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Evaluation of Inland Wind Resource Potential of South Korea According to Environmental Conservation Value Assessment

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Abstract

In order to analyze the effects of environmental regulation on wind power dissemination quantitatively, the country's inland wind resource potential has been estimated using the Environmental Conservation Value Assessment Map and the South Korea Wind Resource Map. The evaluation matrix of wind resource potential is formed by classifying environmental regulations into strong, intermediate, and weak, and economic feasibility into high, middle, and low. The purpose is to estimate inland wind resource potential in order to mitigate the environmental regulation needed to attain the national dissemination target of wind power and determine the most suitable level of the incentive policy.

Keywords: Wind Resource Potential Matrix, Environmental Conservation Value Assessment Map, Wind Resource Map

1. Introduction

The *6th Power Supply and Demand Master Plan (2013-2027)* announced by the Ministry of Trade, Industry & Energy (MOTIE) in February 2013 presented the ambitious goal of expanding the use of renewable energy as a proportion of total power generation from 2.3 % (as of the end of 2012) to 12 %, i.e. an installed capacity of 20 %. According to the plan, wind power must be responsible for providing 17.2 GW, which is 53.6 % of the cumulative 32 GW capacity of renewable energy by 2027, the final year of the plan.[1]

However, as of the end of 2012, the installed capacity of wind power was only 485 MW. The plan calls for the additional installation of 4,720 MW, which is ten times the cumulative capacity recorded in 2012, by the end of 2017, 10,754 MW by the end of 2022, and 1,180 MW by 2027.

The basis for such an exponential expansion of wind power dissemination is that wind power is the

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most economical of all renewable energy sources, as indicated by the Levelized Cost of Energy (LCOE) Analysis Report for 2011. [2] Moreover, wind turbine manufacturing is regarded as a next-generation industrial engine with the capacity to continue the advancement of the heavy machinery industry in South Korea.

MOTIE switched the incentive policy from the Feed-In-Tariff (FIT) to Renewable Portfolio Standards (RPS), assigning the renewable energy supply obligation to major power companies beginning in 2012, and carrying out various support programs, such as 2.5 GW South-Western Offshore Wind Power Implementation Plan, in order to realize the renewable energy dissemination policy.

Despite that, the power companies were required to pay USD 16 million in charges to attain only 65 % of the RPS obligation as of the end of 2012. The main reason for this failure to satisfy the RPS is the shortage of wind power dissemination, which is supposed to play the main role in the dissemination of renewable energy. For its part, the wind industry, including the power companies, has pointed to excessively restrictive environmental regulation as the reason. As a matter of fact, fifty-three applications to construct wind power plants (total installation capacity of 1.8 GW) may not have been approved due to the environmental regulation as of the end of 2012.

To formulate a proper policy when the dissemination of renewable energy conflicts with the environmental protection regulation, a review of the impact of environmental regulations on actual wind power dissemination based on objective and quantitative data is necessary. As such, this study uses the Environmental Conservation Value Assessment Map and the South Korea Wind Resource Map to estimate the country's inland wind resource potential according to the environmental regulation and an economic feasibility scenario to quantitatively assess the impact of environmental regulation on wind power dissemination. Jeju Island is excluded from the analysis of this study because it is implementing its own wind power dissemination guideline under its status as a Special Self-Governing Province. In addition, any islands not connected to the inland by an overland route are also excluded from this analysis.

2. Analysis Data

2.1. Environmental Conservation Value Assessment Map

The Environmental Conservation Value Assessment Map (ECVAM) classifies the environmental value of land with regard to its efficient conservation and utilization according to Article 15-2 (Development and Dissemination of Environmentally-Friendly Planning Techniques, etc.) of the Framework Act on Environmental Policy. [3]

The assessed items of the ECVAM include the 57 types of regions designated for legal conservation use, i.e. ecological landscape conservation regions, natural reserve regions, wild animal special protection areas, wetland protection regions, waterside areas, soil conservation regions, specific islands, natural parks, stream areas, coastal areas, underground water conservation areas, drinking water resource protection areas, natural environmental conservation regions, green regions, restricted development areas, urban parks, conserved mountain areas, natural protection areas, agricultural promotion areas, land readjustment regions, etc. and the 8 types of environmental/ecological value including the following: diversity (species diversity, etc.); naturalness (age-class, ecological naturalness, etc.); rarity (protected/ endangered species diffusion map, etc.); vulnerability (adjacency to roads, adjacency to urban areas, etc.), safety (emergencies, etc.); and connectivity, potential value, etc.

The final regional assessment class of ECVAM is assigned by reiterated calculation of 65 thematic maps for each assessed item assigned to classes 1~5 (class 1 being the highest conservation value). Class 5 refers to already-developed regions.

