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Spatial Decision Support System for Natural Energy Policy in Japan

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Abstract

Today, Japan's self-sufficient rate of energy supply, including nuclear energy, is only 19%.
We therefore propose an effective use of natural energy, which is supposed to have an enormous potential for energy supply. By collecting various factors about what is needed for setting up a natural energy generating system as well as what are required for it, we constructed the Web-GIS mapping system tailored to the individual user's needs.
This service is expected to support decision making in selecting suitable areas for natural energy power generating systems.

Key words: wind power, natural energy, suitable area, Web-GIS,

1. Introduction

The goal of this study is to increase the energy self-sufficiency rate of Japan, because it was only 19% in 2005 [1]. To increase the energy self sufficiency rate, it is useful to introduce more renewable energy, since Japan has no large land which produces fossil fuel resource like oil. There are many types of renewable energy like solar power, biomass and the like, and all of them are promoted by the government as infinite natural resources and clean energy. In this study, we choose wind power generation among them. The reason of that is Japan has the long coastline there is a stable force of wind. Moreover, the efficiency of wind power conversion is comparatively higher than other natural energy; 20% [2]. Because the energy is so attractive to Japanese energy policy, the government sets a goal to introduce wind power plant producing 300 $\times 10^4$kW by 2010 [3].

However, only 108 $\times$ 10^4kW electricity is produced by wind energy in 2005. In other words, only 1.9% of whole electricity is produced by renewable energy including other natural energy resources like solar and biomass [4]. Meanwhile, in Germany, wind power generates 140$\times 10^5$kW and it covers 5% of electric demand, and in Denmark it is 309$\times 10^4$kW, and the rate is 8% [5].

Moreover, examining those wind farms in Japan, the operation of some was removed or shut down because of poor condition like insufficiency of wind power. The number of wind power plants which have been closed was 37, corresponding to 770$\times$ 10kW, since 1985, according to New Energy and Industrial Technology Development Organization [6]. With regards to this, Mr. Nakajo, an observer of industrial security in Hokkaido, says "whether a wind farm produces an effectual amount of electricity or not depends on adequate examinations of wind synopsis before construction" [7].

In parallel with such halts of wind farm, understanding of wind farms by local autonomies and companies hasn't grown enough. Organizations researching about wind power plants, such as where they can construct them, how much output they can get from them, are a minority in Japan. The reason is that negative aspects such as the impact to the landscape and nature is mostly closed up by mass media and that essential knowledge about wind farms' output production is minimal. There's no information to easily understand how much electricity can be made from an increase of wind plants and how much those wind plants contribute to Japan's energy problem.

The last step of our study is to show a map, indicating optimal spots for wind power plants (30m, 50m, 70m), which set aside populated areas, active faults, natural parks and others, using a Web-GIS mapping system so that every member of local autonomies and companies seeing the map can easily understand how much potential wind power has by the visualized display. In fact, as the chairman of wind power energy association in Germany, being advanced in wind power production as stated earlier, recommends that it is key that society makes preparation to receive wind power generation to expand its use [8], increasing awareness to the capabilities of wind energy has a great significance.

At the same time, users can know estimated area and output by seeing the map, that our study aims to support for the decision making in selecting a suitable area for natural energy power generating systems.

2. Method

2.1Method

The method used in this study is based on a similar approach taken at the data about wind farm potential of NEDO (New Energy and Industrial Technology Development Organization).The formula to calculate the output of wind farm is same. The difference between that data and our study is the way to show the results of study. Data by NEDO shows the condition of suitable areas and the output of wind farm in case they are constructed based on tabular list output, not visually on a map. On the other hand, in our study, a map of suitable area for wind farms is made and shown on Web-GIS, so that everyone can easily know the potential of wind power and see the suitable areas for the wind power plant.

