English Summary

Study on Construction of Electric Power System Aimed at Renewable Energy Expansion

Because the power-supply equipments were terribly influenced by the Great East Japan Earthquake on March 11 of 2011, almost all nuclear power plant operations have been suspended, which influences the reduction of greenhouse gas emission. Under these circumstances, the promotion of renewable energy is getting very important as a measure which can realize reduction of greenhouse gas emission and ensuring of energy security simultaneously.

Among renewable energy souces, wind power is especially expected to be expanded because of its abundant potential. On the other hand, wind energy is concentrated in areas far from demand centers such as Hokkaido and Tohoku where there are not enough power grids, and it's difficult to transmit the electricity from wind power plants in those areas. Therefore, construction of electric power system is indispensable for expansion of wind power generation.

In order to deal with such situations, some projects have begun in part of the nation lead by ministries, but country-wide and comprehensive arrangement has not implemented yet. And so it is important for expansion of wind power generation to figure out the areas where construction of electric power system is needed on a nationwide scale and consider the method to construct transmission line.

In this project, in order to contribute to the expansion of wind power generation, the method and plan to construct transmission line for wind energy and the estimated construction cost of transmission line have been studied.

In particular, supposing the capacity of wind power generation in 2050, promising areas for wind power generation were extracted and selected from all over the country, and the areas requiring construction of electric power system were figured out. Furthermore, for 3 areas of which introduction potential is large - Hokkaido (Northern Area and Eastern Area) , Tohoku, and Kyushu , layout plans of transmission lines were suggested based on the optimaization calculation and approximate costs for construction were estimated.

1 Project Overview

Basic policies of this study are as below;

- Supposing the capacity of wind power generation in 2050, method to construct additional transmission lines for wind energy to meet the supposed capacity is considered and approximate construction costs are estimated.

- In order to reduce the influence of annual variation to the utmost extent, the wind conditions throughout the country is calculated based on the numerical weather simulations over the past 20 years and applied newly in this project.
- Access points with existing electric power system are existing substations to which transmission lines of more than the second highest voltage in each electricity supply area, e.g. 275kV, are connected. The voltage of transmission lines to be constructed onshore additionally is the third highest voltage in each electricity supply area, e.g. 154kV.
- Both onshore and offshore (bottom-mounted / floating) wind power generations are considerd in this project.

Figure 1 shows the flow diagram of this project.

