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Wind Potential Evaluation in El Salvador

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Abstract: Master plan for the Development of Renewable Energy was prepared in the Republic of El Salvador. Nationwide wind power potential map was prepared to identify the potential area for wind power development. The map indicates geographical distribution of wind potential over large regions at certain height above ground level. In this study, wind potential maps at 30 m, 50 m and 80 m above ground level were prepared respectively. Wind potential was simulated based on GIS data and global meteorological model. Data were corrected by surface wind data which had been monitored in the assessment area. As a result of wind potential analysis, wind potential areas were identified in the southwest mountainous area, northwest mountainous area and northeast mountainous area.

Key words: Wind potential, map, master plan, El Salvador.

1. Introduction

In December 2015, “Paris agreement” [1] was adopted at COP (Conference of Parties) 21 held in Paris. Based on this agreement, each country accelerates preparation to increase installed capacity of renewable energy technologies for global warming mitigation. In 2015, total installed capacity of the wind turbines became over 400 GW which exceeds installed capacity of the nuclear power plants.

Preparation of nationwide wind power potential map is important to determine wind monitoring sites. Especially, in most of the developing countries, wind potential map of the national level has not developed yet. Therefore it is desirable to prepare wind potential map in short term at the initial stage of wind power development.

“The project for master plan for the Development of Renewable Energy in the Republic of El Salvador” [2] was implemented from August, 2011 by Japan International Cooperation Agency.

Electricity demand in El Salvador is expected to grow at an average rate of 4.7% per annum toward 2026. According to CNE’s (Consejo Nacional de Energía) annual report in 2013 [3], total power generation was 6,095.6 GWh which consisted of: hydropower (30.5%), thermal power (49.2%), geothermal power (13.2%) and biomass (7.1%). Although the ratio of renewable energy sources (hydro, geothermal and biomass) is higher than that of thermal, dependency on thermal power generation is increasing year by year [4].

Under such circumstances, a request was made from the government of El Salvador to the government of Japan on the project for formulation of renewable energy master plan in El Salvador, which includes confirmation on potentials on each renewable energy source, and preparation of guidelines required for promotion of renewable energy introduction.

The joint venture which headed by Nippon Koei Co. Ltd. was implemented the project. The wind potential map was prepared by Japan Weather Association

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based on the collected data and information by the project.

There are some studies to clarify the wind potentials in El Salvador. Wind potential map with 1 km resolution was prepared by SWERA project in 2005 [5, 8]. And based on the prepared map, wind monitoring was conducted by Finnish Meteorological Institute [6].

Nationwide wind power potential map of El Salvador was prepared to identify the potential area in this study. Wind potential map indicates distribution of wind potential over large regions at certain height above ground level. The potential is simulated based on GIS data and global meteorological model. Data are corrected by surface wind data which being monitored in the assessment areas.

2. Specification of Wind Power Potential Map

The nationwide wind potential map was prepared in the study. The main use of the map is to identify wind potential area in the country. The specification of prepared map is as shown below:

(1) Wind potential map: El Salvador (nationwide);

(2) Resolution: 500 meters mesh;

(3) Height: 30 m, 50 m and 80 m above ground level;

(4) Color class: 7 class (by potential):

0-200, 200-300, 300-400, 400-500, 500-600, 600-800, > 800 (W/m^2);

(5) Data set: selected wind potential site (10 sites)

Wind speed (m/s)/Wind density (W/m^2);

Wind direction (wind rose 16 direction);

Weibull parameter (k, c).

The following data were used as input data.

Global meteorological model;

Surface data;

GIS data (1: 25,000).

3. Preparation of Wind Power Potential Map

3.1 Procedure

The wind potential map and the data set were prepared in the following procedures.

(1) As a result of analysis on the meteorological data and influence such as the El Nino phenomenon, meteorological data in 2008 were chosen as suitable annual data for calculation.

(2) Meteorological data by the global model, topography data and land-use data were collected and arranged in an available form. Those data are necessary for following calculation.

(3) Annual wind characteristics (500 m mesh) of target year (2008) were calculated by a numerical value simulation model.

