

# Preliminary Estimation of Onshore/Offshore Wind Resource Potential in South Korea

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**ABSTRACT:** The wind resource potential of South Korea is estimated preliminarily using GIS (Geographical Information System) and the medium-resolution national wind map which is being established via numerical wind simulation. The wind resource potential is classified into theoretical, geographical, technical and implementation potentials, with the calculation results of each stage verified by comparison with those from other countries. In case of developing 5 and 17.5% of the onshore and offshore wind resources, the corresponding technological potential of South Korea has been estimated as 37.7 and 80.3TWh/yr (14.6 & 35.4GW) for onshore and offshore, respectively. The potential for implementation to levels similar to those of leading European countries for wind energy have been approximated to be 9.4 and 20.1TWh/yr (3.6 & 8.8GW) for onshore and offshore, respectively. The sum of these two accounts for 3% of the gross supply of inland energy consumption in South Korea during 2007.

**Keywords:** wind resource potential, national wind map

## NOMENCLATURE

|        |                                                       |
|--------|-------------------------------------------------------|
| A      | Rotor Sweeping Area [ $\text{m}^2$ ]                  |
| AEP    | Annual Energy Production [MWh/yr]                     |
| API    | Average Power Intercepted [ $\text{MW}/\text{km}^2$ ] |
| AWT    | Unit Area Occupied by Turbine [ $\text{km}^2$ ]       |
| CF     | Capacity Factor                                       |
| D      | Rotor Diameter [m]                                    |
| FLH    | Full Load Hours = 8,760 [hr]                          |
| WPD    | Wind Power Density [ $\text{MW}/\text{m}^2$ ]         |
| $\eta$ | Wind Turbine Efficiency                               |

## 1. INTRODUCTION

The renewable energy R&3D (Research, Development, Demonstration & Dissemination), including wind energy, is always led by supporting government policy, and the clear dissemination target being presented at this time becomes a crucial priority. To make this possible, the quantitative

objective of R&3D that can actually be supplied must be derived under timely, industrial and political circumstances and restrictions after identifying the implementation objective, which can be technically developed by estimating the wind resource potential. While the Korean government has announced a dissemination target of 5% of the domestic electricity demand from renewable energy sources by 2011, this value seems to have been selected by considering the targets of other countries and the situation relating to international CO<sub>2</sub> reduction rather than being objectively derived from the estimated potential per renewable energy resource.

Therefore, the question of whether the currently established dissemination target is realistically accomplishable with current technology has to be raised. Therefore, the potential of Korean onshore and offshore wind resources are calculated preliminarily using geographic information data and the

intermediate result of national wind map which is in progress in order to urgently provide the reference data needed to validate and revise the current dissemination target.

## 2. WIND RESOURCE POTENTIAL

### 2.1 Definition

In this paper, with respect to the consistency of the former definitions (van Wijk & Coelingh, 1993; World Energy Council, 1994), the wind resource potential is categorized and defined as follows: Each category narrows down the previous definition because it includes certain limitations and obstacles:

(1) Theoretical potential: The total wind content.

(2) Geographical potential: The total wind content in the area available for wind turbine installation after taking geographical constraints into account.

(3) Technical potential: The wind power generated at the geographical potential, including energy losses due to the power density of the wind turbines and the process of generating electricity using wind turbines.

(4) Implementation potential: The technical potential able to be implemented within a certain timeframe, taking industrial constraints and incentives into account.

### 2.2 Estimation Method

The criteria for determining areas able to be developed by definition categories of wind resource potential and potential calculation methods are explained as follows:

#### (1) Theoretical potential

The theoretical potential was estimated for South Korean territory and the entire area of territorial waters. At this time, the theoretical API was calculated using the following equation, after extracting WPD from the medium-resolution (spatial resolution 3km x 3km) national wind map established by numerical wind simulation, which will be finalized to the high-resolution (1km x 1km) at the end of 2008.

$$API = WPD \times A / AWT \quad (1)$$

The wind resource was estimated at an altitude of 80m above ground level, which is the hub height of most current onshore/offshore wind turbines, while the array layout of the wind turbines was assumed to be  $10D \times 10D$  where  $D$  is the diameter of wind turbine rotors.