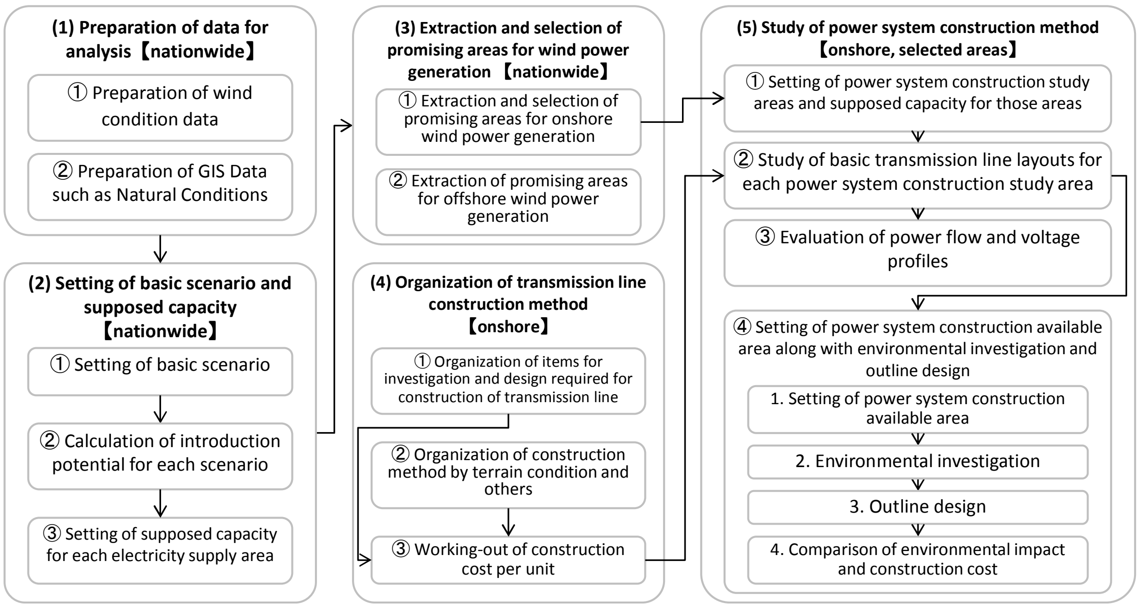

Figure 1　Flow Diagram of Project

The items taken into consideration in this project are shown below;

1. Supposed capacity of wind power generation across the country in 2050 was set by reference to existing target values set by other agencies or associations.
2. Supposed capacity of wind power generation across the country was allocated to each electricity supply areas and each location types (onshore / offshore (bottom-mounted / floating)). In this regard, wind farms in each electricity

supply areas were basically connected to the power systems which blong to corresponding power company. But, as for Fukushima prefecture, which is located in Tohoku District, additional case such that wind farms in eastern rigion (Hamadori region) were connected to the power system of Tokyo Electric Power Company (TEPCO) which is extended to this region ("Shin-Fukushima utilization case") was also considered.

3. Data needed in this project were prepared based on latest and open information. But, when the data or information is difficult to obtain, the assumed data was used.
4. Supposed capacity or introduction potential was set based on installed capacity [kW]. (not based on generated energy [kWh])
5. Extraction and selection of promising area and study of basic transmission line layouts were implemented under certain conditions and judged artificially.

2 Content of Implementation

The contet of implementation in this project is as below;

（1） Preparations of data for analysis

① Preparation of wind condition data

In order to apply to calculation of introduction potential across the country and extraction and selection of promising area, and so on, the high-resolution wind condition (1 hour and 500m in time and spatial mesh respectively, 80m altitude) was calculated besed on the numerica weather simulation over the 20years (1991 - 2010) targeted at electricity supply areas of 6 power companies - Tokyo, Chubu, Hokuriku, Kansai, Chugoku, and Shikoku. Then, the data was made into public database which is consistent with the previously built Kyushu and Okinawa database in FY2013. Furthermore, the public database was marged with the previous database into the countrywide database.

Table 1 shows the specification summary of the high-resolution weather simulation and Table 2 shows the specification summary of the wind condition database. Figure 2 shows the map of average annual wind speed over 20 years across the country. Standard deviations of yearly annual wind speed include the simulation errors derived by comparison with observation values at meteorological stations in the target area. Occurrences of winds according to directions (16 directions) based on wind speed classification were visualized as wind-rose diagrams so as to grasp the wind-direction traits.

Table 1　Specification summary of the high-resolution weather simulation

Caluculating area	Calculation period	Simulation resolution		
		Horizontal	Vertical	Temporal
6 electricity supply areas: Tokyo, Chubu, Hokuriku, Kansai, Chugoku, and Shikoku	1991 - 2010 (20 years)	500 m	10 m or more	1　hour

Table 2　Specification summary of the wind condition database

database component	content
Average annual wind speed over 20 years	20-year average of annual wind speed [m/s] (simulation errors not considered)
Standard deviations of yearly annual wind speed	Standard deviations of yearly annual wind speed over 20 years[%] (simulation errors considered)
Maximum annual wind speed in yearly annual wind speed	Maximum annual wind speed in yearly annual wind speed [m/s] (simulation errors not considered)
Minimum annual wind speed in yearly annual wind speed	Minimum annual wind speed in yearly annual wind speed [m/s] (simulation errors not considered)
Occurrences of winds according to 16 directions	Occurrences of winds according to 16 directions over 20 years