The Ecological and Natural Map (ENM) classifies (classes 1~3 or specially managed areas) mountains, streams, lakes, farms and urban areas according to their ecological value, naturalness, and scenic value so that they can be used for land utilization or development planning or execution under the provisions of Article 34 (Drafting and Utilization of Ecological and Natural Maps).

While the ECVAM classifies the environmental attributes of land according to a comprehensive concept, the ENM is used for actual land utilization or development planning or execution. As class 1 of the ECVAM includes all items under class 1 of the ENM, the ENM can be considered as a subset of the ECVAM, although the actual reference for the environmental impact assessment of various development projects (such as wind power plants) would be the ENM. It should be noted that the total class 1 areas of the ecological map amount to 11,007 km^2 or around 25 % of all the class 1 areas of the ECVAM.

Table 1. Corresponding area by ECVAM Class (Year 2011)

ECVAM Class	Area (km^2)	Ratio (%)
Class 1	44,068	46.5
Class 2	22.414	23.6
Class 3	16,438	17.3
Class 4	5,497	5.8
Class 5	6,375	6.7
Total	94,791	100.0

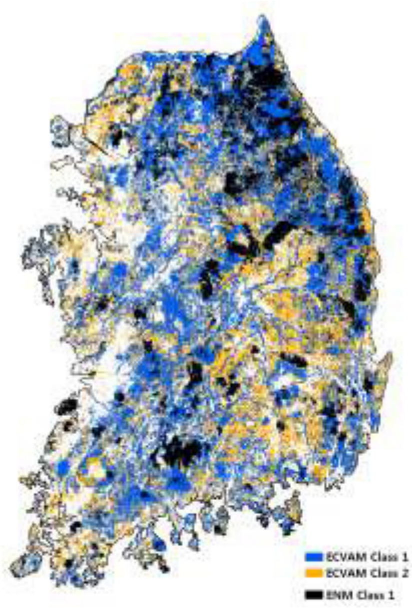

Fig. 1. Environmental conservation value assessment map of South Korea

2.2. South Korea Wind Resource Map

The South Korea Wind Resource Map is a comprehensive database based on the Geographical

Information System (GIS) of wind power developed by the Korea Institute of Energy Research (KIER) as part of the project sponsored by MOTIE to support wind power dissemination under the provisions of the Act on the Promotion of the Development, Use, and Dissemination of New and Renewable Energy. [4]

The first phase of the wind mapping, compiled over a period of ten years from 2001 to 2010, involved the spatial resolution of a 1kmx1km horizontal plane and a 10 m vertical distance over the whole Korean Peninsula and temporal resolution at 10-minute intervals using Weather Research and Forecasting (WRF), which is a mesoscale Numerical Weather Prediction (NWP) model. [5,6] The second phase involved the generation of the final wind resource map of 100mx100m horizontal spatial resolution through 1-way dynamic downscaling of the whole Korean Peninsula using WindSim, which is the Computational Fluid Dynamics (CFD) model.

On land, KIER validated and corrected the South Korea Wind Resource Map using the meteorological-tower data measured according to the IEC 61400-12 Wind Turbine Standard at 200 or so points nationwide over the past fifteen years. [7] The vertical wind speed profiles were validated using LIDAR and SODAR, which are ground-based remote-sensing measurements. [8] At sea, where in-situ measurement is difficult, the map was validated and corrected using marine buoy observation data and offshore wind retrieval data from satellite images taken by the Synthetic Aperture Radar (SAR). [9]

Table 2. Corresponding area by wind power density (at 70 m a.g.l.)

Wind power density (W/m^2)	Area (km^2)	Ratio (%)
~250	76,376	79.9
250~350	10,918	11.4
350~450	4,185	4.4
450~	4,078	4.3
Total	95,558	100.0

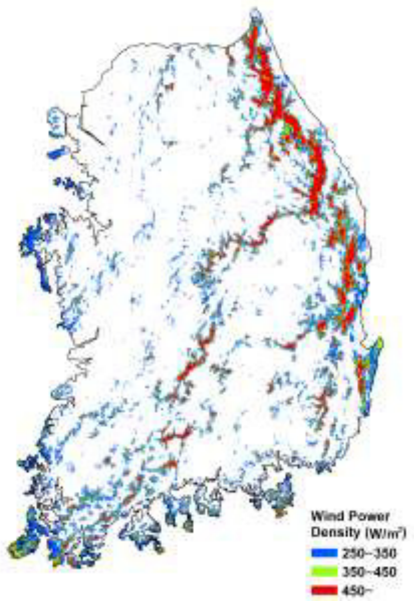

Fig. 2. Wind resource map of South Korea (wind power density at 100 m a.g.l.)

2.3. Electric substation map

Fig. 3 shows the locations of 715 electric substations (black dots) and the distances from them (colored areas) in South Korea. They are categorized into less than 5 km, less than 10 km, and less than 20 km from the nearest substation. Since wind power plant developers are obligated to connect the power systems to substations in South Korea, construction costs increase as the distance from the substations increases.

