International Journal of Environmental Science and Development, Vol.1, No.5, December 2010
ISSN: 2010-0264

Renewable Energy Potential Evaluation and Analysis for Use by using GIS -A Case Study of Northern-Tohoku Area and Tokyo Metropolis, Japan

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Abstract— **The present work is intended to evaluate renewable energy potential in Northern-Tohoku area and Tokyo metropolis and reveal possibility of supplying renewable energy from Northern-Tohoku area to Tokyo metropolis. For this purpose we conducted potential evaluation of renewable energy and analyzed the plan of wind energy use with geographic information system (GIS). The renewable energy potential evaluation consists of three processes with GIS. The first process is simulation of the meteorological parameters such as river discharge and direct solar radiation. The second process is extraction of potential areas with restrictions such as meteorological conditions, geographical features and social environment. The third process is calculation of annual energy production. The evaluation result shows that renewable energy potential in Northern-Tohoku area is 101,904 GWh/year, which contains 58,655 GWh/year of wind power, 10,507 GWh/year of mini-micro hydropower, 356 GWh/year of solar power, 30,854 GWh/year of geothermal and 1,532 GWh/year of biomass. It is possible for the renewable energy potential to satisfy electricity demand not only in Northern-Tohoku area but also in Tokyo metropolis. The analysis result of wind energy use in Aomori prefecture indicated that hopeful wind energy potential of 3276 GWh/year exits in Kamikita area, Shimokita area, Seihoku area and Sanhachi area.**

Index Terms— **renewable energy potential, GIS, solar, wind, mini-micro hydropower.**

I. INTRODUCTION

The present work is intended to evaluate renewable energy resource potential in Northern-Tohoku area and Tokyo metropolis in order to reveal possibility of supplying renewable energy from Tohoku area as a rural area to Tokyo as a huge city. It is necessary for the world to promote renewable energy use from the point of view of reducing greenhouse gas emissions. In Japan, Tokyo metropolitan government and prefectures in northern part of Japan, such as Aomori, Akita, Iwate, Yamagata and Hokkaido, have agreed on interregional cooperation for renewable energy use. The purpose of the agreement is to realize reduction of CO2 emission in Tokyo metropolis and revitalization of the rural economy and expansion of job opportunities in northern part of Japan. There are differences of circumstance between rural areas that have a huge renewable energy potential and a big city that has huge energy demand behind.

The systematic and accurate evaluation of renewable energy potential is important in order to efficiently construct renewable energy facilities. Voivontas for example, developed a Geographical Information System (GIS) decision support system for the evaluation of renewable energy sources potential and conducted the financial analysis of renewable energy investment in Crete, Greece [1]. However, this study was designed only for specific areas and these evaluation methods have not been applied to the other areas. In order to extensively reveal property of renewable energy distribution, the authors developed a new method for the renewable energy potential evaluation using GIS and available digital spatial data [2].

Figure 1 Study area; Hokkaido, Tohoku area and Tokyo metropolis.

Manuscript received December 13, 2010. This work was supported Japan Science and Technology Agency (JST)

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II. Renewable Energy Potential Evaluation

A. *Study Area*

Figure 1 shows that Hokkaido and Tohoku area lie in the northern part of Japan. This study was carried out for Aomori, Akita and Iwate prefectures in Tohoku area and Tokyo metropolis in Japan. The three prefectures in Tohoku area are called Northern-Tohoku area. Northern-Tohoku area has area of 36,497.73km² and population of 3,813,026. Tokyo metropolis has area of 2,187.65km² and population of 13,038,856.

B. *Concept of potential evaluation*

In the renewable energy potential evaluation, we evaluate two kinds of potentials: "theoretical potential" and "practical potential." A theoretical potential is an amount that all energy potential theoretically exist, for example, all solar energy and wind power. A practical potential is an amount that potential is evaluated with restrictions such as climate conditions, geographical features and social environment. In the present work we evaluate the practical potential.

C. *Software and data source*

In the present work we use GRASS ver.5.3 and 6.2 as GIS software. We also use GIS data from the database, published by the Ministry of Land, Infrastructure, Transport and Tourism in Japan.

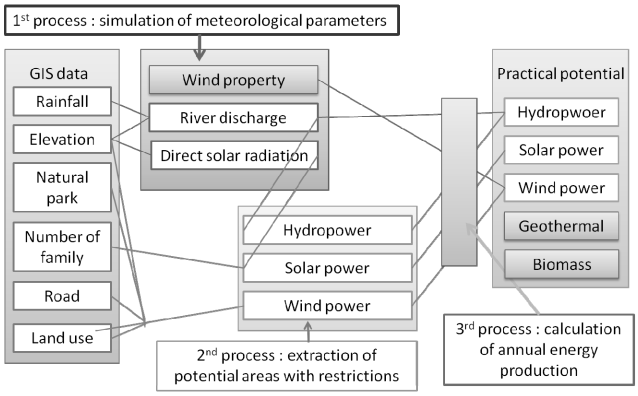

Figure 2 A schematic diagram of GIS evaluation of renewable energy potential.