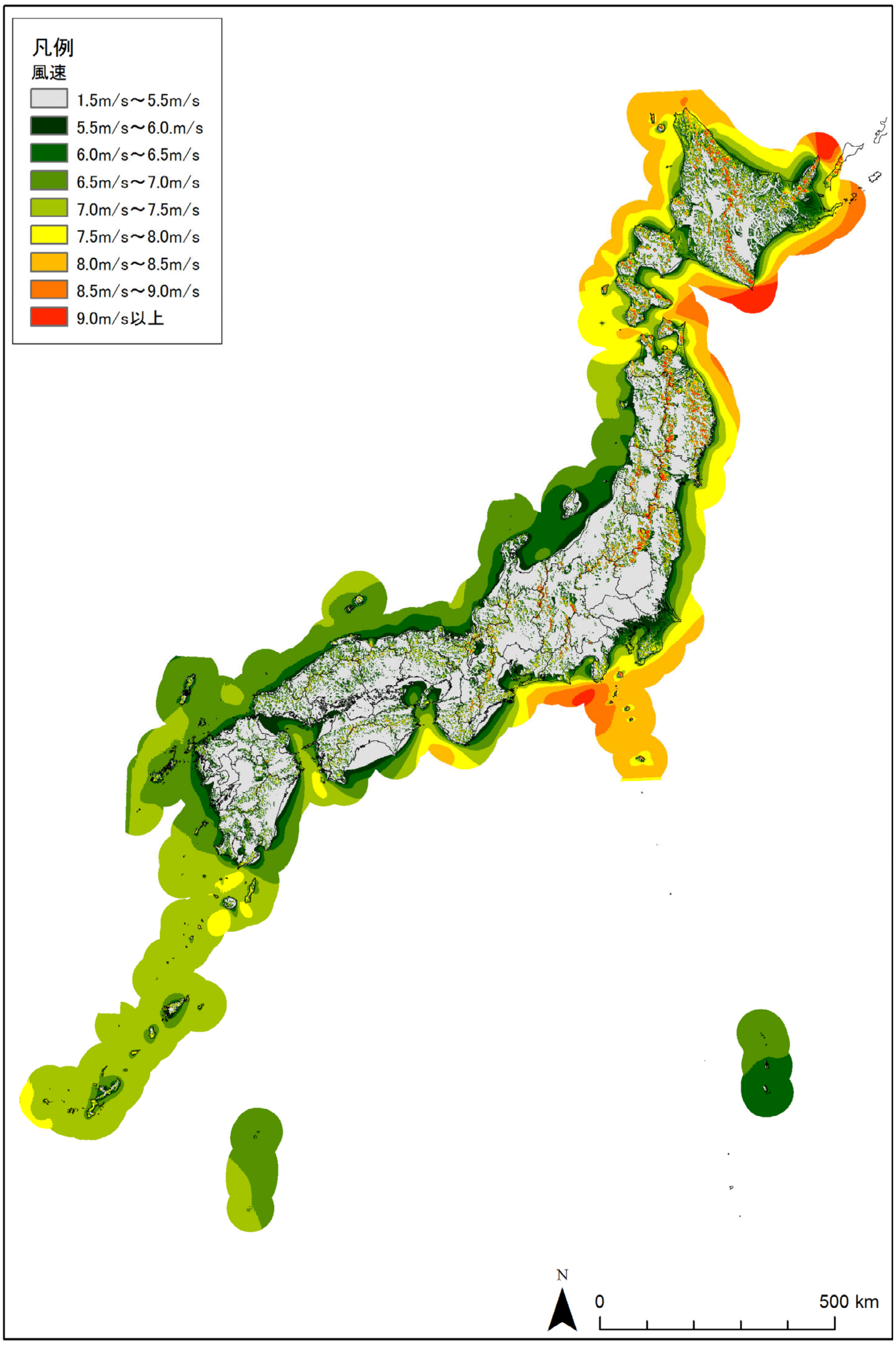

Figure 2　Map of average annual wind speed over 20 years across the country (80m above ground level or sea level, distance from coast line less than 50km)

② **Preparation of GIS data such as natural conditions**

The GIS (geographic information system) data such as natural conditions, social conditions, legal systems, and information about electrical equipment was prepared for use in the lower process like extraction and selection of promising area for wind power generation on the basis of published data. The GIS data of following information were newly created in this project: Japan Self-Defence Forces bases, U.S. military base, existing transmission lines, existing power plants, existing substations and existing switching stations. Figure 3 and Figure 4 show the maps of created GIS data.

