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Research Paper

Analysis of Environmental Sustainability in South Korean Inland Windfarms

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한국 육상풍력발전사업의 환경적 지속가능성 평가 연구

– 58개 환경영향평가서 사례에 대한 정량적 분석 –

정은해

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요약: 풍력발전은 비용 효율적인 신재생에너지원으로 우리나라 뿐 아니라 전세계적으로 빠르게 보급이 확대되고 있다. 환경적 지속가능성을 보장하면서 지속가능한 에너지를 공급하기 위해서는 증거에 기반한 정책수립과 혁신적인 방안 마련이 필요하다. 본 논문은 풍력발전 환경영향평가서 58건의 분석을 통해 1) 국내 육상풍력의 주요 특징이 어떠한가? 2) 환경영향을 최소화하기 위한 사업별 환경적 지속가능성을 분석하는 방법이 있는가?에 대한 해답을 제시하고자 한다. 환경영향평가서에 제시된 개별 육상풍력사업의 환경적 지속가능성과 관련한 변수를 추출하여 이러한 환경변수에 대한 요인분석을 수행하고 개별 변수의 가중치를 계산하여 육상풍력발전의 환경적 지속가능성을 평가할 수 있는 지수를 개발하였다. 이러한 환경적 지속가능성지수는 육상풍력발전의 입지를 고려할 때 활용할 수 있는 유용한 증거에 기반한 의사결정도구로 활용될 수 있을 것이다. 58개 사업은 사업지역의 고도 및 자연성의 정도를 바탕으로 1) 산악형, 2) 목장형, 3) 해안형으로 구분하였다. 본 연구에서는 개별 풍력발전사업에 대한 환경적 지속가능성지수를 성공적으로 계산하였다. 가장 환경적 지속가능성이 큰 사업은 목장형으로 분류된 33번 사업이 1.04였고, 가장 낮은 사업은 산악형으로 분류된 55번 사업으로 −1.44였다. 둘째, 분석결과는 목장형이 환경지속가능성 지수가 평균 0.4551로 환경적 지속가능성이 가장 높고, 해안형이 평균 0.3712으로 중간이었으며, 산악형이 평균 −0.3457로 가장 낮은 것으로 나타났다. 이러한 결과는 육상풍력발전과 관련된 기존의 연구에서 제시된 결과를 보다 계량적으로 증명하고 있으며, 신재생에너지개발과 관련한 정책에 활용할 수 있는 중요한 함의를 제공하고 있다.

주요어: 신재생에너지, 육상풍력, 환경영향평가, 환경지속성 지수, 지속가능성

Abstract: Wind power has been rapidly growing over last decade in the world as well as in South Korea as a feasible renewable energy source. Providing sustainable energy to all while securing environmental sustainability requires evidence based policy making and innovative solutions.

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Through analysis of 58 cases of South Korean Environmental Impact Assessment (EIA) Report, this paper seeks to identify answers to the following two questions. What are the key characteristics for inland windfarm? Is there a way of measuring environmental sustainability to compare each location to reduce negative environmental impact? Variables related to environmental sustainability of each windfarm case were collected from EIA report and the factor analysis of environmental variables was conducted to calculate the weight for each variable to build environmental sustainability index (ESI) to provide as evidence-based tools for decision making on the location of inland windfarm. 58 cases were categorized as three types 1) Mountain type 2) Ranch Type and 3) Coastal Type depending on their height and degree of naturalness. For analytical research, first, it was successfully calculated environmental sustainability of each windfarm case ranging from 1.04 (#33, Ranch type) to -1.44 (#55, Mountain type). Second, the analysis results showed that ranch type is most environmentally sustainable (Average ESI = 0.4551), followed by coastal type (Ave ESI = 0.3712) and lastly mountain type (Average ESI = -0.3457). These findings are consistent with the previous researches on inland windfarms and provides substantive policy implication on the renewable energy policies.

Keywords : Renewable Energy; Inland Wind Farm; Environmental Impact Assessment; Environmental Sustainability Index; Sustainability

I. Introduction

Wind power has been developed as a renewable energy source since the 1990s due to low cost of construction and operation and high development potential all over the world. However, there are concerns on its negative environmental and social impacts, especially countries with limited land area such as Republic of Korea.

In Korea, most of inland windfarms are located in the mountain areas. Only 16 out of 94 EIA cases (2012-2018) were located in coastal areas. From the early stage of windfarm development, there were concerns over the ecosystem destruction and terrain changes in the areas of ecological importance such as Baekdudaegan which is designated in the main mountain areas in Korea. Coastal windfarms are mostly located in western and southern part of Korean Peninsula (Lee 2016).

Though Energy policies such as energy pricing, Renewable Portfolio System (RPS) and Feed in Tariff (FIT) are the driving forces of wind farm development, environmental regulation also plays a significant role. Environmental Impact Assessment is the main environmental policy measures for the establishment of windfarms. There have been strenuous tensions over green versus green conflicts. Windpower industry requested the prompt permission from environmental authorities on the establishment of windpower in the areas which are economically cost-effective while environmental NGOs with local residents are claiming for stronger regulations to protect ecologically important areas and reducing the negative impact from noise and vibration. Hence, Environmental Impact Assessment (EIA) policy has been changed several times. Ministry of Environment (MOE) of the Republic of Korea introduced new regulation by establishing guidance for selection of in-land wind farm location in 2012 (MOE 2012). Due to the resistance from the Energy Industry, Korean Government eased the regulation in 2014 by announcing new guideline for environmental impact assessment of inland wind farm development cautiously allowing the siting of windfarm in the environmentally sensitive areas if the impact are proved minuscule (MOE 2014) and MOE again strengthened its regulation on windfarm by asking mandatory EIA before the endorsement of renewable energy project in 2018 due to increasing social conflicts on windfarm development (MOE 2018). Since 2020, there were another strong requests from wind industry to expedite and streamline EIA process to promote Windfarm inland and offshore. As a result, Korean government established the task force for EIA of windfarms in 2021 whose mission is streamlining and expediting the process for reviewing the EIAs.