D. *Procedure*

A schematic diagram of GIS evaluation of renewable energy potential is shown in Figure 2. This renewable energy potential evaluation consists of three processes. The first process is simulation of the meteorological parameters such as river discharge and direct solar radiation. The second process is extraction of potential areas with restrictions such as meteorological conditions, geographical features and social environment. The third process is calculation of annual energy production. In this process we develop a scenario for

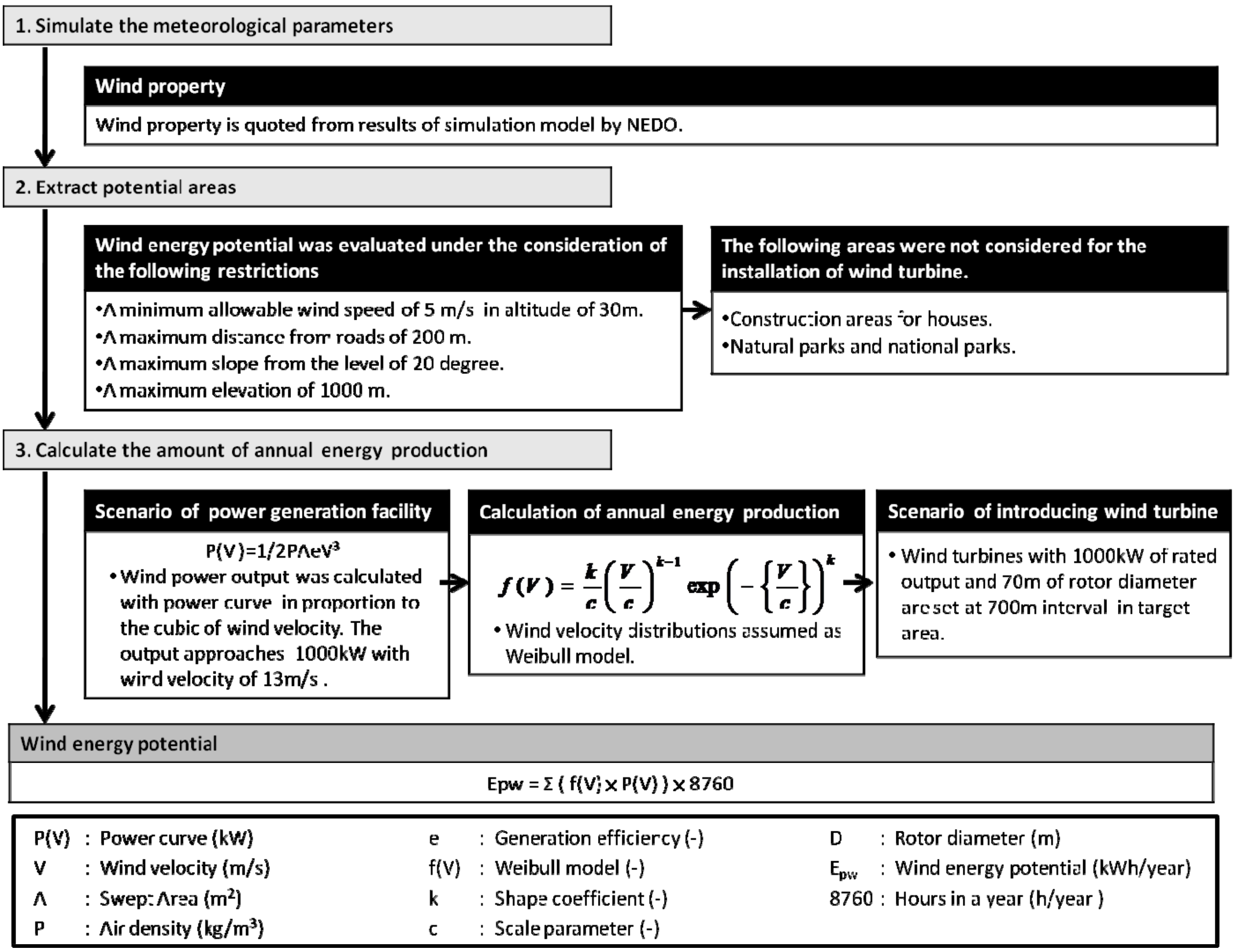

Figure 3 Evaluation process of wind energy potential.

calculation of the power generation facility, annual energy production and number production of introducing facilities.

E. Wind energy

Figure 3 shows an evaluation process of wind energy potential. First, a wind property was quoted from the results of the simulation model by NEDO [3]. Second, potential areas for wind power were extracted under the consideration of the following restrictions;

- A minimum allowable wind speed of 5 m/s (in altitude of 30m) ;
- A maximum distance from roads of 200 m;
- A maximum slope from the level of 20 degrees;
- A maximum elevation of 1000 m.
- The following areas were not considered for the installation of wind turbine;
- Construction areas for houses;
- Natural parks and national parks.

Third, in order to calculate electrical output of wind power generation, we developed a scenario that wind electrical output was calculated with power curve. The power curve is in proportion to the cubic of wind velocity and approaches 1000kW with 13m/s of wind velocity. Additionally, wind speed distributions were assumed as the Weibull model for calculation of annual energy production [3]. The number of introducing wind turbines was calculated on condition that wind turbines are set at 700 m interval in a potential area. The calculation for wind energy potential is described in (1). Wind energy potentials tend to be estimated bigger where extracted potential area is larger with this evaluation method.

$$Epw = \Sigma \left(f(V) \times P(V) \right) \times 8760 \quad (1)$$

Epw: Wind energy potential (kWh / year)
V: Wind velocity (m/s)
f(V): Weibull model (-)
P(V): Power curve (kW)
8760: Hours in a year (h / year)

F. Mini-micro hydropower

Figure 4 shows an evaluation process of mini-micro hydropower potential. First, the river discharge was simulated from elevation and amount of an annual rainfall data with GRASS r.watershed module. Second, potential areas for mini-micro hydropower were extracted under the consideration of the restriction that a minimum allowable river discharge is 0.01 m^3/s. Third, in order to calculate electrical output of mini-micro hydro electric generation, we developed a scenario that facilities is small scale hydropower: conduit type and afflux type power generation. This evaluation also assumed that hydro electric generators were set at 50m interval in each river in the potential area and that the heights of facilities were calculated from maximum slope data and 50 m grid digital elevation model data at 50 m interval of horizontal distance. Additionally, we assumed that outflow rate of water from rainfall to river discharge is 30 % and that utilization ratio of river discharge is 20 % for calculation of annual energy production. The calculation for mini-micro hydropower potential is described in (2). Mini-micro hydropower potentials tend to be estimated bigger where output per unit is huge with this evaluation method.