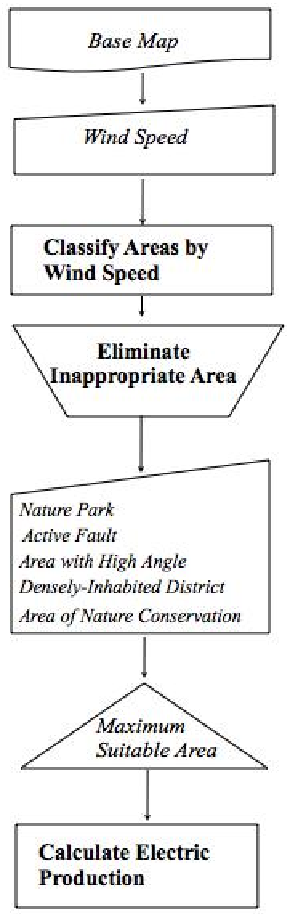


Fig.1 method flowchart

2.2 Overview of the study

(1) Classify all parts of Japan to 15 levels by wind speed.

(2) Estimate suitable areas where we can construct wind farms by eliminating areas of nature conservation, where density of population is high and so on.

(3) Calculate electric production of wind farms if they were constructed and operated.

2.3 Study Area

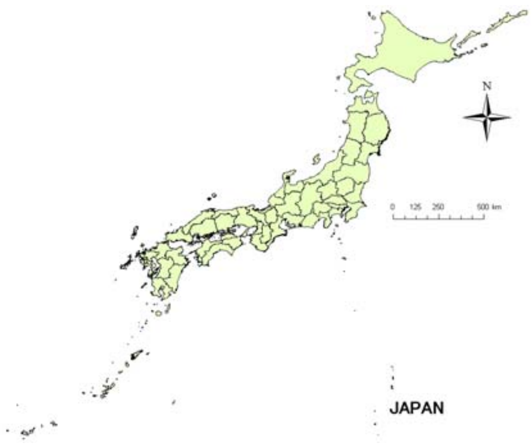


Fig.2 Study area Japan

Lands throughout Japan are the subject area of this study. Because the goal of our study is to increase the rate of energy self-sufficiency, knowing how much wind energy can contribute to Japan's energy problem is important.

We narrow down wind power generation because it is most suitable for Japan, because of Japan's long coastline where there is a stable force of wind. Moreover, efficiency is comparatively high as 20% of wind energy converts to electric energy, while solar energy is only 7%. [9)]

2.4 Database

2.4.1. Base Map

The prefectural boundary data which we use is offered by ESRI Japan. Following data was converted based on tertiary mesh (its unit is 1km) of Digital National Land Information.

2.4.2 Wind Force

Wind force data is from the map showing wind synopsis made by NEDO (New Energy and Industrial Technology Development Organization). This map by NEDO uses the data from 2000 when wind direction and wind speed is average, and it considers about both climate and engineering factors. As the mesh unit of this data is 500m, we firstly choose one fixed position in 500m units and then, the converted it to tertiary mesh of Digital National Land Information.

2.4.3 Slope Angle

The data comes from the maximum angle of gradient from tertiary mesh data of elevation and angularity made by Digital National Land Information in 1988. The largest angle of gradient is equal to the largest angle in one mesh.

2.4.4 Area of Nature Conservation

The data indicating areas of nature conservation was gotten from Digital National Land Information. This data is based on Land Use Basic Plan in the law of Land Use Plan. We merge this polygon data.

2.4.5 Nature Park

This data comes from the Digital National Land Information data and indicates the areas of natural parks. The area of natural parks is aesthetic landscapes, and its conservation and promotion of use are necessary. We merged all these polygon data.

2.4.6 Forest

Digital National Land Information researched the data showing the areas of forest in 2006. The areas of forest in this data indicate national forests, and conservation forests set down by Act of Planning the Utilization of the National Land. We merged all these polygon data.

2.4.7 Densely-Inhabited District

This data is polygon data of densely inhabited districts, which use the borough of census as the basic unit. A densely inhabited district is defined as the area where basic units neighboring other unit, in same local authority, both of which have high density of population (density of population per 1km square is over 4000).