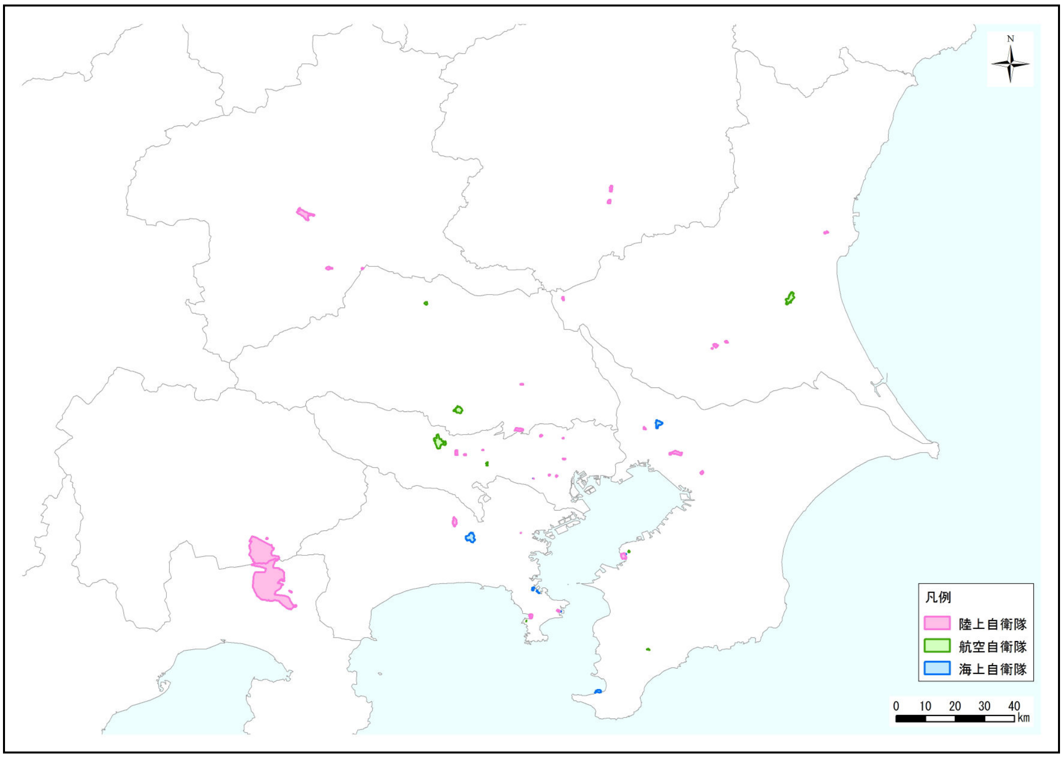

Figure 3 Example of GIS data map (SDF base)