Conversely, the API statistics calculated from the wind map in this research were  $3.8 \pm 1.1$  and  $3.9 \pm 0.5 \text{ MW/km}^2$  for onshore and offshore, respectively; similar to the  $4 \text{ MW/km}^2$  found by Hoogwijk et al. (2004) and the  $5 \text{ MW/km}^2$  of the NREL (Elliot and of Schwartz, 1993; and etc.). For reference, the standard deviation of the onshore API was greater than that of the offshore API as the land low wind speed territory is wider than that at sea.

Once the API has been calculated, the AEP can be calculated using the following equation:

$$AEP = API \times FLH \times CF \times \eta \quad (2)$$

Any loss while calculating the theoretical and geographical potentials have not been considered. The capacity factor from the wind speed distribution function, as derived from national wind map and power curves of domestic wind turbines currently being developed has also been calculated.

#### (2) Geographical potential

The geographical limitations to onshore wind farm developments are urban areas, water bodies, roads, national parks and steep slope areas. While the areas that can not be developed have been excluded under GIS analysis using land cover and numerical elevation data offered by the Ministry of Environment, the buffer been considered.

From the experience gain during Korean wind farm developments so far, serious obstacles exist, such as local residence societies and NGOs, etc. Therefore, a very conservative standard has been applied while determining the areas for possible onshore developments by reflecting such a reality, and as a result about 5% of the

national territory has been evaluated as being to be developed.

The depth of water, offshore distance (from shoreline) and maritime national parks, etc. were considered in the case of offshore developments. With respect to the depth of water, only 30m or less was stated as being possible for offshore wind farm developments. The offshore distance from the coast was considered as impossible for development due to several problems, such as landscape damage, sea farms and ship passage interruption, etc. in case of being 5km or less while 25km or greater was excluded as well considering the increase of grid connection costs. In this paper, only the territorial sea area was considered as a narrow definition, but the offshore potential might become greater when the possible area of wind farm development is enlarged to EEZ which is already in development in Europe.

#### (3) Technical potential

2MW and 3MW onshore and offshore wind turbines were chosen as representative domestic wind turbines. Generally, the wind conditions for which wind farm development is possible only in areas of wind class of 4 or greater, where the economic feasibility has been approved from European and North American experiences. For the loss coefficient, availability and the array efficiency due to wake losses were considered so that  $\eta=0.8$  is used. If the economic feasibility of wind farm development is approved from the wind class 3 since when a low wind-speed wind turbine has been developed in the near future, then wind resource potential would increase considerably.

#### (4) Implementation potential

The implementation potential is to be estimated from the technical potential considering the current technology, political and social limitations, etc. within a given period. However, as an alternative method in this study, the implementation potential was estimated by referring to the development records of leading European countries

in implementing wind power. Therefore, API was adjusted from the examples of Denmark and Germany, etc. by approximating their APIs. It is based on the assumption that various technological, industrial and political bottlenecks that may occur in the process of the implementation period up to the level of those countries would be solved by us as we learn from the experience of those countries.

### 2.3 National Wind Map

The most important data for calculating the wind resource potential is the spatial information of the wind resource. In this research, a medium-resolution wind map (spatial resolution 3km x 3km), which is the intermediate result of national wind map made through numerical wind simulation, was used. The medium-resolution wind map is the previous stage of the final high-resolution one (1km x 1km). However, its accuracy has been verified through the meteorological correlation process by comparing it with ground-level observation data.

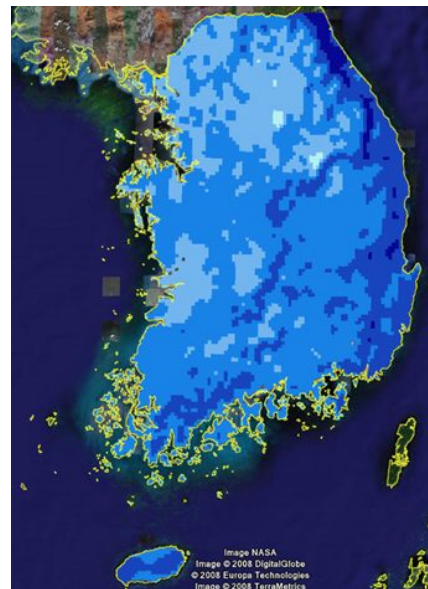


**Figure 1:** Medium-resolution national wind map displayed on Google Earth<sup>TM</sup>.

According to literature survey on wind resource potential estimation in the past, most cases assume the wind resource spatial

distribution of the entire area of national territory using only ground-level meteorological observation data. Therefore, not only numerous assumptions have had to be involved, but the margin of error of the calculated result could only be great because the calculation process is quite complicated. Conversely, in this study, because the wind map prepared by numerical wind simulation (Kim et al., 2006) and verified meteorologically (Lee et al., 2007) is employed, the calculation of wind resource potential is relatively simple, scientifically logical and its accuracy is considered as being high.