Lack of data and evidence on wind farm leads to conflict of views on environmental sustainability. The frequent changes of environmental regulation undermine the stable investment for renewable energy. The conflict over renewable energy showcases green versus green conflict, hence hinders common understanding and social agreement on effective measures on climate change.

Building Environmental Sustainability index (ESI) is a way of empirical studies to understand the characteristics of certain projects or options. These indexes serve as a metric to evaluate each project or option and also highlight the variables that are the most influential based on empirical findings (Jung et al. 2018). In this paper, 58 Korean inland windfarm cases were analyzed based on their Environmental Impact Assessment Report. Through quantitative analysis of environmental variables of each case, Environmental sustainability index of inland windfarm of Korea would be developed. Based on their altitude and land use type, three categories of inland windfarm, Mountain, Ranch and Coastal type were identified and the three types were compared using the established environmental sustainability index.

II. Literature Review

1. Wind power in the Republic of Korea

Since the enactment of the "Alternative Energy Development Promotion Act" in 1987, Korean government tries to expand the renewable energy portion through various measures. Korea's pledge to reduce greenhouse gas emission by 30% by 2030 compared to BAU in 2007 was the momentum for departure from the test-bed cases to the commercialization of wind power.

Most of researches on wind power are focused on benefit and cost analysis and the estimation of wind power potential using on geographical information system. Kim calculated the potential of wind energy using four categories 1) Theoretical Potential, 2) Physical Potential, 3) Technical Potential and 4) Implementation potential. In the case of inland wind power, considering the geographical constraints and technical level, and environmental requirements, the actual area possible for wind power is estimated to be 1,219 km^2 and the implementation potential is estimated to be 4.6 MW (Kim 2008; Kim & Hwang 2014). Lee estimated 15 MW at 3,004 km^2 are realistic wind power potential excluding areas where wind density is less than 200 W/m^2, areas of grade 1 and 2 Ecological importance, as well as steep areas (>20 degrees) (Lee 2014) but Jeon estimated 1.758 MW at 351 km^2 if considered 1 km of the buffer zone needs to be set for wind power to avoid negative impact on noise and vibration (Jeon 2016).

As of 2020, the total capacity of wind power generation facilities in Korea is 1.64 GW. Compared to necessary wind power capacity of 17.764 GW by 2030 by Cho (Cho 2015) and 20 GW by 2030 by Ministry of Trade, Industry and Energy of the Republic of Korea (MOTIE) (MOTIE 2017), 16.12 to 18.36 GW of wind power needs to be newly constructed in 10 years. If this is to be realized, there needs to make extraordinary measures to increase social and environmental acceptability through technological breakthrough which allows more efficiency with less environmental damage.

2. Regulations on Wind power

Regulation for wind power siting varies but through planning law and regulation as well as EIA shows the common features such as exclusion of environmentally and esthetically valuable areas, distance to the settlement or private or public property. Though Europe and North America put some environmental guidelines for wind power, it is through qualitative guidance on Environmental Impact Assessment mostly in the state or provincial levels. Most of countries guide developers to avoid ecologically or culturally important areas such as endangered species habitat, parks and heritage. For noise, most of countries regulates that windpower does not exceed noise level of 50 DB in daytime and 40 DB in nighttime at the edge of windpower site. Regulations on shadow flickering and low-frequency vibration are being discussed and only a few countries in Europe has specific regulation on these impacts (Lee 2016).

McKenna et al made a cost-benefit analysis of onshore wind farm in Europe, considering terrain slope, proximity to urban areas, protected regions, and road network, classifying European area into 44 classes (McKenna et al. 2015). Swart et al investigated the land eligibility of onshore wind turbines in the EU where the avoidance of protected areas was the only exclusion constraints resulting in the most potential area in Europe are agricultural areas followed by forests in the work commissioned by European Environmental Agency (European Environmental Agency 2015). Huber et al summarized four categories of ecosystem services potentially conflicting with wind turbines such as 1) physical and experiential interactions, 2) habitat and gene-pool protection, 3) perceived landscape beauty, 4) provision of food and fiber (Huber et al. 2017). Regarding height and slope of the windfarm site, mountainous areas are generally not favored due to increased cost of transmission cost and difficulties in maintenance and landslide proneness (McKenna et al. 2015).

Though EIA has been the main tool for siting of wind farm, very few quantitative studies have been done due to lack of specific data of each cases and most of papers focused on regional or national potential based on the available wind resources and the country or region specific regulations. It is fortunate that most of EIA reports are accessible through web so that actual data can be withdrawn from them in the Republic of Korea. From literature review for this paper, it is found that there are relatively small numbers of paper that quantitatively analyze individual wind farm cases. Building index for environmental sustainability is one way of empirical studies for analyzing the current status and enabling to compare each option for a better decision making.