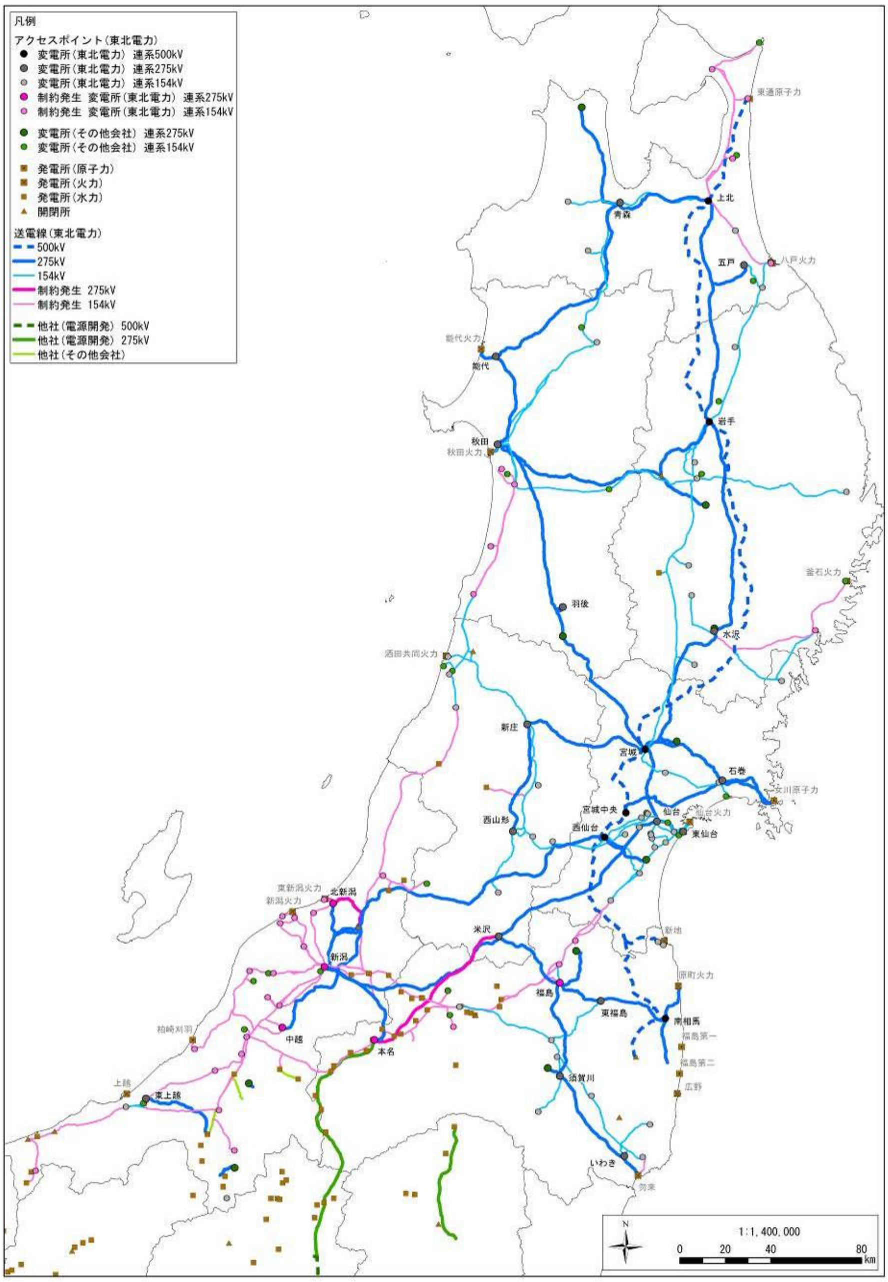

Figure 4　Example of GIS data map (electrical equipments)

(２)　Setting of basic scenario and supposed capacity

①　Setting of basic scenario

In order to figure out available wind resources in 2050, scenarios for the future social situation relavant to environment, etc. were considered.

In regard to onshore wind energy, 2 scenarios were set depending on 2 environmental items of unfeasible conditions for wind turbine installation; protection forest areas, and habitats of golden eagle and mountain hawk-eagle. The basic scenario includes both items in infeasible conditions, and the referential scenario excludes both. The reference scenario was implemented only for Tohoku Electric Power Company supply area.

As for island areas, only the main island of Okinawa was taken into consideration.

Table 3 and Table 4 show the estimation conditions of introduction potential for onshore wind power generation and offshore wind power generation respectively.