(4) Based on a calculation result, the statistics conversion from wind speed level to wind power energy, and annual average wind speed, accumulated value and relative frequency of wind speed was carried out.

(5) Annual average wind power potential maps (30 m, 50 m and 80 m above ground level) were prepared.

(6) Based on the wind potential maps, considering with natural and social condition area, high potential area (10 sites) were selected. In the selected sites, various data were maintained as a wind characteristics database and recorded in DVD with a designated format. The handbook for the wind map was made. In addition to preparation and operation procedures, analysis results are explained.

3.2 Weather Simulation Model for Evaluation of Wind Potential

(1) WRF (weather research and forecasting) model

On the basis of WRF model, annual wind power potential was simulated in this study. WRF model was developed under the cooperative work between U.S. NECP (Centers for Environmental Prediction) and NCAR (American Center for Atmospheric Research). The model is used all over the world as regional weather model. One-year weather simulation of 2008 which is targeted year for the simulation was carried out using this model. The situation of the wind of 8,784 hours in a year was calculated in 5 km mesh every day for every one hour.

FNL (global final analysis), objective analysis data of NECP, was used for the simulation of initial value and boundary value for weather simulation by WRF. FNL is re-analyzed global weather data by NCEP. NFL includes value of distributed meteorological data in three-dimension which are calculated based on monitored meteorological data such as ground surface data and upper air observation, and satellite data. Data of terrain and land-use are included in WRF model which is prepared by USGS (United States Geological Survey).

Monitoring period for the simulation is one year, from January to December 2008. The calculation area is categorized into 2 areas as shown in Table 1. In the wide area (area 1), it was calculated each 15 km horizontal mesh. In the neighboring area of El Salvador (area 2), it was calculated each 5 km horizontal mesh.

(2) MASCON (Mass-consistent flow) model

On the basis of the results of calculation on wind speed in each 5 km horizontal mesh by WRF model, wind potential data which cover nationwide of the country area by 500 m horizontal mesh are calculated. Table 2 shows the calculation area. MASCON model is a model to correct wind velocity to satisfy law of conservation of mass using topography data (an

Table 1 Area for calculation (WRF model).

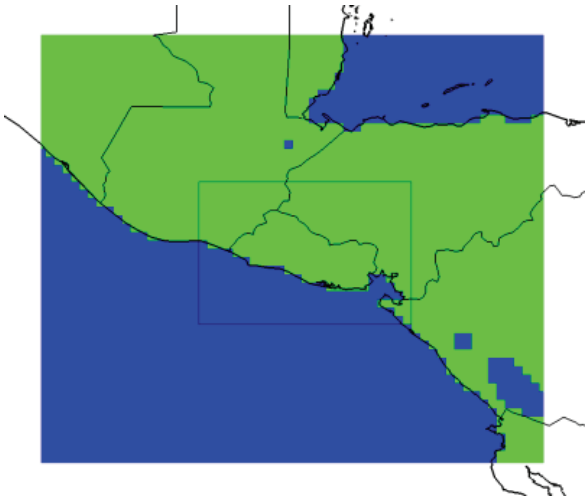
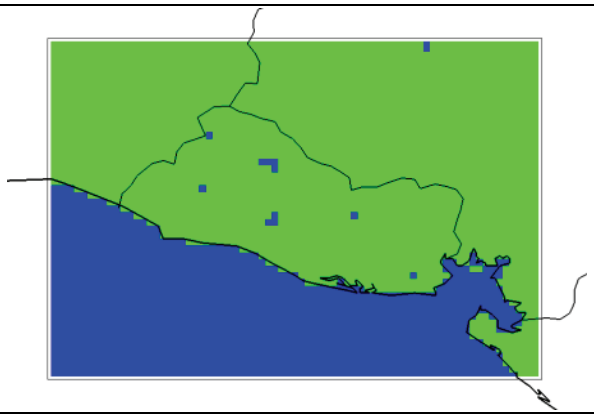
	Area 1
Horizontal mesh	15 km
No. of mesh	60 × 52
Calculation area	
	Area 2
HorizontaL Mesh	5 km
No. of Mesh	75 × 51
Calculation area	

Table 2 Calculation area (MASCON model).