2.4.8 Active Faults

The number of active faults which exist in our study area is 1827.

2.4.9. Present Wind Power Plants

The addresses of present wind power plants were from NEDO. Those addresses are geo-coded to obtain x y cords.

2.5 Prospect of Data

2.5.1 Wind Speed Map

We classify areas to 15 levels by wind speed. 1m/h~15m/h wind speeds are classified and color coded at the interval of 1m/h (1m/h<2m/h, 2m/h<3m/h…etc).

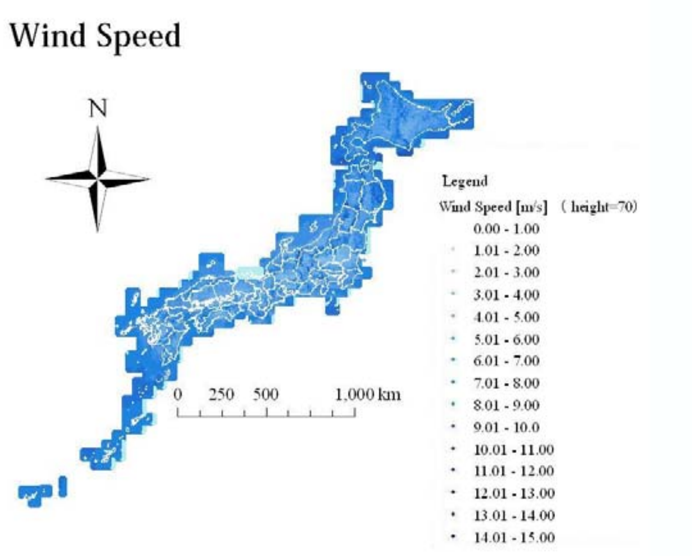
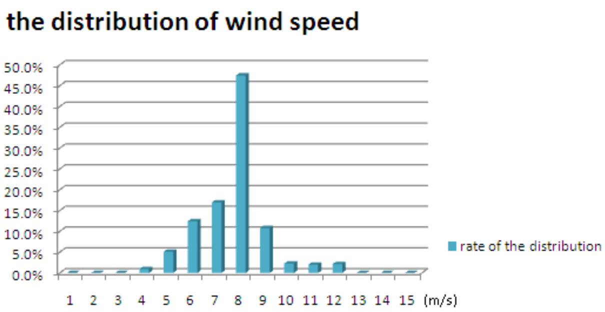


Fig3.Wind Speed in Japan

2.5.2 Wind Speed Distribution of Japan

The number on vertical lines shows the number of positions, which exist one point in 500m². The number on horizontal lines shows speed of wind (m/h). As you see below, points which have wind speeds of 8~9m/h are the most abundant.

Table1



2.5.3 The relationship between present wind power plants and wind speed

Places which have fast wind speed lie mainly in the areas which have high elevation or are near the coastline. In addition, comparing areas along the Sea of Japan and the Pacific Ocean, the former has high wind speeds. Also, in Japan, the wind blows from west to east because of the effect from seasonal winds.

Hokkaido Region

Comparing other areas, areas near the coastline have high wind speed in Hokkaido. (Adding to this, areas which have high elevation such as Ishikari, Yubari and a chain of mountain in Hidaka also have high wind speeds.) Especially, the wind which blows in areas along the Sea of Japan is strong, and this corresponds to, many power plants being concentrated in the areas near the Sea of Japan.