Table 3 Estimation conditions of introduction potential for onshore wind power generation (unfeasible conditions)

Category	Item	**Basic scenario** Exclude protection forest, and habitat of golden eagle and mountain hawk-eagle	Referencialscenario Include protection forest, and habitat of golden eagle and mountain hawk-eagle
Natural conditions	Annual mean wind speed	Less than 6.0m/s	Less than 6.0m/s
	Altitude	1,200m or more	1,200m or more
	Maximum tilt angle	20 degrees or more	20 degrees or more
	Above-ground opening	Less than 75 degrees	Less than 75 degrees
Legal systems	Legal system classification	1)Special protection zones and Class 1 special zones within national and quasi-national parks 2)Class 1 special zones within prefectural natural parks 3)Wilderness areas 4)Nature conservation areas 5)State-designated and prefecture-designated special protection zones within wildlife protection areas 6)World natural heritage sites 7)Protection forest areas	1)Special protection zones and Class 1 special zones within national and quasi-national parks 2)Class 1 special zones within prefectural natural parks 3)Wilderness areas 4)Nature conservation areas 5)State-designated and prefecture-designated special protection zones within wildlife protection areas 6)World natural heritage sites
Social conditions,land use, etc.	City planning classification	Urbanization promotion areas	Urbanization promotion areas
	Land-use classification	Fields, building lots, lots used as trunk transportation lines, rivers and wetlands, golf courses	Fields, building lots, lots used as trunk transportation lines, rivers and wetlands, golf courses
	Distance from residential area	Less than 500m	Less than 500m
	Others	Areas restricted by the Civil Aeronautics Act	Areas restricted by the Civil Aeronautics Act
Consideration for rare raptores	golden eagle, mountain hawk-eagle	Meshs surrounded by habitat meshs in all directions	

Table 4 Estimation conditions of introduction potential for offshore wind power generation (unfeasible conditions)

Category	Item	Basic scenario
Natural conditions	Annual mean wind speed	Bottom-mounted: less than 7.0m/s Floating: less than 7.5m/s
	Distance from coast line	30km or more
	Water depth	200m or more
Legal systems	Legal system classification	1)Marine park zones within national and quasi-national parks

② **Calculation of introduction potential for each scenario**

The introduction potential for wind power generation in each electricity supply area was calculated for each scenario on the basis of the data (wind condition data and GIS data) prepared in the upper process. The outcome of this calculation is to be used for setting of supposed capacity for each electricity supply area in the lower process.

Table 5 shows the calculated introduction potential in each electricity supply area.

Table 5 Calculated introduction potential in each electricity supply area

Unit: GW

Electricity supply area	Onshore		Offshore		
	Basic scenario	Reference scenario	Total	Bottom-mounted	Floating
Hokkaido	118.23	181.78	248.45	92.21	156.24
Tohoku	38.03	88.78	79.01	21.62	57.39
Tokyo	2.84	6.18	47.85	21.48	26.37
Hokuriku	2.46	5.18	0	0	0
Chubu	5.86	11.29	26.21	11.00	15.20
Kansai	6.56	16.12	1.14	0.13	1.01
Chugoku	6.57	18.89	0	0	0
Shikoku	2.71	6.10	4.81	1.57	3.24
Kyushu	6.58	14.19	5.69	1.07	4.62
Okinawa	1.74	1.84	3.48	3.47	0
Sum	191.57	350.35	416.62	152.56	264.07
Hamadori	3.69	4.64	3.07	3.07	0

③ **Setting of supposed capacity for each electricity supply area**

Supposed capacity of wind power generation in 2050 for each electricity supply area and each location types (onshore / offshore (bottom-mounted / floating)) was set on the basis of introduction potential by reference to existing target values. The allocation method to each electricity supply areas and each location types was decided according to the method published by Japan Wind Power Association in June 2012.

Table 6 shows the supposed capacity for each electricity supply area. As for Shin-Fukushima utilization case, the supposed capacity for Tohoku area except Hamadori region in basic scenario was set to 22.2 GW (11.1 GW for onshore, 11.1 GW for offshore respectively), and the capacity of Hamadori region (included in the value of

Tokyo area) was set to 2.1 GW. Also, the supposed capacity for Tohoku area except Hamadori region in reference scenario was set to 8.1 GW (4.0 GW for onshore, 4.1 GW for offshore respectively).