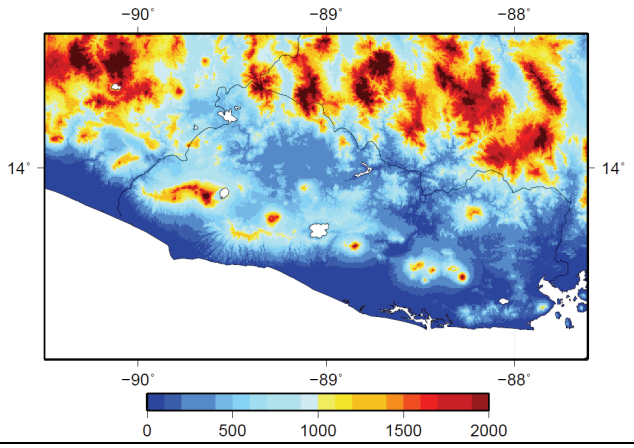
	MASCON model calculation area
Horizontal mesh	≈ 500 m
No. of horizontal mesh	625 × 367
No. of vertical mesh	15 (layer)
End points of the area	Longitude: West: 90.497685, East: 87.608796 Latitude: North: 14.696759, South: 13.002315
Calculation area and altitude	

Table 3 Standard definitions of wind power class.

Class	Resource potential	Wind speed (m/s)	Wind power density (W/m^2)
		30 m height	
1	Poor	0.0-5.1	0-160
2	Marginal	5.1-5.9	160-240
3	Considerable	5.9-6.5	240-320
4	Good	6.5-7.0	320-400
5		7.0-7.4	400-480
6		7.4-8.2	480-640
7		8.2-11.0	640-1,600
		50 m height	
1	Poor	0.0-5.6	0-200
2	Marginal	5.6-6.4	200-300
3	Considerable	6.4-7.0	300-400
4	Good	7.0-7.5	400-500
5		7.5-8.0	500-600
6		8.0-8.8	600-800
7		8.8-11.9	800-2,000

altitude level). This calculation can examine detailed topography effect by relatively little time. And, initial value to input into the calculation was prepared based on the result of WRF by interpolating weight points of the distance. DEM of resolution approximately 500 m which is prepared by digital data of SRTM was used for the topography altitude level.

4. Wind Power Potential Map

The heights of wind potential maps which prepared in the studies are 30 m, 50 m and 80 m above ground level. According to NREL, the area where wind power energy density becomes over 320 W/m^2 at 30 m above ground level, and over 400 W/m^2 at 50 m above ground level is suitable for wind power development. Table 3 shows an evaluation standard of the wind power energy density and wind speed.

Nationwide wind potential maps of El Salvador are shown in Figs. 1-3.