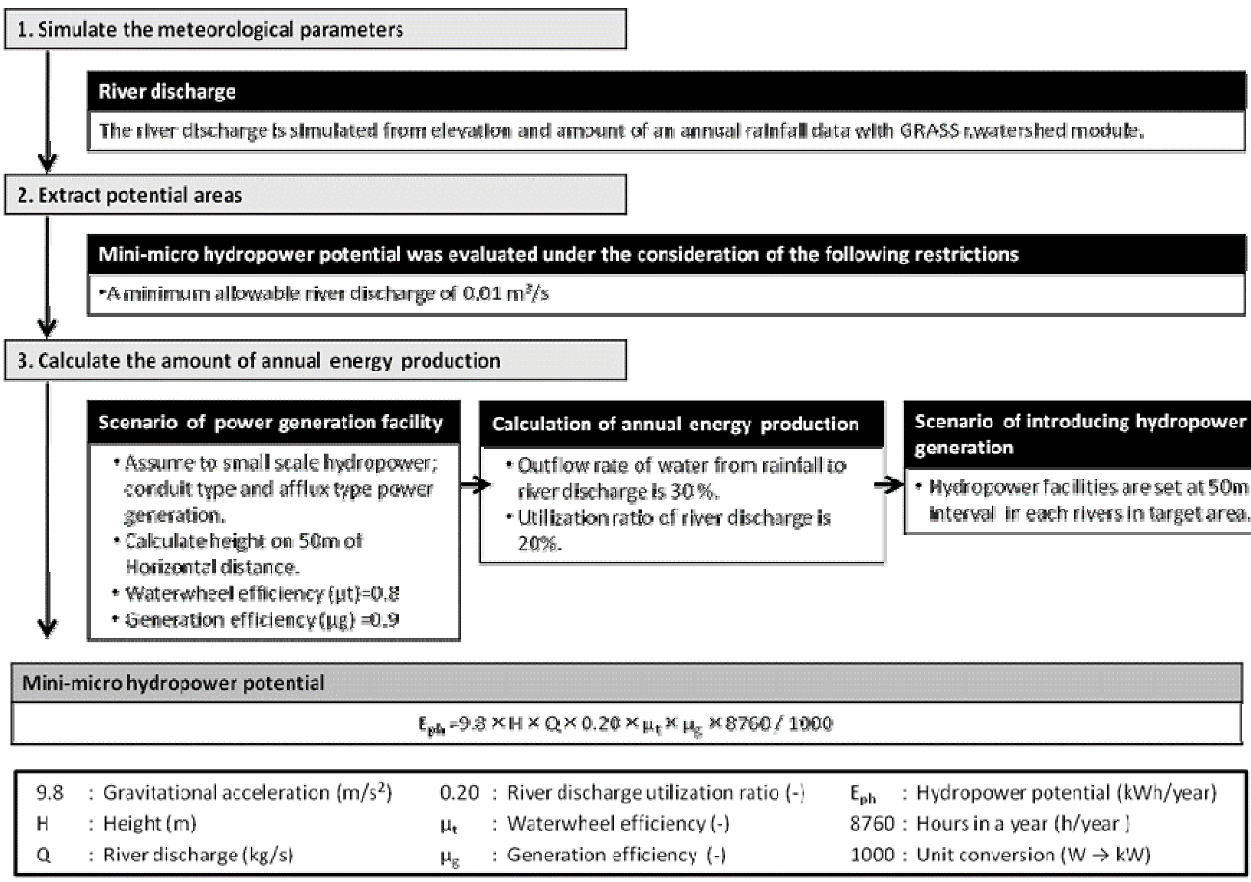

Figure 4 Evaluation process of mini-micro hydropower potential.

$$Eph = 9.8HQ \times 0.20 \times \mu t \times \mu g \times 8760 \ / \ 1000 \quad (2)$$

Eph: Hydropower potential (kWh/year)
9.8: Gravity acceleration (m/s^2)
H: Height (m)
Q: River discharge (kg/s)
0.20: Utilization ratio of river discharge (-)
µt: Waterwheel efficiency (-)
µg: Generation efficiency (-)
8760: Hours in a year (h / year)
1000: Unit conversion from W to kW (-)

G. Solar energy

Figure 5 shows an evaluation process of solar energy potential. First, the direct solar radiation was simulated from elevation data with GRASS r.sun module. Second, potential areas for solar energy were extracted under the restriction that a minimum allowable direct solar radiation is 0.1 kWh/m^2 a day. This restriction extracts almost all inhabitable areas as potential areas. Third, in order to calculate photovoltaic output, we developed a scenario that we introduce 1 kW photovoltaic cell to each household. Additionally, we assumed that PV system utilization is 12 % for calculation of annual energy production. The number of introducing photovoltaic cell was calculated with number of household in each 1 km grid. The calculation for solar energy potential is described in (3). Solar power potentials tend to be estimated bigger where population is huge with this evaluation method.