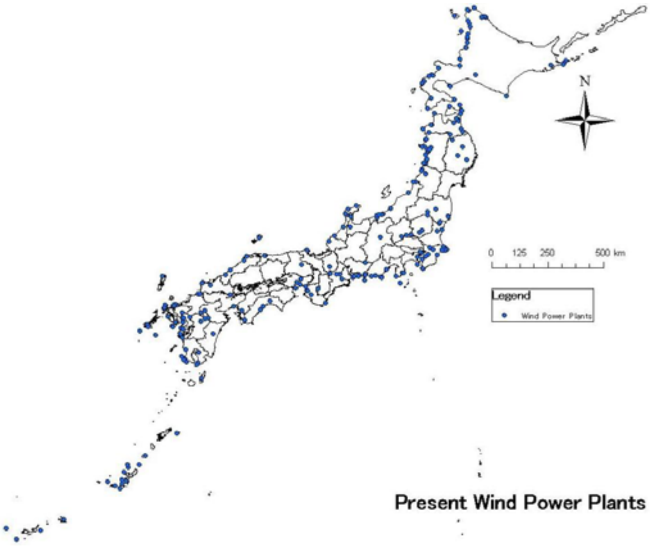


Fig.4 Present wind power plants

Tohoku Region:

Areas along the Sea of Japan and areas of upland, Kitakami, have fast wind speeds in Tohoku Region. Corresponding to this, present wind power plants exist there. There are no power plants constructed in the areas that have low wind speed.

Kanto and Chubu Region:

In total, the area which has low wind speed is relatively larger than other districts. Especially inland areas not facing the sea have low wind speed. Most power plants are built in areas which the annual wind speed is higher than 5m/s, however some are built in the areas which has wind speed lower than 5m/s, however that speed does not appears to make business sense.

Shikoku, Kyushu, and Chugoku Region:

There are no wind power plants near the Seto Island Sea even it is near the coastline, because it is surrounded by the Chugoku and Shikoku hill districts.

2.6 Process

2.6.1. Elimination unsuitable area

Elimination of the following areas for safe construction:

(1) Areas which have slope over 5 degrees

(2) Areas of nature conservation

(3) Areas of natural parks

(4) Areas where the density of population is high

(5) Areas which have active underground fault

(6)Areas where the wind speed is under 5 m/s

2.6.2 Calculation of electric production from wind farms

2.6.2.1 Notation

E_{pw} : output per year (kWh)

V_i : output of power generation at wind speed class i (kW)

f_i : appearance ration of wind speed class i. set to 100% because wind speed of annual average(%) is used

e : Net output per year (kWh)

a : availability ration set at 95% which is commonly used as the utilizable ratio for large-scale wind plants. The value considers fault time and checkout time. (%)

c : correction factor of energy output : 95 % commonly used for flat land (%)

P : Potential of output per pixel (kWh)

Table2 Calculation Data

	Rotor Diameter	Rating Output	Rating Wind speed	Cut-in Wind speed	Cut-out Wind speed	Area Receiving Wind	The number of installation
30m above The ground	40m	500kWh	12m/s	3m/s	24m/s	1256m^2	7 plants
70m above The ground	70m	1500kWh	12m/s	3m/s	22m/s	1846m^2	1 plant

A : cross-section area (=area where wind is receive) (m^2)

ρ : air density fixed as 1.2kg/m^3

n : the number of installation per 1 pixel: calculated from rotor diameter of each height of wind plant as showing below. (Placing wind power plants, 10 times the length of rotor is required to keep a safe distance from other plants.)

w : annual average wind speed at each location (m/s)

K_w : kinetic energy of wind

M_w : mass of wind

2.6.2.2 Formulation

Wind energy is kinetic energy, because it is fluid which has mass. Therefore by applying the principle of kinetic energy and multiply mass by square of speed because kinetic energy is equal to that. We conclude following formula to calculate output of wind power generation at certain wind speed (V_i).

$$V_i = \frac{1}{2} \times M_w \times w^2 / 1000 \qquad (1)$$

Mass of the wind (M_w) in the formula above refers the mass of air which go through given cross section area (A) per unit time. Therefore, it is obtained by a product of cross section area (A), air density (ρ), and wind speed (w) as following.

$$M_w = A \times \rho \times w^3 \qquad (2)$$

Inserting formula (2) into formula (1), output of power generation at certain wind speed is calculated by following formula.

$$V_i = \frac{1}{2} \times A \times \rho \times w^3 / 1000 \qquad (3)$$

Then, to calculate electric energy per year by wind power plants, the following formula is used.

$$E_{pw} = \sum (V_i \times f_i \times 8760) \qquad (4)$$

Output per year is the sum of the output of power generation at wind speed class i that is multiply by appearance ration and 8760 hours.