The cost of connecting the power system is about USD 0.1 million per km and USD 1 million per km for ground connection and underground connection, respectively, based on a 22 kV distribution line when connecting 20 MW system. If a substation has no or insufficient capacity for power transmission access, an additional USD 1.5 million will be needed for the installation of an additional transformer and facilities.

Table 3. Corresponding area of distance from substations

Distance from substation	Area (km^2)	Ratio (%)
< 5 km	26,770	28.2
< 10 km	50,897	64.2
< 20 km	91,350	96.4

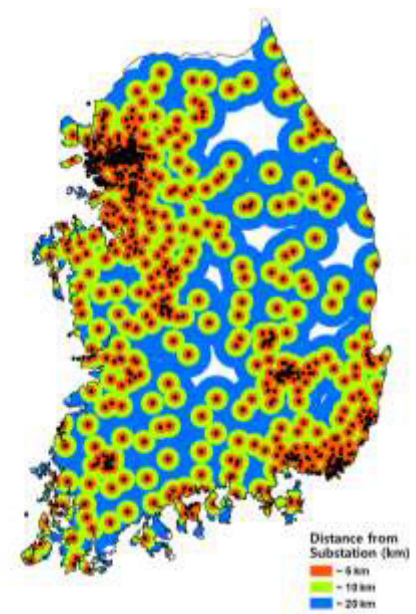

Fig. 3. Electric substation map of South Korea

3. Analysis Method

This study estimated the inland wind resource potential using a 3 x 3 matrix formed by categorizing environmental regulations into strong, intermediate, and weak, and the economic factors into high, middle, and low. Once the wind power capacity needed to attain the renewable energy dissemination goal is estimated, the matrix cell corresponding to the target value can be identified, and the level of environmental regulation and economic feasibility needed to attain the target can be assessed. The assessment of such potential in the form of a matrix can be used to obtain scientific and rational analytical data to help establish the national strategy, such as mitigation of environmental regulation and control of the incentive program to secure economic feasibility in order to promote the dissemination of wind power plants.

3.1. Wind Resource Potential Estimation

This study assumed that the minimum feasibility for developing wind power plants is assured when the wind power density is 250 W/m^2 (wind class 2 according to the US National Renewable Energy Laboratory (NREL)) or higher above a ground level of 100 m. To verify such an assumption, twenty currently active wind power plants (excluding ten plants in Jeju Island) were analyzed using the South Korea Wind Resource Map of KIER. The analysis indicated that three plants are located in areas with a wind power density of 250 W/m^2 (wind class 2; poor) or less; nine in areas with a wind power density of 250～350 W/m^2 (wind class 3; fair); and eight in areas with a wind power density of 350 W/m^2 (wind class 4; good) or more. The wind power plants in areas with a wind power density of 350 W/m^2 or less are mostly situated near industrial complexes and were developed by wind power demonstration projects supported by the government, as the connection to electric substations was easily enabled. As the wind power plants were developed at the wind class prevalent in Korea, where the average wind speed is lower than in Europe, it is set as the minimum level for economic feasibility.

This study adopted 5 MW/km^2 as the Average Power Intercepted (API), which is the theoretically installable wind turbine capacity per unit area. Although Kim (2008) [10] used 4 MW/km^2 as suggested by Hoogwijk et al. (2004) [11], we believe that 5 MW/km^2, as suggested by Elliott et al. (2010) [12], is more rational when considering the recently increased wind turbine capacity.

Table 4. Wind resource potential by wind class

Wind power density (W/m^2)	Wind class (US NREL)	Wind power capacity (GW)
~250	Class 1	-
250~350	Class 2	54.6
350~450	Class 3	20.9
450~	Class 4~	20.4
Total		95.9

3.2. Environmental Regulation Scenario

The following three environmental regulation scenarios for wind power plant development were considered:

- Weak environmental regulation: Development in class 1 areas of the ENM plus national parks is not allowed (11.6 % of national territory)
- Intermediate environmental regulation: Development in class 1 areas of the ECVAM is not allowed (46.5 % of national territory)

- Strong environmental regulation: Development in class 1 and 2 areas of the ECVAM is not allowed (70.1 % of national territory)

3.3. Economic Feasibility Scenario

The following three economic feasibility scenarios for wind power plant development were considered:

- High economic feasibility: Wind power density of 250~350 W/m^2 (wind class 2) and a connection distance to the electric substation of less than 20 km
- Middle economic feasibility: Wind power density of 350~450 W/m^2 (wind class 3) and a connection distance to the electric substation of less than 10 km
- Low economic feasibility: Wind power density of 450 W/m^2 or higher (wind class 4 or higher) a connection distance to the electric substation of less than 5 km

The following two factors representing economic feasibility were selected: the connection distance to the substation, which directly affects construction cost (expense); and wind power density, which determines wind power generation (income).