### 3. RESULTS AND DISCUSSIONS

The estimated results of wind resource potential by category have been summarized in Table 1.

Wind originates from inhomogeneous solar radiation on earth that cause temperature differences, and then from pressure gradients in the earth's atmosphere. Consequently, it is conceptually difficult to calculate the power of wind. The theoretical potential is rather derived from theoretical solar energy reaching the atmosphere. According to the estimation of Hubbert (1971), total wind power on earth is roughly equivalent to 2% of the solar energy reaching the atmosphere, which is about 44,638TWh/yr on the onshore of South Korea.

While 2% of solar energy falling on the onshore of South Korea is 893TWh/yr, it is a comparable value with 987TWh/yr, which is a theoretical potential calculated in this research (see Table I). Through this, it could be indirectly confirmed that the estimation method of theoretical potential by introducing API from the wind map in this research is valid and logical for practical purposes.

The estimated technical potential has been confirmed that that is within a reasonable range in order of its magnitude when compared with potentials of other countries, i.e., United States offshore

500GW, onshore 1,000GW (NREL, 2005), China offshore 250GW, onshore 750GW (Chan, 2007), Japan offshore 708TWh/yr (Kogaki et al., 2003), India offshore 65GW (IWTMA, 2005), Denmark onshore 8GW (Bathelmie et al., 2008; same hereafter), UK onshore 70GW and German onshore 13GW.

**Table I:** Onshore/offshore wind resource potential of South Korea.

| Category                 | Onshore            |               | Offshore           |               |
|--------------------------|--------------------|---------------|--------------------|---------------|
|                          | Potential [TWh/yr] | Capacity [GW] | Potential [TWh/yr] | Capacity [GW] |
| Theoretical potential    | 987.0              | 369.0         | 880.8              | 309.0         |
| Geographical potential   | 480.1              | 18.0          | 152.6              | 56.5          |
| Technical potential      | 37.7               | 14.6          | 80.3               | 35.4          |
| Implementation potential | 9.4                | 3.6           | 20.1               | 8.8           |

### 4. CONCLUSION

Using the medium resolution national wind map prepared by numerical wind simulation and geographical information system for the wind resource potential of South Korea, the preliminary estimation was performed by classifying the potential to 4 stages and onshore and offshore separately. The conclusion of this study can be summarized as:

(1) The potential has been classified into 4 stages of theoretical, geographical, technical and implementation, while being calculated by introducing API calculated by wind map for the theoretic potential that was once difficult to estimate in the past. It has been verified that the estimated value also corresponds to the theoretical approximation that the theoretical potential of wind energy is applicable to 2% of theoretic potential of solar energy.

(2) In the case of developing 5% of offshore area and 17.5% of onshore area, the corresponding technical wind resource potential of south Korea was estimated as 37.7TWh/yr (14.6GW) for onshore and 80.3TWh/yr (35.4GW) for offshore.

(3) For calculating the implementation potential, the method of applying the implementation record of European countries has been attempted. According to this alternative method, the offshore and onshore implementation potentials are 9.4TWh/yr (3.6GW) and 20.1TWh/yr (8.8GW), respectively. When summing up the two, it amounts to 3% of the gross inland energy consumption in 2007 of South Korea.

(4) Most of the former estimation studies for national wind resource potential clarification, many complicated methods and assumptions are introduced especially in order to estimate the spatial distribution of wind power density and consequently, there was a great margin of error in the process. However, this study solved these problems at once by employing the wind map that is prepared by the most advanced prediction method, numerical wind simulation.

Through this research process of preliminary estimation, a schematic system for calculating wind resource potential of South Korea was established. For the next stage, it will be attempted to estimate the potentials by adding detailed data such as specifications and power curves, etc on all of domestic wind turbines as well as applying various implementation scenarios of domestic wind power dissemination.

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