3. Sustainability Indices

Sustainability indices (SI) have become increasingly important to sustainability research and practice but the validity of SIs is heavily dependent on how their components are weighed and aggregated (Gan X et al. 2017). Most common methods are putting same weight for each variable as in the SDG index that Sustainable Development Solutions Network (SDSN) and OECD developed for measuring the progress of each SDG (SDSN 2017; OECD 2017). Another way of weighting is using expert surveys. Based on the result of expert survey, the weight was calculated. Factor analysis is one of the main tools to look for correlation between multiple information which are widely used in various academic fields. Through principal component analysis and varimax rotation, the weight for each variable can be calculated and can be used to build the composite index (Kline 1993; Jung et al. 2018).

Next, from an analytical point of view, there are significant amount of literature on sustainability index to ensure EIA to provide evidence-based policy tools. There are many papers on making index according the type of development projects such as residential areas, public infrastructure and industrial facilities. Manzini et al assessed the environmental sustainability of energy projects as an interaction between nature and human society with emphasis on spatial aspects and on the inclusion of short and long term perspectives (Manzini et al. 2011). Regarding wind power, only one paper on China's windpower focused on economic gains (amount of electricity), social gains (job creation) and environmental gains (greenhouse emission reduction) (Gan X et al. 2017). Some are focused on economic, social and environmental features in a balanced manner and in these days there are increasing number of papers focusing on the ecosystem services and the quantitative analysis of ecosystem services as a good indicator of sustainability (Koo et al. 2012; Santangeli 2016; Ryu 2017).

IV. Methodology

1. Measuring Environmental Sustainability

Most in-land windfarms are located either in the mountainous areas or in the coastal areas for getting high wind velocity. Wind Resource Map coincidentally shows that appropriate wind farm sites are located in the high mountain or the coastal areas. Mountain type and coastal type seems to be very different in terms of environmental impacts.

EIA provides a lot of information on the environmental impact of the project. Main contents of EIA are as follows. 1) Outline of Project; 2) Current status of Economic, Social and Environmental Features of the site; 3) Scoping for relevant items of EIA; 4) Expected Environmental Impact (Landscape and Aesthetic aspects, Impacts on water resources, air quality, waste, dust, biodiversity, noise and vibration, etc; 5) Recommendation to mitigate negative impact including the comparison among various alternatives (MOE 2012).

As wind farms do not have significant environmental impacts on air quality, water quality, and waste management except the construction stage, these variables of little importance were excluded.

There can be three categories of environmental impact throughout the operation of the projects (MOE 2012; MOE 2014; MOE 2018; Jeon 2016).

First one is the impact on the landscape. Where there is big terrain change (TERR) and construction of entrance road or transmission facilities (TRANS), there is high possibility for the damage in the landscape (MOE 2018; Lee 2016). Slope is another important variables as wind farms located in steep areas have negative impact on the landscape as well as they are more prone to natural disaster.

Second is the impact on the biodiversity and ecosystem. If the site is in the vicinity to the habitat or migratory route of wildlife, it is certain that it has more negative impact on the biodiversity and ecosystem (Lee 2016; Lee 2014). The impact for biodiversity and ecosystem is difficult to analyze quantitatively. For example the portion of land or proximity to the major habitats or migratory routes

Table 1. Definition of the Variables

Type of Variable	Variable	Definition	Range	Index
Enabling	COST	Cost per MW installation	157~11,500 million won	↘
	LAND	Land Areas per MW installation	4,574~265,304 m^2	↘
Environmental	FORESTSH	Proportion of Forest Area out of Total Area	0~100%	↘
	SLOPE	Average Slope	0~24.72 degree	↘
	TERR	Terrain change (Cut+Fill volume/areas)	0.15~7.28	↘
	DGN	Average Degree of Green and Naturalness	1.17~7.00	↘
	NOISE	Proximity to the settlement	55~2,700 meter	↗
	TRANS	Distance to the existing transmission system per MW installation	514~29,817 meter	↘

were difficult to calculate from the data of EIA report. The affected population of endangered species is another important variable for biodiversity but can not be quantitatively measured so far. Therefore, Degree of Green and Naturalness (DGN) and the share of forest areas (FORESTSH) were chosen as variables to describe the impact on the biodiversity and ecosystem (Lee 2016).

Third one is the impact on the community such as noise, vibration and flickering. It would be better to have the number of population (residents) who are affected by the noise, vibration and the flickering from the operation of wind farms (Jeon 2016). The number of population and the magnitude of impact on the nearby community are not available in the EIA report and other sources. Rather, most of EIA reports have data on the distance to the nearest facilities and villages and the expected noise level in those locations. Some cases exceed the noise and vibration standards in the construction stage but most of the cases are within the limit of the noise and vibration standards. As low-frequency noise and vibration and flickering was not included in the EIA until recently, they were not analyzed in the EIA. The distance to the nearest community (NOISE) is a good indicator of possible environmental negative impact to the community.

Table 1 shows two enabling variables (COST, LAND) and six environmental variables (FORESTSH, SLOPE, TERR, DGN, NOISE, TRANS). Enabling variables are economic ones such as how much money and land areas were invested per Megawatt capacity of windfarm facilities. The lower the variable is (↘), the better in terms of enabling conditions. Environmental variables are mostly better when the varibles are lower number (↘). For example, If the terrain change is bigger, and the slope is steeper, the environmental sustainability becomes lower. As NOISE is calculated by proximity to the settlement, environmental sustainability gets better if this varible has higher number.