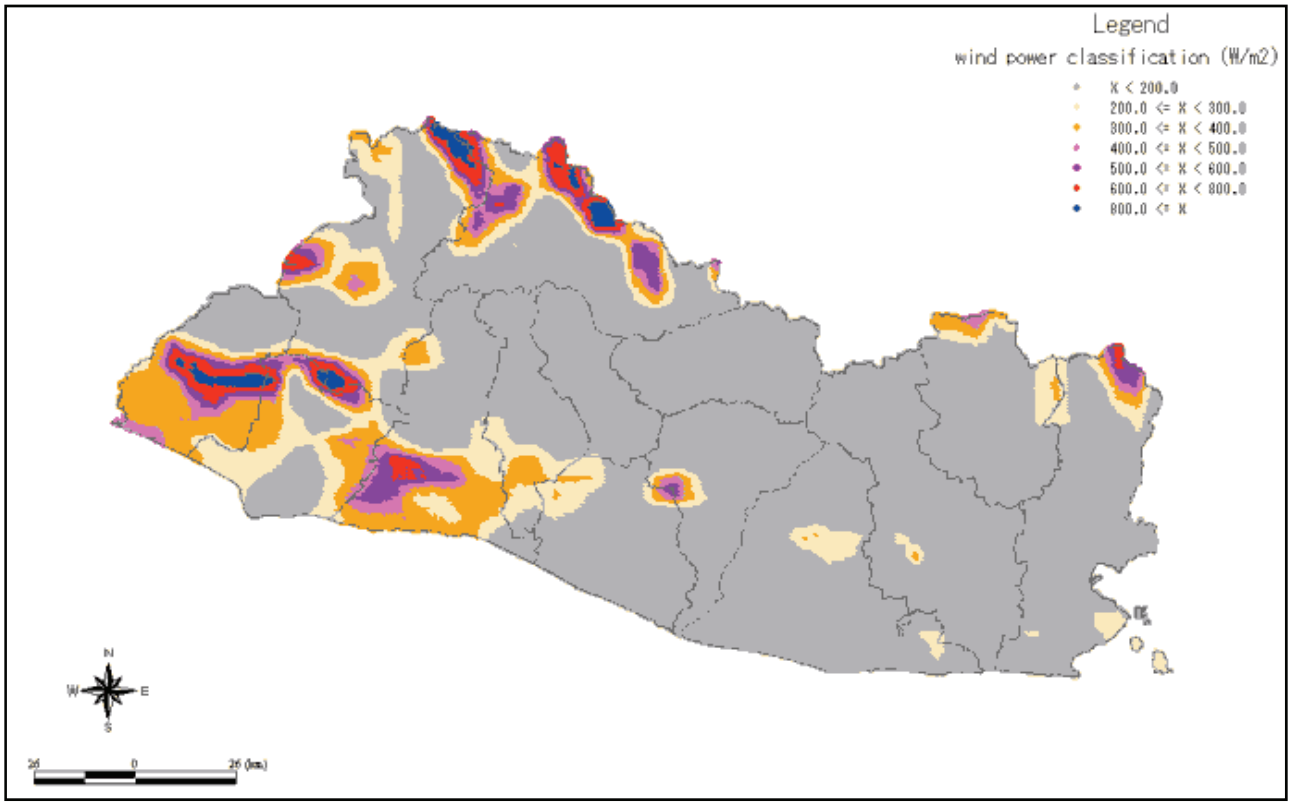


Fig. 1 Wind potential map of El Salvador (30 m above ground level).