$$Eps = Nh \times Cp \times Se \times 8760 \quad (3)$$

Eps : Solar power potential (kWh)
Nh: Number of household (family)
Cp : Capacity (kW / family)
Se : System utilization (-)
8760: Hours in a year (h / year)

H. Potential Evaluation Result

The results of renewable energy potential evaluations in Tohoku area are summarized in Figure 6. It summarized each potential by each municipality and the municipalities in darker color have huge renewable energy potential. Figure 6(a) shows that municipalities with huge wind power potential locate in Aomori prefecture, northern part of Northern-Tohoku area. Figure 6(b) shows that municipalities with huge mini-micro hydropower potential locate in Akita and Iwate prefectures, southern part of Northern-Tohoku area. Figure 6(c) shows that a few municipalities with huge solar power potential exist in Northern-Tohoku area.

The renewable energy potential evaluations in Tokyo metropolis are summarized in Figure 7 (a), (b) and (c). Figure 7(a) shows a few municipalities with huge wind power potential exist in Tokyo. Figure 7(b) shows that municipalities with huge mini-micro hydropower potential locate in western part of Tokyo. Figure 7(c) shows that municipalities with huge solar power potential exist in centre area of Tokyo.

The sum of wind, solar and hydropower potential in Northern-Tohoku area and Tokyo are shown in TABLE 1 with geothermal and biomass energy potential. The geothermal potential is quoted from Geothermal Potential Map in Japan [4]. The biomass potential is quoted from Biomass GIS Database [5]. TABLE 1 shows the sum of renewable energy potential in Northern-Tohoku area is 101,904 GWh/year, which contains 58,655 GWh/year of wind power, 10,507 GWh/year of mini-micro hydropower, 356 GWh/year of solar power, 30,854 GWh/year of

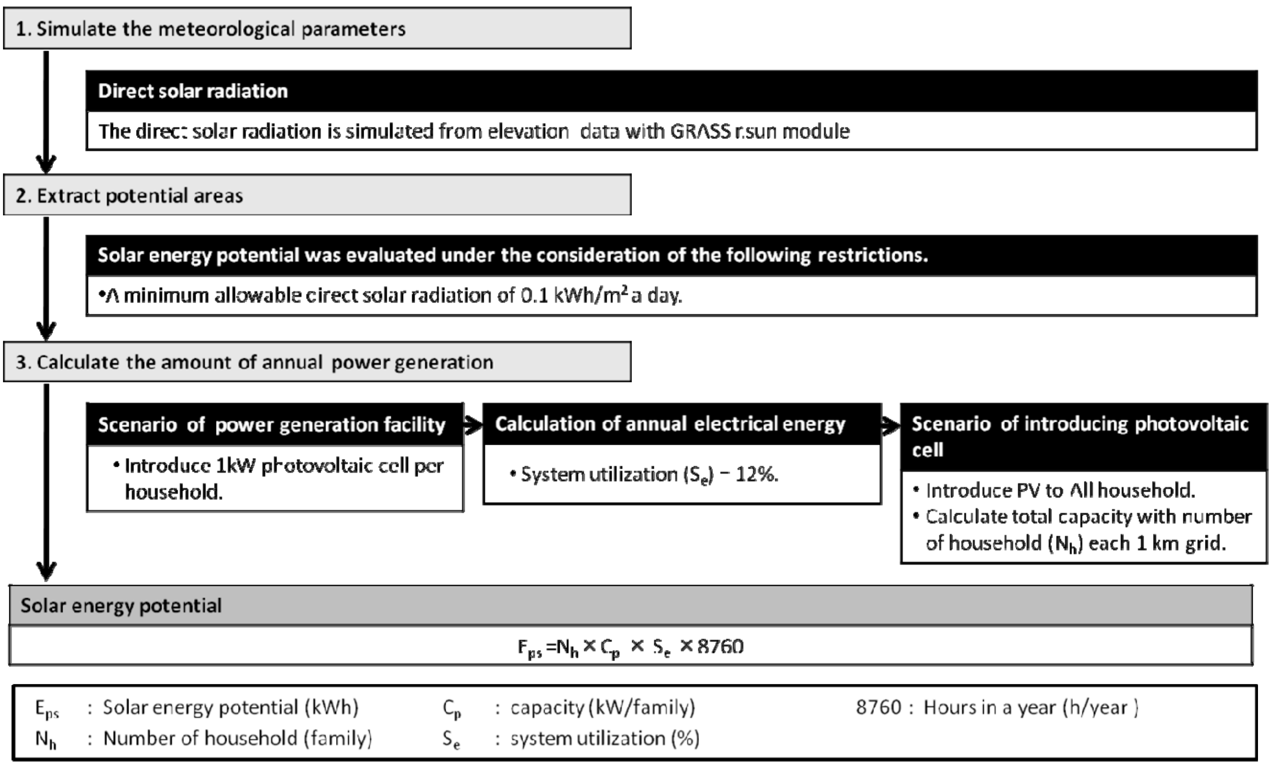

Figure 5 Evaluation process of mini-micro hydropower potential.