2. Factor Analysis and Principal Component Analysis

Factor analysis is a statistical method to explain variability among observed and correlated variables in terms of a potentially lower number of unobserved variables called factors (Kline 1993). Factor analysis is basically to find such joint variations with observed variables in response to unobserved latent variables and the observed variables are assumed as linear combinations of the potential factors and error terms. Factor analysis aims to find independent latent variables. The objective of applying the factor analysis is that the information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. At the initial stage, there are too many variables to conduct a research and in fact, there is no prior information on the relationship among observed variables. Then, the relationship among unobserved latent variables can be identified by minimum number of factors. Factor analysis helps to deal with data sets where there are large numbers of observed variables that are thought to reflect a smaller number of underlying/latent variables. It is one of the most commonly used inter-dependency techniques and is used when the relevant set of variables shows a systematic inter-dependence and the objective is to find out the latent factors that create a commonality. Factor analysis and another statistical method principal component analysis (PCA) are different. PCA is a more basic version of exploratory factor analysis (EFA) that was developed in the early days prior to the advent of high-speed computers. From the point of view of exploratory analysis, the eigenvalues of PCA are inflated component loadings, i.e., contaminated with error variance (Kline 1993).

For environmental and SDGs researches, factor analysis can be applied usefully (Jung et al. 2018). In this study, the application of factor analysis is to find the latent relationship, while reducing the number of variables for the research. Technically with imputed, standardized, and representative indicator variables, a factor analysis was run by Environmental Sustainability Variables. The factor analysis for Environmental Sustainability of Inland Windfarm has the number of six variables (Forest Share, Slope, Terrain Change, Average Degree of Naturalness, Proximity to settlement, Distance to transmission). Main purpose of conducting factor analysis in this study is to find out proper weights for each environmental sustainability variables to create an index for environmental sustainability index of inland wind farm based on the actual data in Korea. Brief process of factor analysis is as follows (Kline 1993; Jung et al. 2018).

$$\frac{X-\mu}{\sigma^2} = Z = LF + \epsilon \quad (1)$$

X is a matrix of environmental variables indicators.
μ is a matrix of mean variables of environmental variables indicators.
σ^2 is a matrix of variance of the environmental variables indicators.
F is a matrix of factors, unobserved random variables
L is a matrix of factor loadings, unobserved constants.
ϵ is a matrix of error terms.

The analysis is with the following assumptions.

1) F and ϵ are independent.
2) $E(F) = 0$
3) $Cov(F) = I$ (Identity matrix, assuming factors are not correlated)

By squaring each side of equation (1), then since Cov(F) = E[(F−E(F)(F−E(F)T] = E(FFT) = I, (2) and (3) were drawn as follows.

$$ZZ^T = L(FF^T)L^T + \epsilon\epsilon^T = LL^T + \epsilon\epsilon^T \quad (2)$$

$$[\epsilon\epsilon^T]^2 = (ZZ^T - LL^T)^2 \quad (3)$$

It is found that LL^T, a set of factor loadings, minimizes the square error terms. This means that LL^T needs to be identified so that the highest factor loadings can be utilized to make proper weight for environmental sustainability index.

Factor analysis results in factor loadings of each factor for each indicator variables. Factor loading means how well the unobserved factor explains the corresponding indicator variables. Therefore, the higher the factor loading is, the better the factor explains corresponding indicator variables. The highest factor loadings for each indicator variable were chosen and squared. The value of squared factor loading becomes weight for the environmental variables indicator (Kline 1993; Jung et al. 2018) And, finally, the weighted sum of all indicator variables becomes an index of environmental sustainability of certain inland wind farm case.

3. Data Collection

Though there are various data sources for inland windfarms such as renewable energy statistics, the data and information on individual windfarm cases are rare. In this study, data was gathered through EIA report.

Through Environmental Impact Assessment, the developer needs to submit the report assessing and predicting the environmental impacts of specific development projects and to provide the proposed plan is the best alternative. As EIA does not have power to cancel the project and simply present the measures to reduce environmental impacts as much as possible, it was criticized to make ways to endorse the development projects which has bad environmental impact. To consider the environmental impact from the early stage of planning, Strategic Environmental Impact Assessment (SEA) were introduced since 2005. State-led development and administrative plans and large-scale development projects need to have SEA in the planning stage. Prior Environmental Assessment for small development projects in the sensitive areas were merged to SEA since 2005 (MOE 2012; MOE 2014; MOE 2018).

To analyze as many cases as possible, Strategic Environmental Impact Assessment Reports (SEA), Prior Environmental Assessment (PEA) Reports as well as Environmental Impact Assessment (EIA) Reports have been analyzed. Some cases have gone through several steps such as SEA and EIA, or PEA and EIA. Many cases have gone through only EIA, but had several amendments in the process. The details of each project has been modified in the process of Environmental Impact Assessment. In this study, the final stage of report that the developer submitted to Environmental Authority were used as a data source. For example, if case A had SEA and EIA, EIA report in the later stage of the review were used analyzed in this paper. In the process of these reviews (hereinafter referred as EIA), Environmental Authority give permission for the development project often with conditions such as excluding environmentally sensitive areas and rehabilitation of entrance road after the construction of wind farm. As these conditions are difficult to identify and gather, the information on the EIA report that the developer submitted were used.