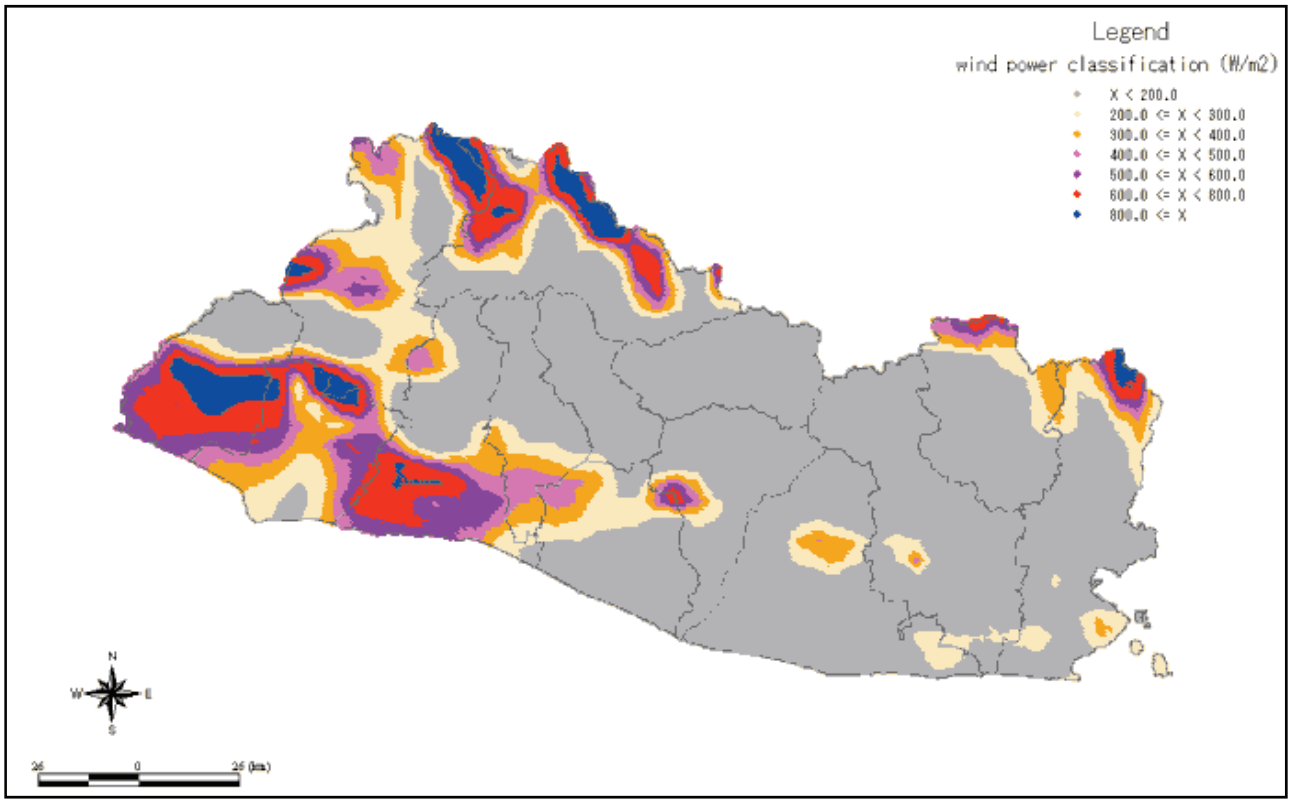


Fig. 2 Wind potential map of El Salvador (50 m above ground level).