However, because there are many factors which reduce the electric energy, the calculation of output should consider each factor, such as availability and correction factor. Availability ration is the portion of time which minus fault time and time to check out among 8760 hours. Also, correction factor considers the affection on wind energy output by land shape. Both values of availability and correction factor were fixed 95% as NEDO recommends.

$$e = E_{pw} \times a \times c \qquad (5)$$

Gathering formulas (4) and (5), potential of energy output per pixel can be calculated.

$$P = V_i \times f_i \times 8760 \times a \times c \times n \qquad (6)$$

Moreover, inserting formula (3) into (6), we can get potential of energy output per pixel (P).

3. Results

3.1 Suitable Area

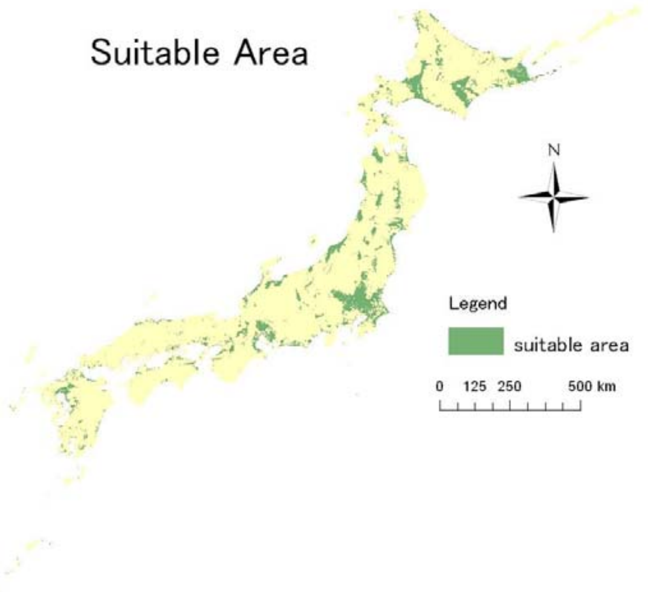


Fig.5 Suitable Area eliminating negative factors

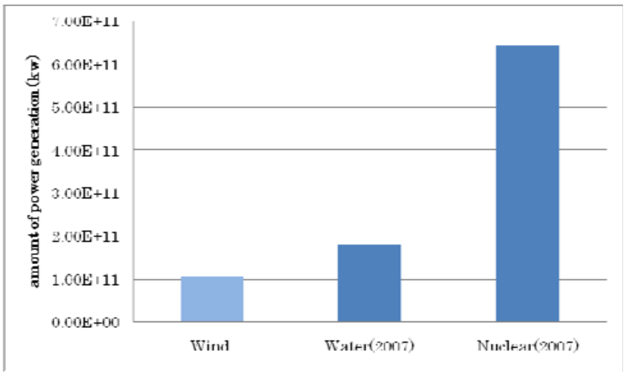
The result of 30m high wind turbines are visualized here. The square of the suitability area is 46,594km². Most of the areas are located in coastal areas.

Though there are some midland areas, they have mostly lower wind potential.

In addition, we extract only the areas where the wind speed is more than 5m, in order to calculate the potential of power generation. As a result large areas are excluded and the square of high energy potential is finally 12,210km².