Out of 77 completed EIA cases, 66 cases were found in the Environmental Impact Assessment Support System Portal (EIASS) which is being operated by Korea Environment Institute. Out of 66 Cases, four cases were declined by the Environmental Authority and four cases have gone through SEA and EIA (two cases), and PIA and EIA (one case), two EIA (one case). These four declined cases and four repeated cases were excluded so that 58 cases of EIA became the subject of analysis.

4. Analytical Results

1) Data conversion

Six environmental variables are different in terms of scale and the direction for environmental sustainability. For example, Forest Share is from 0 to 100% and environmental sustainability is increasing when the forest share is higher. Terrain

Table 2. Weights of each variable through Principal Component Analysis

	Highest Factor Loading		Factor Squared			Factor Squared		Final weight
	F1	F2	F1	F2				
FORESTSH	0.8488		0.720461			0.355467		0.206969
SLOPE		0.8174		0.668143			0.459457	0.191940
TERR		0.8866		0.786060			0.540543	0.225814
DGN	0.8633		0.745287			0.367716		0.214101
NOISE	0.6398		0.409344			0.201965		0.117594
TRANS	0.3895		0.151710			0.074852		0.043582
	A: Explained Variance of Factor		2.026803	1.454202				
	B: Total Variance of Factor				3.481005			
	A/B		0.582246	0.417754	1			

Change is from 0.15 to 7.28 and the higher number means lower environmental sustainability. The data of each variable were converted so that it has the value from -1 to 1.

2) Calculating weights

Based on (2) and (3), the highest factor loadings were calculated and were squared to calculate the weights of six variables. Principal Component Analysis were conducted using Stata. The result from Stata is shown in the table 2 how the weight for each variable were calculated. The highest factor loadings for FORESTSH, DGN, NOISE and TRANS is F1 while F2 is the highest ones for SLOPE and TERR. The sum of the squared highest factor loadings means how well F1 or F2 explains the variance of Factor. F1 explains the variance as much as 2.026803 while F2 explains as much as 1.454202. Final weight are calculated by multiplying F^2/Explained Variance of Factor and A/B. The weight for Terrain Change, Average Degree of Naturalness, Forest Share and Slope were 22.58%, 21.41%, 20.6% and 19.19% while those of Noise and Distance to Transmission were only 11.75% and 4.35%. The variables that have lower weight has limited contribution to the environmental sustainability compared the ones with higher weight.

3) Categorizing into three types of inland wind farm

Most in-land windfarms are located either in the mountainous areas or in the coastal areas for getting high wind velocity. Wind Resource Map coincidentally shows that appropriate wind farm sites are located in the high mountain or the coastal areas (Kim 2018; Kim & Hwang 2014). Mountain type and coastal type seems to be very different in terms of environmental impacts.

Among the mountainous sites, some are already developed for the agricultural purposes such as ranch, vegetable farms, or recreational facilities. These already developed mountain areas will be categorized as Ranch type. In the early stage of wind power development, these already developed mountainous sites were selected because of less burden for the environmental damage and the low construction cost because they can utilize existing infrastructure such as road and electricity transmission system (Lee 2016; Lee 2014).

Out of 58 cases, there are 32 cases of Mountain type which its altitude is higher than 200 meters and average DGN is higher than 5. 13 Cases are Ranch Type which its altitude is higher than 200 meters and average DGN is lower than 5. 13

cases are Coastal Type which its altitude is lower than 200 meters. Out of 13 cases, one case (Hwasoon windfarm) is located alongside of lake, not located in the coastal areas. Mountain types are located in the eastern part of Korean peninsula where coincides the location of the Baekdudaegan. Ranch types are located in the inner land while coastal types are located in western and southern part of Korea (Annex 2 : Map of 58 windfarms).

4) Comparison of three types based on Environmental Sustainability Index

Table 3 and Figure 1 show that ranch type is most environmentally sustainable (Average ESI = 0.4551), followed by coastal type (Ave ESI = 0.3712) and lastly mountain type (Average ESI = -0.3457). The sum of ESIs of 58 windfarms is zero. Negative number means low ESI. Mountain type is not performing well such as forest share (FORESTSH, -0.1193), degree of green and naturalness (DGN, -0.1503), slope (SLOPE, -0.0535) and Terrain change (TERR, -0.0569). Mountain type was expected to perform well for proximity to the settlement (NOISE) as it would be remote to villages and other settlement. However, it is slightly better (0.0138) compared to the average, the difference compared with ranch (0.0046) and coastal type (-0.0386) was not very distinct. Coastal type performs better in environmental component such as Terrain Change (TERR, 0.0501), Slope (SLOPE, -0.1213), and DGN (0.1456). However, NOISE (-0.03801) and TRANS (-0.0027) is under average. Ranch type performs best considering all six variables.

Table 3. Result of Environmental Sustainability (ES) Index of three types of inland windfarm

	ES Index	Average Year	Forest share	Slope	Terrain	DGN	Noise	Trans
Ranch	0.4551	2012.1	0.1357	0.0859	0.0754	0.2000	0.0046	0.0027
Coast	0.3712	2014.2	0.1684	0.1213	0.0501	0.1456	-0.0386	-0.0027
Mountain	-0.3457	2016.1	-0.1193	-0.0535	-0.0569	-0.1503	0.0138	0.0000