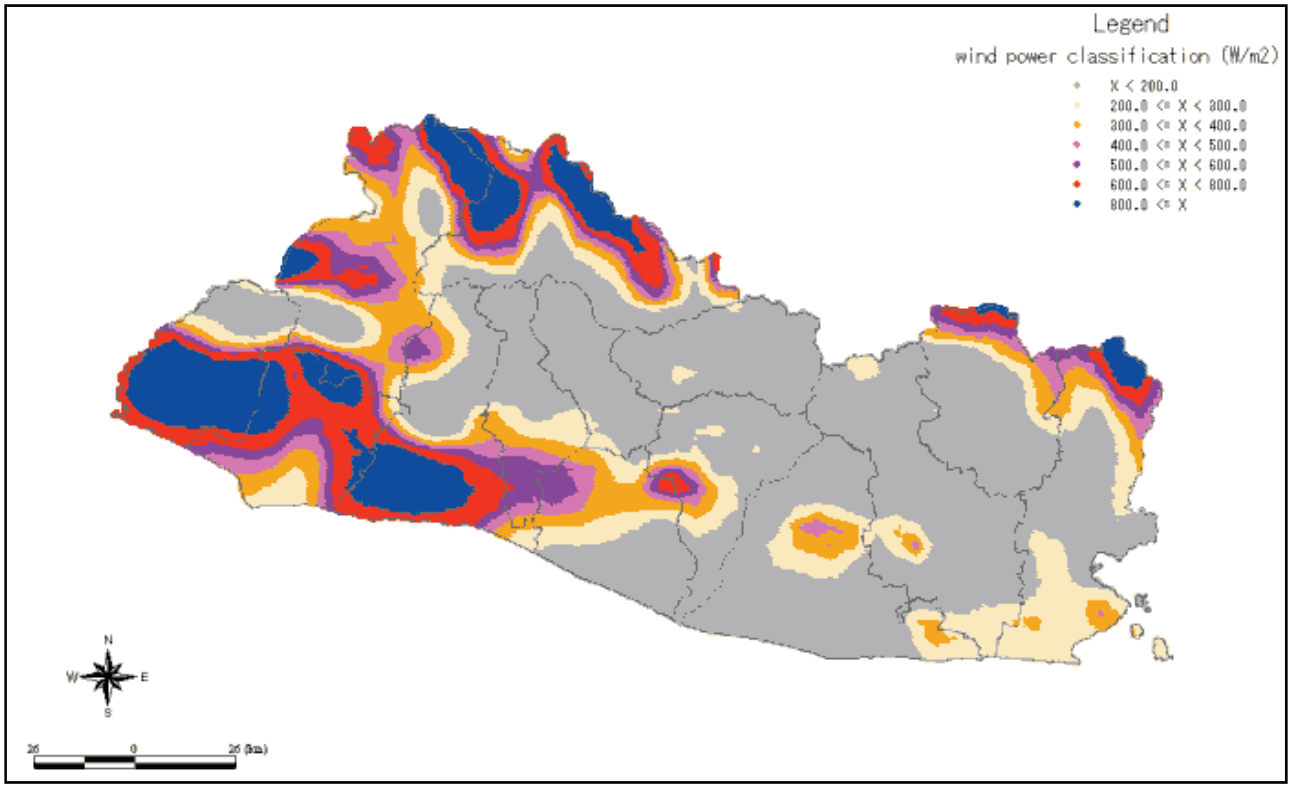


Fig. 3 Wind potential map of El Salvador (80 m above ground level).

5. Analysis Results

5.1 Wind Power Potential

As a result of wind potential analysis in El Salvador, it was recognized that wind potential was large in the following areas.

- A southwest mountainous area (area from a ridgeline in the south side);
- A northwest mountainous area (around ridgeline);
- A northeast mountainous area (around ridgeline to border).

In addition, the distribution of wind potential in the site mentioned above is almost similar at each altitude. However, the potential becomes larger with the increase of altitude. The area with over 800 W/m^2 is large at 80 m above ground level.

5.2 Wind Potential Sites

In the study, suitable sites for wind power development were identified from the wind potential map. On the basis of the map, a database was prepared. For the selection of wind potential area, the areas where wind potential is greater than 700 W/m^2 at 50 m above ground level are selected. As a result, 12 areas shown in Fig. 4 were selected. Largest potential in the area was selected as a representative data of the area.

Wind speed and potentials at 30 m, 50 m and 80 m above ground level are shown in Table 4. Similarly, each Weibull distribution parameter (c, k) [7, 8] is shown in Table 5.

5.3 Comparison to Monitoring Data

The annual average wind speed is calculated based on wind speed of every hour and day in each mesh area. In addition, annual average wind speed and wind potential are almost corresponding if there are no large differences on the frequency distribution. In area of existing weather stations, which compared actual value with calculated value is shown below. It is considered that the calculated values are almost corresponding with the actual values of 2008.

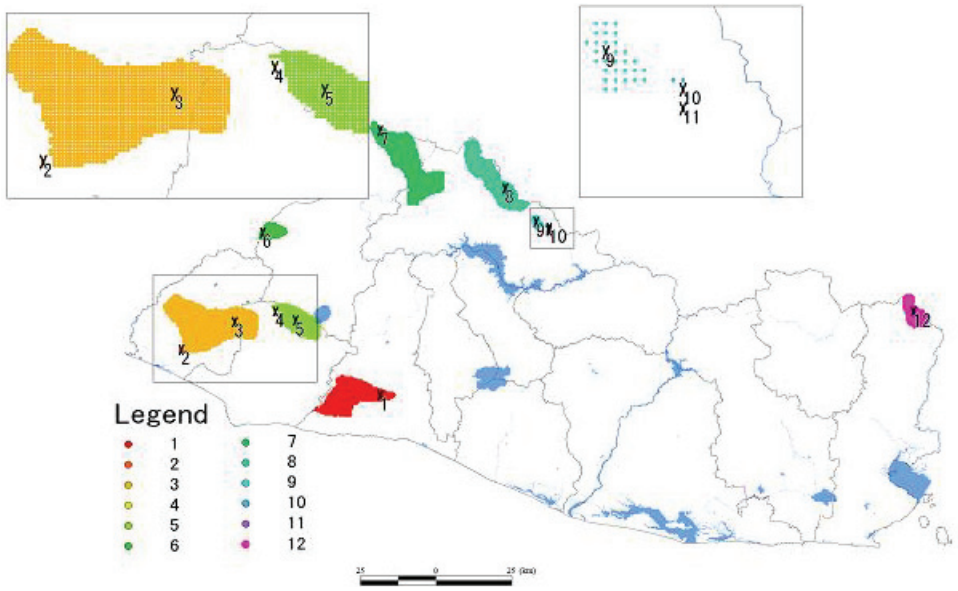


Fig. 4 Wind potential area.