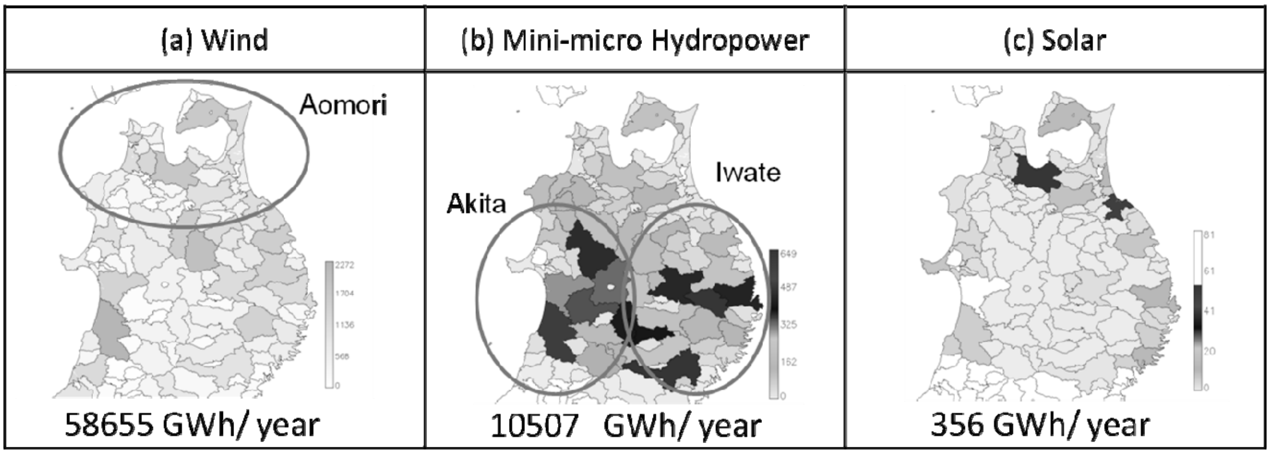

Figure 6 Renewable energy potential evaluations in Northern-Tohoku area.

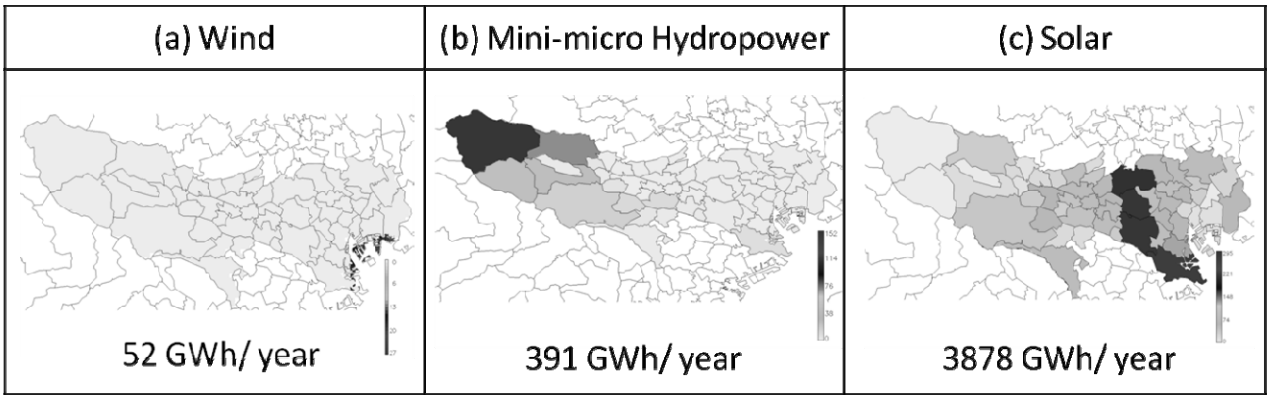

Figure 7 Renewable energy potential evaluations in Tokyo metropolis.

geothermal and 1,532 GWh/year of biomass. Tokyo has the 6,706 GWh/year of total renewable energy potential, which is 6.5 % of that of Northern-Tohoku area. On the other hand electricity demand in civilian sector is 16,680 GWh/year in Northern-Tohoku area and 78,519 GWh/year in Tokyo [6]. The electricity demand in Tokyo is tenfold bigger than the renewable energy potential. In Northern-Tohoku area electricity demand is about 16% of the renewable energy potential. The renewable energy potential in Northern-Tohoku area is bigger than the electricity demand in civilian sector in Tokyo.

III. Wind Energy Potential Analysis for Use

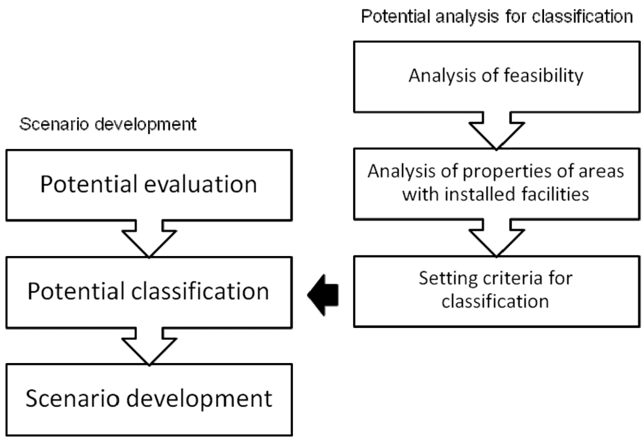

Figure 8 Process of wind energy potential analysis for use.

TABLE 1 Results of renewable energy potential of prefectures in Tohoku area and Tokyo.