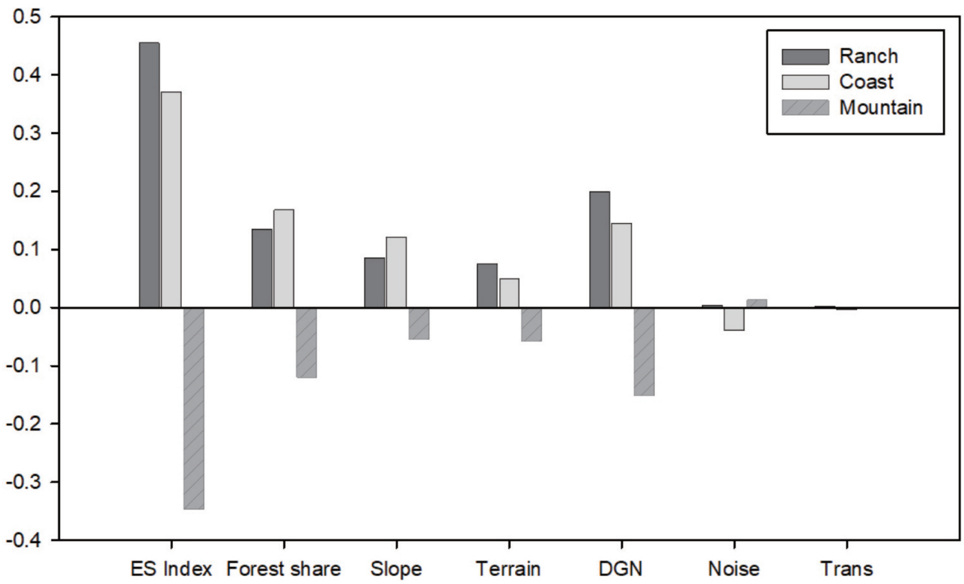

Figure 1. ESI of Ranch, Coast and Mountain type of wind farm.

Another interesting features are the year of EIA submission. Out of 58 cases, earliest case was in 2003 and it was Ranch Type. Average year of submission of Ranch type is 2012 compared by 2014 of Coastal type and 2016 of Mountain type (Table 3). It can be explained that ranch types were economically cost effective due to less construction cost. Also, as it is already developed for agricultural purposes, the concerns over environmental damage from the removal of forest or terrain changes are relatively less. Coastal and Mountain types have been constructed in more recent years.

5. Discussions

Renewable energy source such as wind power is considered as environmentally sustainable considering mitigation impact of greenhouse gases (European Environment Agency 2015; Huber et al. 2017). In the early stage of EIA for windfarms, most of EIA were small sized projects which can be fast-tracked for swift construction. However, as many inland windfarm were established mostly in mountain areas including Baekdudaegan, there were demands to regulate the siting of inland windfarm (Lee 2016; Jeon 2016).

Due to growing concerns on the negative impact of inland windfarms, Environmental Authorities released series of guidelines since 2012 (MOE 2012; MOE 2014; MOE 2018). First EIA guidance on windfarm in 2012 was established focusing on the terrain change and biodiversity impact, prohibiting the cases higher than 3.0 in the terrain change index. In 2014, second EIA guidance was announced for easement of inland windfarm allowing windfarm in the Environmentally Sensitive Areas. In 2018, third EIA guidance was announced for strengthening regulation for limiting windfarms in the ESA and recommending assessment of low-frequency noise and vibration and flickering. In 2019, there was slight amendment of guideline to specify the distance to be kept from the environmentally important areas for siting of inland windfarm. In 2021, MOE is in the process of establishing EIA guidelines for off-shore windfarm to be applied from 2022.

It is interesting to find that terrain change of 11 windfarms out of 58 cases are higher than 3. If 2012 guideline were continuously applied, these were not be allowed (MOE 2012). 6 windfarms were located in the area that average slope is more than 20 degrees. Considering the disaster proneness, it is not desirable to locate built establishment in the steep areas. 15 windfarms are located in the area where altitude is higher than 1,000 meters. Though altitude itself doesn’t necessarily related to the negative environmental impact, it does mean that these are located in the ridges of mountain areas, thus may cause the disturbance on the migration of animals as well as negative impact on the landscape (Lee 2016). Even though several EIA guidelines were enforced, many windfarms are not very good in terms of environmental sustainability according to the result of this study. For examples, ESI of three mountain type windfarms are lower than -1.0 (Taebaek-2, Namhae and Jangheung). 6 cases are between -0.5 to -1.0 (5 are mountain type and 1 is coastal type). There is no ranch type case which has lower ESI index than -0.5. Despite that most EIAs were completed, some projects were being on hold or cancelled due to strong objection from the local community and environmental NGOs.

It is important to understand the positive and negative impacts of windfarm. This study shows the concrete results based on quantitative data of individual windfarms. Through analysis of six environmental variables, ESI can be calculated for individual windfarm sites. Difference between highest scored one and lowest one are 2.48. It is consistent as the highest one is Ranch type and the lowest one is Mountain type.

Based on the findings of this study, agricultural land is more suitable site for windfarms in terms of environmental sustainability. This reinforces the fact that most of inland windfarms are located in agricultural areas in Europe even though there is lack of descriptive guidance on terrain change index or slope (European Environment Agency 2015; Jeon 2016; Konadu 2015). Coastal type is second preferred option where high yield of wind velocity. Mountain type, especially where high terrain changes and steep areas and in the vicinity of wildlife habitat or Baekdudaegan, would be the last preferable option. 32 cases out of 58 were mountain type. Therefore, construction of mountain type of windfarm needs to be reviewed more rigorously to minimize the negative environmental impacts. This research has limitation as it focused on environmental sustainability using only six variables. Further studies analyzing more variables on environmental sustainability (e.g. habitat and migratory route, the proximity to the protected areas) and economic and social sustainability (e.g. B/C ratio, Electricity Yield, Community Acceptance) would provide more comprehensive features on inland wind farm.