Table 4 Data of wind potential sites (wind speed, wind potential).

Point (area)	Annual mean wind speed (m/s)			Annual wind potential (W/m^2)		
	30 m	50 m	80 m	30 m	50 m	80 m
1	6.50	7.32	7.66	574.0	843.8	1,010.2
2	5.15	5.94	6.62	401.6	703.4	1,036.7
3	8.20	8.52	8.69	1,072.2	1,231.2	1,348.9
4	6.61	7.42	7.94	485.1	707.0	899.1
5	8.19	8.48	8.55	1,100.8	1,237.1	1,281.8
6	8.22	8.87	9.33	806.0	1,013.6	1,193.8
7	8.61	8.95	9.08	1,183.2	1,363.3	1,460.1
8	7.26	7.81	7.96	1,029.6	1,287.6	1,402.6
9	5.82	6.26	6.44	589.5	749.0	849.5
10	5.96	6.30	6.47	591.6	708.8	794.9
11	5.94	6.30	6.46	576.9	700.9	782.6
12	6.75	7.56	7.98	636.4	911.5	1,103.1

Table 5 Data of wind potential sites (Weibull parameter (c, k)).

Point (area)	Weibull parameter c			Weibull parameter k		
	30 m	50 m	80 m	30 m	50 m	80 m
1	7.05	7.91	8.20	1.33	1.30	1.25
2	5.46	6.13	6.70	1.16	1.07	1.00
3	8.72	9.06	9.26	1.36	1.33	1.29
4	7.12	7.90	8.39	1.49	1.45	1.43
5	8.80	9.02	9.13	1.27	1.29	1.28
6	9.05	9.73	10.22	1.69	1.68	1.66
7	9.03	9.39	9.56	1.37	1.32	1.29
8	7.33	7.90	8.01	1.10	1.07	1.04
9	5.89	6.30	6.45	1.10	1.07	1.04
10	6.20	6.54	6.69	1.15	1.13	1.10
11	6.21	6.60	6.71	1.16	1.14	1.11
12	7.09	7.92	8.33	1.34	1.31	1.26

Table 6 Monitored data and calculated data.

Code	Weather station	Annual average wind speed (m/s) (10 m, 2008)	Calculated wind speed (m/s)	
			(10 m)	(30 m)
4	Ilopango	4.6	3.5	4.6
31	La Union	2.9	3.4	4.5
32	San Miguel	2.0	2.4	2.7

6. Conclusions

Renewable energy technologies are utilized in developing countries for the purpose of supply energy and mitigate climate change. On the other hand, Renewable energy such as wind or solar has large diurnal and seasonal variation, therefore potential survey has to be conducted in initial stage of development.

Also, it is significant to prepare nationwide wind potential map because wind characteristics are strongly depending on the topographical condition.

(1) As a result, wind potential area in El Salvador became clear.

- A southwest mountainous area (area from a ridgeline in the south side);
- A northwest mountainous area (around ridgeline);
- A northeast mountainous area (around ridgeline to border).

(2) The wind potential map prepared in the study shows wind potential area in the southwestern part is larger compared to the existed wind power potential map of El Salvador. It is considered the differences caused by differences of resolution and year of the data set. In this study, wind potential map was prepared based on the data of 2008, and horizontal mesh 500 meters. On the other hand, existing wind potential map was prepared based on the data of 2004, and horizontal mesh 1,000 meters.

(3) Wind potential map of El Salvador was prepared in approximately 3 months. The map was able to contribute to developing national master plan of the wind energy in the country.

(4) It is necessary to install wind monitoring tower to monitor wind characteristics in the wind potential sites and analyze the data to select suitable area for introduction of wind generation system.

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