GWh/year	Wind	Mini-micro hydropower	Solar	Geothermal	Biomass	Sum
Aomori	21589	1778	179	1280	492	25318
Iwate	23315	5332	57	7913	534	37151
Akita	13752	3397	120	21661	506	39436
Sum of Northern-Tohoku area	58655	10507	356	30854	1532	101904
Tokyo	52	391	3878	0	2385	6706

The renewable energy potential in Northern-Tohoku area is enough to satisfy electricity demand in Tokyo metropolis. The wind energy in Aomori prefecture is one of the most important energy as shown in the preceding chapter. In this chapter, we analyzed wind energy potential and developed scenario of introducing wind energy facilities in Aomori prefecture. Figure 8 shows the procedure. This study analyzed feasibility of introducing wind energy facilities and set criteria for classification. We analyzed properties of the areas with installed wind energy facilities in order to analyze feasibility of introducing wind energy facilities.

A. Purpose of scenario development

The present work set the restriction of a minimum allowable wind speed of 5 m/s (in altitude of 30m) to calculate practical potential. However most of wind energy facilities have been installed in areas with the faster wind speed than 5 m/s. Table 2 shows amount of wind energy potential with different restrictions of a minimum allowable mean annual wind speed. The potential is 5,500GWh/year with a minimum allowable mean annual wind speed of 6.5 m/s. In this chapter we developed a scenario in order to make use of the wind energy potential with mean annual wind speed of 6.5 m/s.

B. Study area and grid setting

Figure 9 shows study area and grid setting. The study area: Aomori prefecture locates in Northern-Tohoku area. The study area is divided into 10km square grids. The black square symbols show positions of installed wind energy facilities. The location data were quoted from [3].

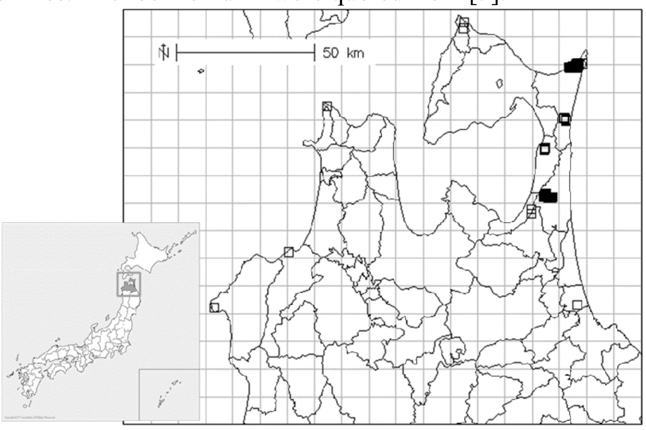

Figure 9 study area and grid setting.

C. Potential evaluation result of wind energy

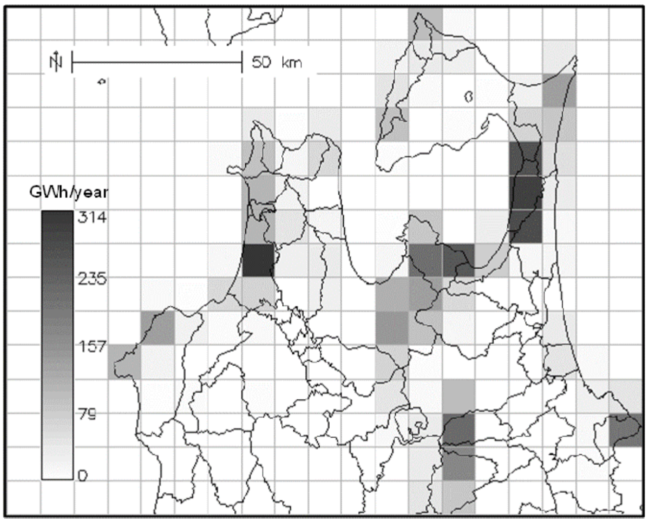

Figure 10 evaluation results of wind energy potential in Aomori prefecture

Figure 10 shows evaluation results of wind energy potential with a minimum allowable mean annual wind speed

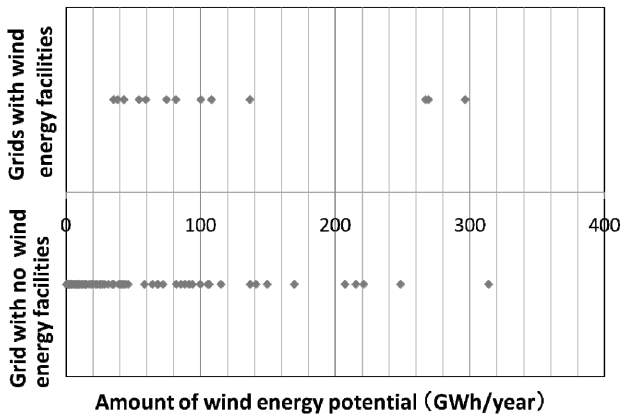

Figure 11 Relationship between evaluated potential and installed wind energy.

of 6.5 m/s on condition that the other of restrictions are same; distance from roads, slope from the level, elevation, construction areas for houses and natural parks and national parks.

TABLE 2 AMOUNT OF WIND ENERGY POTENTIAL WITH DIFFERENT RESTRICTIONS

GWh/year			
Restrictions	Over 5m/s	Over 6m/s	Over 6.5m/s
Potential	21589	11542	5526

D. Classification of wind energy potential

1) Concept of classification

We classified wind energy potential in order to develop scenario of making use of wind energy potential with mean annual wind speed of 6.5 m/s. The criteria for classification were decided based on feasibility of introducing wind energy facilities. We compared properties of areas with installed wind energy facilities at present in order to analyze feasibility of introducing wind energy facilities. We focused attention on properties of amount of potential, average elevation and average slope. The areas with higher elevation or slope value are concerned about the possibility of increasing construction costs.