Table 6　Supposed capacity for each electricity supply area

Unit: GW

Electricity supply area	Basic scenario					Reference Scenario				
	Total	Onshore	Offshore			Total Total	Onshore	Offshore		
			Total	Bottom-mounted	Floating			Total	Bottom-mounted	Floating
Hokkaido	4.50	4.00	0.50	0.50	0	3.70	3.30	0.40	0.40	0
Tohoku	25.00	12.50	12.50	7.00	5.50	11.50	5.70	5.80	3.80	2.00
Tokyo	15.00	1.40	13.60	7.10	6.50	16.60	3.00	13.60	7.10	6.50
Hokuriku	1.20	1.20	0	0	0	2.50	2.50	0	0	0
Chubu	10.30	2.90	7.40	3.60	3.80	13.00	5.60	7.40	3.60	3.80
Kansai	3.50	3.20	0.30	0	0.30	8.30	8.00	0.30	0	0.30
Chugoku	3.20	3.20	0	0	0	7.10	7.10	0	0	0
Shikoku	2.20	1.30	0.90	0.30	0.60	3.40	2.60	0.80	0.30	0.50
Kyushu	4.50	3.20	1.30	0.40	0.90	8.30	7.00	1.30	0.40	0.90
Okinawa	0.60	0.60	0	0	0	0.60	0.60	0	0	0
Sum	70.00	33.50	36.50	18.90	17.60	75.00	45.40	29.60	15.60	14.00

（３）　Extraction and selection of promising areas for wind power generation

①　Extraction and selection of promising areas for onshore wind power generation

Firstly, the promising areas were extracted on the basis of introduction potential areas derived in th previous process. As for the electricity supply area of which introduction potential is much larger than supposed capacity, the stricter condition was applied. Secondly, based on the firstly extracted promising areas, aggregated meshes feasible for wind farm were selected manually based on terrain information and so on. The secondly selected promising areas are to be used as objects of the study of power system construction method in the lower process.

Table 7 shows the extracted and selsected promising areas for onshore wind power generation.

Table 7　Extracted and selsected promising areas for each electricity supply area (onshore wind power generation)

Electricity supply area	Supposed capacity	Promising area		
		Firstly extracted	Secondly selected	
	(GW)	(GW)	(GW)	(ratio)
Hokkaido	400	1,051	969	2.42
Tohoku	1,250	871	1,987	1.59
Tokyo	140	284	203	1.45
Hokuriku	120	246	192	1.60
Chubu	290	586	340	1.17
Kansai	320	656	327	1.02
Chugoku	320	657	407	1.27
Shikoku	130	271	149	1.15
Kyushu	320	658	348	1.09
Okinawa	60	174	166	2.77
Sum	3,350	5,454	5,088	1.52

② **Extraction of promising areas for offshore wind power generation**

Promising areas were extracted within the calculation condition of supposed capacity preferentially from the nearest area to each access point.

Table 8 shows the extracted and selsected promising areas for offshore wind power generation.

Table 8　Extracted and selsected promising areas for each electricity supply area (offshore wind power generation)

Electricity Supply Area	Supposed Capacity (GW)		Promising area			
			Firstly extracted (GW)		Secondly selected (GW)	
	bottom-mounted	floating	bottom-mounted	floating	bottom-mounted	floating
Hokkaido	0.50	0.00	0.68 (10 km)	0.00 -	0.60 (10 km)	0.00 -
Tohoku	7.00	5.50	9.91 (30 km)	9.02 (40 km)	7.47 (30 km)	8.96 (80 km)
Tokyo	7.10	6.50	7.52 (30 km)	15.26 (50 km)	7.60 (40 km)	7.83 (70 km)
Hokuriku	0.00	0.00	-	-	-	-
Chubu	3.60	3.80	5.88 (20 km)	5.58 (20 km)	4.37 (20 km)	4.75 (40 km)
Kansai	0.00	0.30	0.00 -	1.01 (30 km)	0.00 -	1.01 (30 km)
Chugoku	0.00	0.00	-	-	-	-
Shikoku	3.00	0.60	0.48 (30 km)	3.04 (60 km)	0.48 (30 km)	2.69 (60 km)
Kyushu	4.00	0.90	0.44 (30 km)	1.68 (60 km)	0.44 (30 km)	1.68 (60 km)
Okinawa	0.00	0.00	-	-	-	-
Sum	18.90	17.60	24.91 -	35.59 -	20.96 -	26.92 -