IV. Conclusion

To keep the global temperature rise below catastrophic level, countries are moving forward to achieve carbon neutrality by 2050. Korean government became the 14th countries to legalize carbon neutrality and strengthened its intended determined contribution by 2030 from 24.4% to 40% in the COP26 in Glasgow United Kingdom. Decarbonizing energy source is becoming the first priority more than ever. However, green versus green conflicts over renewable energy, such as Food and water shortage from biofuel production, ecosystem damage from wind power and solar power, becomes more prevalent due to increased demand (Huber et al. 2017; Koo et al. 2012).

The environmental sustainability index which was developed through this study can play important roles. First, it helps understanding common features of wind farms all over the world. Wind velocity is different according to the latitude, altitude as well as distance to the ocean, etc (Kim 2008; Kim & Hwang 2014). What is the main factors to get the highest yield while minimizing the negative environmental impacts?

Second, through ESI, the trade-offs of different variables can be analyzed. The cases with high forestshare and terrain change are mostly remote mountain areas which are distant from settlement. The inter-relatedness of variables can be more deeply studied. Though this study covered only six variables due to limited quantitative data available, if more variables are added, more understanding of trade-offs among the variables could be analyzed.

Finally, ESI can be utilized to develop more detailed guidelines for assessing economic, social and environmental impacts of wind power and can provide criteria for decision making (Gan X et al. 2017). For example, the project of lower value of sustainability index may need to be declined unless additional measures are undertaken.

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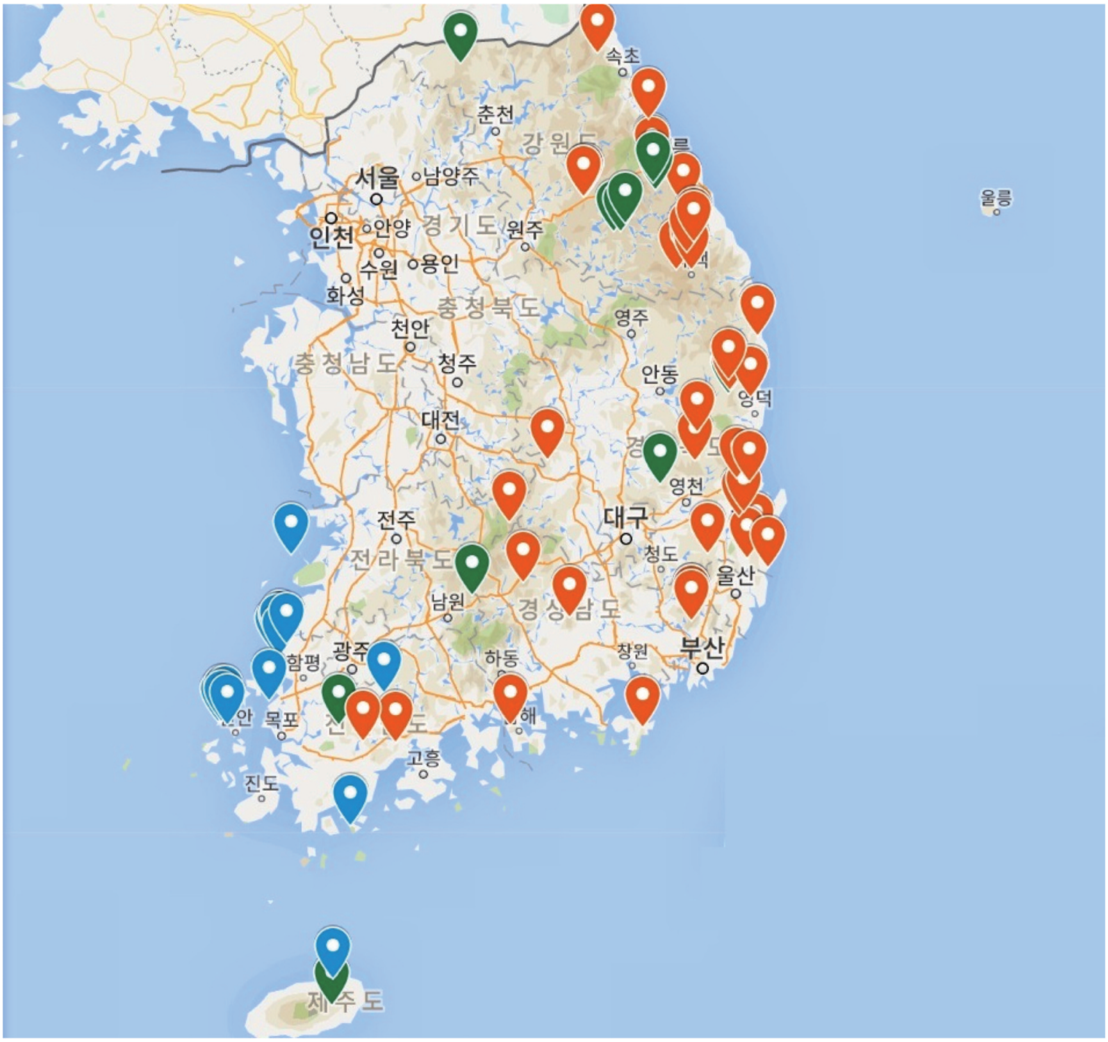
Annex 1 : Characteristics of 58 wind farms