2) Analysis of feasibility of introducing wind energy facilities

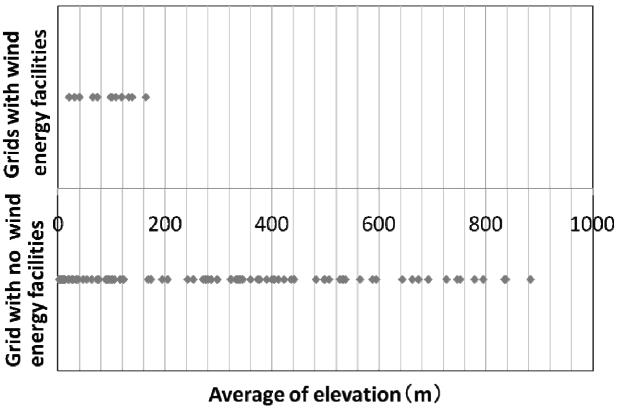

Figure 12 Relationship between average of elevation and installed wind energy.

Figure 11 shows relationship between evaluated potential and installed wind energy facilities at present in every grid. Figure 11 indicates that the grids with installed wind energy facilities have wind energy potential of over 30 GWh/year. Figure 12 shows relationship between average elevation and installed wind energy facilities at present in every grid. Figure 12 indicates that the grids with installed wind energy facilities have average elevation of lower than 200m. The relationship is consistent with tendency of lower elevation to be encouraged in planning introducing wind energy facilities. Figure 13 shows relationship between average slope and installed wind energy facilities at present in every grid. Figure 13 indicates that the grids with installed wind energy facilities have average slope of lower than 10 degrees except for one grid. The relationship is also consistent with tendency of lower slope to be encouraged in planning introducing wind energy facilities.

3) Setting criteria for classification

The areas with following properties are seen as a strong possibility of introducing wind energy facilities from the analysis results as mentioned above.

- Amount of evaluated wind energy potential is over 30 GWh/year in the grid.
- Average elevation is lower than 200 m in the grid.
- Average slope is lower than 10 degrees in the grid.

E. Classification result of wind energy practical potential

Figure 14 shows the potential classified according to amount of evaluated wind energy potential, average elevation and average slope in Aomori prefecture. The potential is 5,500 GWh/year with a minimum allowable mean annual wind speed of 6.5 m/s in Aomori prefecture. Figure 14 indicates that the evaluated wind energy potential of 5025 GWh/year is with wind energy potential of over 30 GWh/year in each grid. The wind energy potential of 5025 GWh/year includes potential of 3276 GWh/year with average elevation of lower than 200m and average slope of lower than 10 degrees in each grid. On the other hand, the wind energy potential of 5025 GWh/year also includes potential of 1114 GWh/year with average elevation of higher than 200m and average slope of higher than 10 degrees in each grid.

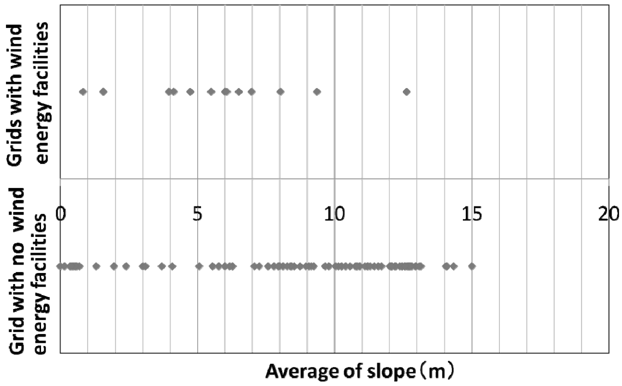

Figure 13 Relationship between average slope and installed wind energy facilities.

Figure 15 shows that the distribution of classification results in Aomori prefecture. In Figure 15 darker gray shows hopeful grid. The hopeful grids colored with darker gray exist in several parts of Kamikita area, Shimokita area, Seihoku area and Sanhachi area, which are with lower elevation and slope. In fact, there are many installed wind energy facilities at present in Kamikita area and Shimokita area. On the other hand, there are a few installed wind energy facilities in Seihoku area and Sanhachi area until now. In addition the grids with light gray exist in southern part of Aomori prefecture, which has higher average elevation and has no installed wind energy facilities.

F. Scenario development

In Aomori prefecture, wind energy potential of 3276 GWh/year is with wind energy potential of over 30 GWh/year in each grid, with average elevation of lower than 200m and average slope of lower than 10 degrees in each grid. These hopeful grids exist in several parts of Kamikita area, Shimokita area, Seihoku area and Sanhachi area. At present, there are many installed wind energy facilities in Kamikita area and Shimokita area. Therefore, it is important for making use of the huge wind energy potential to introduce wind energy facilities in Seihoku area and Sanhachi area in Aomori prefecture. In addition the grids with huge wind energy potential exist in southern part of Aomori prefecture. However it is necessary to analyze construction cost due to

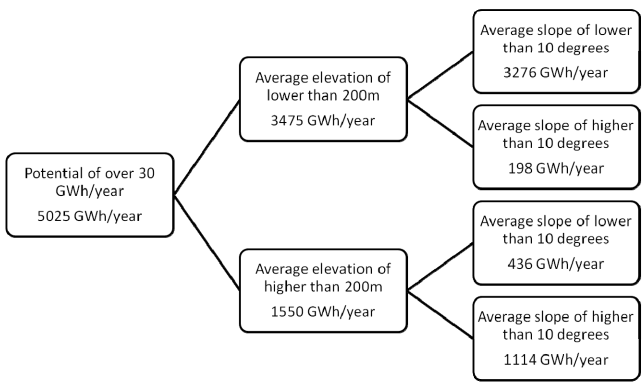

Figure 14 Classified potential in Aomori prefecture.

higher average elevation and slope in southern part of Aomori prefecture.

