an EMS is nominally installed, there is no systematic interaction between the ESS and the generator, and thus workers manually determine the charge rates of the ESS and the operating time of the generator. According to some media, diesel generators tend to be operated excessively without regard to the amount of power generation through renewable energy generators or the charge rates of the ESS due to concerns about the power supply in islands being cut off [48]. Since there has been no proper interconnection between renewable energy generators, diesel generators, and their ESS, it is difficult to achieve the goal of electricity demand on the islands being met by renewable energy sources alone.

6. Discussion and Conclusions

The political environment and the economic environment in Korea’s EII projects have a close relationship. The Korean government has made visible progress in EII projects by selecting six islands and proactively attracting business operators. The Korean government’s first step toward creating EII can be seen as successful in that business operators agreed the vision of the project proposed by the government, i.e., that it is possible to solve energy problems on islands and at the same time to bring economic benefits to the operators by installing renewable energy systems. However, in order to achieve the aim of the policy, it is necessary to provide the operators with the power to continue their business. The EII projects were implemented in such a way that private operators invest their own capital in the projects, and the government provides institutional support. However, as the government’s plan for support has been delayed, the project also has been delayed. The most important issue for operators is the unit price of electricity per kWh because it is directly linked to profits, but until now it is not easy to accurately calculate it. Operators do not want to put up capital and carry out the construction due to the uncertainty in forecasting revenue. It is said that project participants cannot easily receive financial investment because of the uncertainty. The government also said that it would offer a way to differentiate the weights of REC for islands with high electricity production costs from 2015, but up to now there has been no specific guidance. Since the weights of REC have a significant impact on the profitability of the business, how the weights are determined is important for the operators.

In order to make companies more confident in entering the EII projects, the government should hurry to create policies that reflect future oil price volatility in PPAs and differentiate the weights of REC. If the government adopts a method to set the oil price zone and to apply weights depending on the zone, the business operators can predict the future economic feasibility even if the oil prices fluctuate. Nevertheless, if it is difficult to predict the economic feasibility of the projects, promoting the projects by utilizing a public fund such as the EPIBF can be a helpful alternative. As for the policy on the weights of REC, the government should rapidly proceed as planned originally. If the schedule is delayed, the reasons for the delay should be disclosed in detail and then the government should seek the operators’ understanding. If economic uncertainty is high, companies will avoid investments and look at the situation due to the irreversibility or adjustment costs of the investment [49]. Policy uncertainty also plays a role in preventing corporate investment as a major factor in increasing uncertainty in future economies [50].

Business operators also are responsible for the stagnation of the EII projects it that operators have already recognized them as a private investment project from the outset, and participated in the projects after analyzing their economic feasibility. Operators have been asking for government support after oil prices dropped, but it is not easy for the government to accept all requests from operators. Operators should not only focus on the economic feasibility of the project, but also try to accumulate their experiences such as DC distribution and ESS construction. If they establish a new record such as the world's first energy self-sufficient island through only renewable energy sources and a microgrid system, they will have a great advantage in advancing into international markets in the future.

In terms of the social environment, efforts to enhance the acceptance by local residents need~~s~~ to be pursued in a balanced manner. Although there is little interest in the acceptance by residents, since it is still in the early stage of the project, securing acceptance will be a major challenge as the projects progress. According to successful examples of energy self-sufficient region projects in Europe, securing the acceptance of the residents in the light of cultures, environments, and current situations in each region is considered as the most important success factor [33]. In the case of Gussing in Austria, Juehnde in Germany and Samsø Island in Denmark, energy self-sufficient region projects were implemented as a local development strategy to address the issues of the regions. In Gussing, the projects were carried out to solve the problems of high fossil fuel energy consumption and a high unemployment rate; in Juehnde and Samsø Island, to solve economic difficulties. Moreover, in Juehnde, a bio-energy village was established that considered abundant biomass resources. In Samsø Island, which has strong community consciousness and a cooperative spirit, most of the renewable energy facilities are owned by residents, and residents take charge of operating, inspecting and repairing the facilities. Emphasizing the community involvement, they establish educational facilities and institutions in each region and try to increase the motivation of residents to participate.

However, the EII projects in Korea focus on reducing electricity generating costs rather than making efforts to secure the acceptance of the residents. True energy independence in the islands can be achieved by maintaining adequate demand through energy demand management in the region itself and by reducing the dependence on external support through the exploitation of renewable energy sources available in the region to the fullest. Hence, the active participation of local residents is required for successful EII projects. Furthermore, efforts to secure the acceptance of the residents are essential to secure renewable energy facilities as the government aims to achieve. From the perspective of the government or business operators, it is important to develop technology and secure economic feasibility. However, in the long term it is necessary to devise measures to secure community involvement, such as allowing residents to directly participate in the operation and maintenance of facilities and inducing community activities with incentives.

In terms of the technological environment, in order to ensure a stable supply of electricity through renewable energies, it is important to improve the technology of each ESS, PCS, and EMS which make up the microgrid system, as well as to make distributed energy resources in the system be connected organically and instantly. Unlike public relations of EII projects that are currently underway, virtually all the other projects fail to achieve energy independence through renewable energies alone due to the lack of technology. First, based on a detailed review of the weather conditions and topography of each island at the time of project planning, it is necessary to organize renewable energy generation efficiently and to construct facilities accordingly. As the capacity of ESS is not enough, there is a lot of wasted electricity when electricity demand is low, whereas electricity is insufficient when electricity demand is high. This should be overcome through efficient scheduling of the charging and discharging of an ESS and the close linkage between diesel generation and renewable energy generation. Since we cannot expect excellent optimization calculations and predictions from EMS right now, we need to collect sufficient weather data of each island to obtain weather patterns and to decide the schedule of the charging and discharging of the

ESS.

Currently, all the islands where EII projects are underway rely on diesel generation, but generally there is no link between ESS and diesel generators. Since it cannot be completely independent from diesel generation immediately, it seems desirable to reduce the reliance on diesel generation gradually through the interworking among the diesel generator, ESS, and renewable energy generators. On top of all that, the ESS and microgrid technologies need to improve continually.

This study analyzes the case of Korea's EII projects in terms of the political, economic, social, and technological environment and discusses directions for improvement. Previous studies about energy self-sufficient projects in island districts were mostly on related technology, economic evaluation, case analyses of successful projects. This study examined the reasons behind the delays in the EII projects and extracted implications for development of those projects, which have been ambitiously implemented at the government level in Korea but have not yet achieved success. We identified how important removing uncertainty of businesses is for successful implementation of projects. Also, efforts to enhance the acceptance by local residents needs to be pursued in a balanced manner. To ensure a stable supply of electricity through renewable energies, it is also important to improve the technology for the microgrid system and to make distributed energy resources in the system be connected organically. In the future, we will be able to provide more comprehensive insights through a cross-country comparative study by considering various EII projects all over the world.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A designed the research; B, C analyzed the data; A,B,C wrote the paper; all authors had approved the final version.

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