4. Results and Implications

4.1. Theoretical Wind Resource Potential

Areas with a wind power density of 250 W/m^2 or higher, i.e. wind class 2 or higher, account for around 20 % of total land area of South Korea. In other words, that corresponds to about 96 GW of the country's theoretical inland wind resource potential. In the case of class 3 or higher, the theoretical inland wind resource potential decreases to approximately 41 GW.

One thing to note is that the land on which wind power plants can actually be developed should be free of roads, streams, buildings, and stiffly inclined terrain, and thus would provide only 1/2 or less of the theoretical potential given in Table 4.

4.2. Wind Resource Potential Matrix

As the dissemination of wind power in South Korea has to deal with both the conflicting environmental conservation issue and the renewable dissemination issue, the national wind power dissemination policy must balance these two conflict values. To that end, the inland wind resource potential was restructured in the form of a matrix, as shown in Table 5, so that the environmental regulation scenario and the economic feasibility scenario could be considered at the same time to identify the balanced point.

According to the wind resource potential matrix, the wind power immediately available for dissemination from strong environmental regulation and high economic feasibility is only 0.1 GW. Even if both factors were mitigated to intermediate environmental regulation and middle economic feasibility, it would still amount to only 2.7 GW. Therefore, it is clear that a more easing of the environmental regulation will be essential for the effective dissemination of wind power.

As mentioned in the introduction, 17.2 GW of cumulative wind power capacity will be needed to reach the targets of the *6th Power Demand and Supply Master Plan (2013~2027)*. Assuming that 1/3 can be achieved by onshore wind power and 2/3 by offshore, then the required installation capacity will be 5.7 GW. If strong environmental regulation is maintained, 5GW will have to be developed in wind class 1 areas where the economic feasibility is poor. Even if the environmental regulation were to be eased to the intermediate level, 2.6 GW or more would be needed in the wind class 1 area.

Therefore, it might be necessary to ease the environmental regulation to the weakest level in order to attain the inland wind power dissemination target of 5.7 GW while still maintaining intermediate or higher economic feasibility. In that scenario, the potential would be 6.9 GW, which is still not enough since the potential given in Table 5 does not exclude geographical obstacles such as steep terrain, roads, streams, buildings, and so forth. As such, the inland wind power dissemination target can only be attained if the environmental regulation is eased even in some class 1 areas of the ENM.

Table 5. Wind resource potential matrix considering environmental regulations and economic feasibility

Wind resource potential		Environmental regulations		
		Weak	Intermediate	Strong
Economic feasibility	Low	41.6 GW	20.8 GW	8.7 GW
	Middle	6.9 GW	2.7 GW	0.7 GW
	High	1.3 GW	0.4 GW	0.1 GW

5. Conclusion

This paper presents an inland wind resource potential matrix analysis to consider both an environmental regulation scenario and a wind power dissemination scenario with the aim of resolving the intense conflict between the environmental regulation logic and the wind power dissemination logic.

An analysis of the 3 x 3 matrix format wind resource potential, which is composed of three levels of environmental regulation and economic feasibility, reached the following conclusions:

- According to the South Korea Wind Resource Map, areas with wind class 3 or higher, where the minimum feasibility for wind power plant development is assured, represent around 20 % of the total land area of South Korea and correspond to a theoretical potential of 41 GW.
- As the class 1 areas on the Environmental Conservation Value Assessment Map account for 47% of the country's total land area, the exclusion of class 1 areas only would reduce the wind resource potential to the 1/5 level. Therefore, the scenario in which the environmental regulation is limited to class 1 areas on the Ecological and Natural Map, plus national parks, was selected as the factor to prevent environmental destruction.
- In order to attain the targets of the 6th Power Demand and Supply Master Plan (2013~2027) set by the Ministry of Trade, Industry and Energy, inland wind power dissemination must reach 5.7 GW by 2027, i.e. the final year of the plan. As it will be difficult to attain that goal by following the scenario of middle economic feasibility, the environmental regulation must be eased to a weak level. Moreover, to expand wind power plant development to low economic feasibility, a support policy that provides differentiated incentives according to wind power density, like that implemented in Germany, will be needed.
- As South Korea is very vulnerable to energy security risks in terms of energy consumption and dependency on imports, the expansion of renewable energy dissemination has to be the key mid- to-long-term national goal. However, environmental conservation cannot be ignored for the sake of wind power dissemination. This study has developed an assessment of the wind resource potential matrix that takes into account those two conflicting values. Using the matrix, the study presents a policy analysis method that not only helps review the level of easing of the environmental regulation needed to promote wind power dissemination, but also assesses the installation capacity that can be secured by

improving economic feasibility through an incentive policy.

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