G. Discussion

In this paper, we classified wind energy potential in Aomori prefecture based on feasibility of introducing wind energy facilities in order to develop scenario. We analyzed feasibility of introducing wind energy facilities from the analysis of properties in each grid with installed wind energy facilities at present. However a different analysis such as cost analysis and environment assessment could be applied in the analysis of feasibility of introducing wind energy facilities. We plan to develop different method of potential classification to develop scenarios.

IV. Conclusion

The renewable energy potential in Northern-Tohoku area is 101,904 GWh/year, which contains 58,655 GWh/year of wind power, 10,507 GWh/year of mini-micro hydropower, 356 GWh/year of solar power, 30,854 GWh/year of geothermal and 1,532 GWh/year of biomass. Tokyo has the 6,706 GWh/year of total renewable energy potential and 78,519 GWh/year of electricity demand. The renewable energy potential in Northern-Tohoku area is bigger than the electricity demand in civilian sector in Tokyo. It is possible for renewable energy potential in Northern-Tohoku area to satisfy electricity demand not only in Northern-Tohoku but also in Tokyo metropolis. The analysis result of wind energy use in Aomori prefecture indicated that hopeful wind energy potential of 3276 GWh/year exists in Kamikita area, Shimokita area, Seihoku area and Sanhachi area.

Acknowledgment

This research was supported by Japan Science and Technology Agency (JST) and conducted as a part of a R&D project in community-based actions against global warming and environmental degradation.

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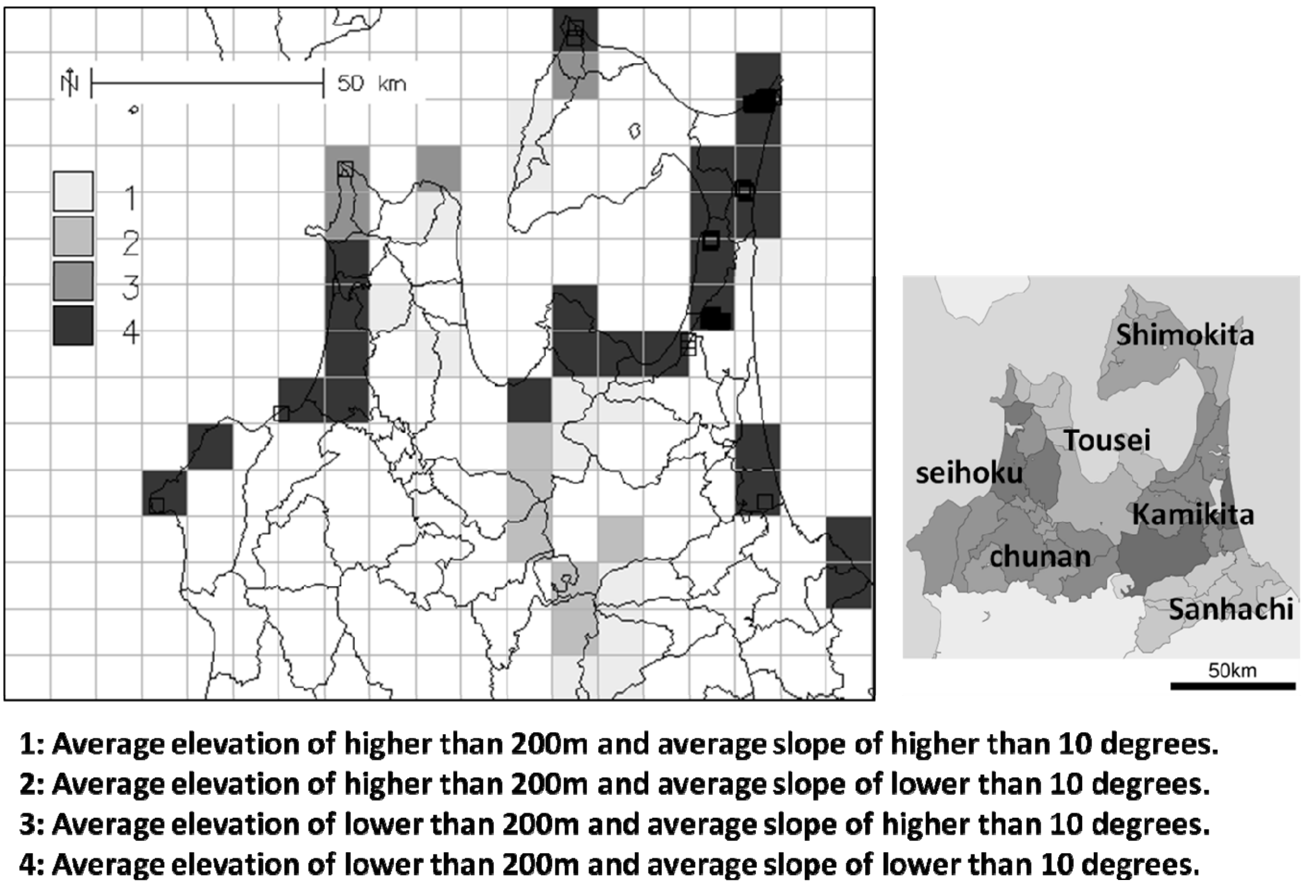

Figure 15 distribution of classification results in Aomori prefecture.