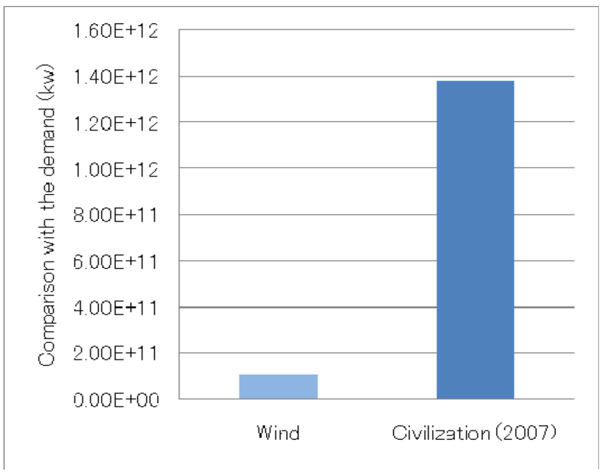
3.2 The potential of wind power generation

Table3 Comparison the results to other power generation methods



This graph represents three kinds of power generation. Wind indicates the amount of energy in the case that the suitable areas are efficiently filled with wind power plants. Comparing with other non-fossil energy generation, the wind power generation is still smaller, but wind power is similar for hydro power. The result means that wind power generation could become one of the main energy resources.

Table4 Comparison the result with demand



This graph compares the potential of wind power generation with public demand in Japan (2007).It is obvious that public energy demand could not be managed only by wind power. In order to construct a sustainable society, we combine or choose possible renewable energy as to the required conditions.

3.3 Examination of the suitable area

The analysis was made based on one mesh in suitable area selected by criteria in this study. The mesh data was converted to a KML file and added as a layer on Google Earth. The Model used at this time is the mesh at Hamatonbetsu City in Hokkaido. This area consists of cultivated land near the coastline and there are no buildings disturbing the wind flow.. Also, comparing to the map expressing wind speed, this area averages 6~7m/s wind speed. Moreover, inland of this area averages 7~8m/s wind speed. , Based on these figures the conclusion that this location is suitable for wind power is seems to be correct. Yellow square in the figure refers to 1km mesh.

Fig.6 Hamatonbetsu, Hokkaido
45°7'9.82"N/142°23'29.44"E by Google Earth

4. Discussion

Since Japan has no large land areas which produce fossil fuel resources like oil, the low energy self-sufficiency rate affects directly if the import of resources stops by any diplomatic or political problems. Therefore, an increase of the self sufficiency rate of energy supply is an urgent need for Japan. However, the popularization of natural energy, especially wind power, has fallen behind when compared with European countries. Thus, our study has produced a map of Japan which shows suitable areas for wind farms and the output from the study is used to promote the establishment of more wind power plants and to make local autonomies and companies take notice of its potential.

There are few studies to support the decision making to select suitable areas for wind farms, which narrow down each local area like Okinawa prefecture, but there are no studies which examine the decision making process to select suitable areas for wind farms throughout all of Japan.

Moreover, although a similar estimation for suitable area for wind farms was made by NEDO, it is only in list form and is difficult to visualize. That means the results are difficult to attract the attention and to make people take serious notice about potential of wind power.

Our study opens the map showing the suitable areas for wind power plants using a Web-GIS mapping system, so that everyone can more easily see the result. The features of Web-GIS allow the users to choose variable layers like wind speed, suitable area and so on. Thus, users can see the information they want in the situation of their choice on where to construct wind power plants.

Visual information in the form of map can be a useful measure to achieve the goals or policies for concepts which are more difficult to grasp. Also, this study examines Japan as a whole allowing the introduction of promoting wind power nationwide.

When selecting suitable areas for wind plant, several factors which are important for the efficiency of wind power generation: positional relationship between wind plant and electric line, radio wave disturbance, air-traffic disturbance, destruction of the landscape, capability of off shore wind plant, area of frequent electrical storms, and route of typhoons. Solving these problems is needed to improve the precision of this study.

Furthermore, this study we only makes the argument about wind power, but to achieve the goal of increased energy self-sufficiency for Japan, prevalence of other renewable energy resources are necessary, because only in combination with many kinds of energy resources, having different optimal locations, more large area can be considered for producing electricity. Therefore, our next study will deal with the potential of other renewable resources.

Acknowledgements

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