ID	Installed MW	Budget	AREA	FOREST SHARE	ALT	SLOPE	CUTFILL	TERR	DGN	NOISE
1	24	72,533	44,812	15.52	1300		166,697	3.72	1.6	750
2	46	155,000	57,234		1000		54,738	0.96	4.195	1,241
3	20		86,710	100.00	850		207,581	2.39	6.822	420
4	28	78,000	87,602	34.41	1,200		126,707	1.45	3.0577	250
5	26		31,026	13.89	1,199	18.20	161,310	5.20	2.169	1,200
6	35	105,000	116,376	99.60	1,445	17.30	263,362	2.26	6.87	800
7	58		1,319,572	69.60	800	15.00	750,069	0.57	6.08	540
8	30	72800	93,354	100.00	1,005	16.60	346,005	3.71	6.3363	1,265
9	30		69,006	100.00	1,080	16.60	248,527	3.60	5.9728	1,030
10	39	81,200	64,584	100.00	1,143	4.60	90,908	1.41	4.1736	2,700
11	4		19,083	0.00	1,085	12.90	6,258	0.33	2.1136	449
12	39	94500	36,870	11.06	1,200	12.00	71,514	1.94	6.1134	1,480
13	20		60,735	100.00	1,123	24.72	346,183	5.70	6.5519	586
14	25	68,000	99,896	98.48	1,095	17.60	219,556	2.20	6.1411	772
15	40	112,500	81,524	100.00	620	20.00	271,130	3.33		2,050
16	39	123,600	92,132	100.00	1,193	5.40	229,933	2.50	6.81	626
17	5		9,733	100.00	1,028	20.20	35,587	3.66	7	521
18	62	180,000	452,560	98.61	804		500,546	1.11	1.586	1,660
19	18	39,020	77,266	93.20	540	7.72	163,382	2.11	5.3954	50
20	54	109,300	201,704	77.83	674	10.00	438,536	2.17	4.919	565

ID	Installed MW	Budget	AREA	FOREST SHARE	ALT	SLOPE	CUTFILL	TERR	DGN	NOISE
21	27		196,590	91.03	559	5.10	295,298	1.50	6.4786	240
22	76		197,435	98.07	565	15.67	779,526	3.95	5.8008	203
23	18	57600	83,248	99.92	635	6.20	203007	2.44	6.6294	985
24	6		22,022	17.91	263	5.00	109,203	4.96	6.886	540
25	38	190,000	177,849	96.45	430	20.00	469,045	2.64	5.0926	752
26	20	50,080	59,372	100.00	707	23.00	72,420	1.22	6.8839	845
27	6	944	25,044	100.00	220	4.90	66,073	2.64	6.7624	1,381
28	20	6,000	66,099	90.98	723	4.80	105,108	1.59	5.8176	66
29	23	61,400	87,992	97.85	680	16.17	237,952	2.70	6.153	140
30	15		88,509	100.00	355	19.90	107,808	1.22		880
31	15	37,000	71,663	89.47	814	5.40	67,328	0.94	4.7114	165
32	5	3,200	13,343	100.00	600	13.19	35,600	2.67	5.7279	490
33	0	1,156	4,907	0.00	464	6.88	3,467	0.71	2.83	
34	36	100,000	102,007	100.00	1,040	19.30	411,000	4.03	5.6997	
35	3	7,480	9,908	10.00	0	0.00	6,601	0.67	1.17	14000
36	12		35,610	7.23	700	11.40			1.51	
37	3		10,575	100.00	720	22.80	23,975	2.27		500
38	19		90,648	100.00	600	13.50	3	0.00	6.438	1,000
39	36	100,000	99,391	100.00	514	11.30	116,736	1.17	6.3585	193
40	20	50,000	29,491	100.00	896	7.30	45,638	1.55	5.6549	806
41	26	82,000	87,949	100.00	763	18.80	12,882	0.15	5.716	745
42	15	43620	28,468	66.24	330		43,329	1.52	3.9883	86
43	48		11,260	0.00	145			0.00	5.166	
44	40	110,000	112,000	8.64	465	11.41	90,160	0.81	4.15	650
45	20	50,000	21,295	0.00	5		31,379	1.47	2	300
46	20	50,900	32,475	97.94	45	14.90	92,321	2.84	6.1001	930
47	21	50,000	16,630	0.00	5		48,735	2.93	2	750
48	30	75,000	22,420	0.00	5		43,493	1.94	2	550
49	43	111953	79,780	0.00	23	5.30	54,894	0.69		496
50	30	65,000	799,838	99.90	100	2.60	102,724	0.13	6.776	467
51	32	86,404	102,774	88.43	103	19.80	364,170	3.54		445
52	48		45,823	37.83	145	6.60	33,425	0.73	5.166	255
53	18	42,400	17,540	26.73	30		38,687	2.21	1.447	415
54	17	44,800	28,820	77.97	75	15.30	94,054	3.26	6.0804	950
55	39	117,000	79,360	100.00	767	24.30	577,632	7.28	6.514	1,455
56	20	8,420	45,533	96.64	415	16.90	58,880	1.29		78
57	15		16,424	32.48	38	6.60	31,186	1.90	2.073	130
58	16	49,000	82,229	100.00	415	19.70	236,946	2.88	6.2089	1,568

Annex 2 : Map of 58 windfarms



Blue : Coast Type Green : Ranch Type Red : Mountain Type