* Distance in parentheses means the largest distance from acsess point.

（4） **Organization of transmission line construction method**

① **Organization of items for investigation and design required for construction of transmission line**

General work process for transmission line route setting was organized from the point of investigation, surveying, design, and cost estimation. In addtion, scope of this project was defined.

② **Organization of construction method by terrain condition and others**

The latest information about application of surveying technology to setting of transmission line route was organized. Furthermore, general construction method and specification for transmission line was organized in accordance with terrain conditions.

③ **Working-out of construction cost per unit**

Transmission line construction cost per unit length (1 km) was worked out for each voltage class, each terrain class and each line type so as to be referenced in study of basic transmission line layouts in the lower process.

Average cost of 154 kV class and 110 kV class was estimated at 350 million yen per km and 330 million yen per km respectively.

（5） **Study of power system construction method**

① **Setting of power system construction study areas and supposed capacity for those areas**

In regard to each electricity supply areas, positional relashionships of secondly selected promising areas to transmission lines were organised by superimposing both maps.

Besides, 3 areas of which introduction potential is large - Hokkaido (Northern Area and Eastern Area) , Tohoku, and Kyushu - were set as power system construction study areas in this project.

The supposed capacity of Northern Area and Eastern Area of Hokkaido was set to be 3.3 GW according to the introduction potential ratio and so on.

② **Study of basic transmission line layouts for each power system construction study area**

The basic transmission line layouts, which are constructed with the new transmission lines dedicated to interconnection from the access points on the existing power system to the spread (secondly selected) promising areas, were organized in three areas

(Hokkaido, Tohoku, and Kyushu) set as the consideration areas in the previous process. In order to study about the basic layouts of transmission line, "Net Optimizer with EXPRIMG" based on the Genetic Algorithm (GA) and the Extended-Prim's Algorithm (Kousaka et al., 2014) was applied to the following optimization problems. In the Genetic Algorithm (GA), the index considering wind condition, which was defined as the value obtained by dividing the construction cost for the new transmission lines with the total wind power generation (kWh), was minimized by choosing the adequate combination of the (secondly selected) promising areas with satisfying the supposed installation capacity. The construction cost for the new transmission lines was calculated with the Extended-Prim's Algorithm for determining the index considering wind condition. The Extended-Prim's Algorithm performs the adequate transmission network to minimize the cost by connecting the chosen combination of the promising areas with the new transmission lines considering the transmission capacity.

Table 9 and Figure 5 shows the each value and the layout of the network with Shin-Fukushima utilization case in basic scenario.

Table 9 Each value of network with Shin-Fukushima utilization case in basic scenario

Area	Voltage class	Connected capacity	Electrical energy per year	Total length	Total construction cost	Construction cost		Transmission cost (3% interest)
	(kV)	(GW)	(TWh)	(km)	(billion yen)	(million yen/km)	(thousand yen/kW)	(yen/kWh)
Hokkaido	110	3.516	9.18	405.7	147.91	365	42,069	1.4
Tohoku (exept Hamadori)	154	11.185	34.50	1163.9	436.07	375	38,986	1.1
Hamadori	154	2.115	6.85	138.8	54.03	389	25,546	0.7
Kyushu	110	3.204	7.45	651.8	229.93	353	71,766	2.8
Sum / Ave.	-	20.020	57.98	2360.2	867.94	368	43,354	-

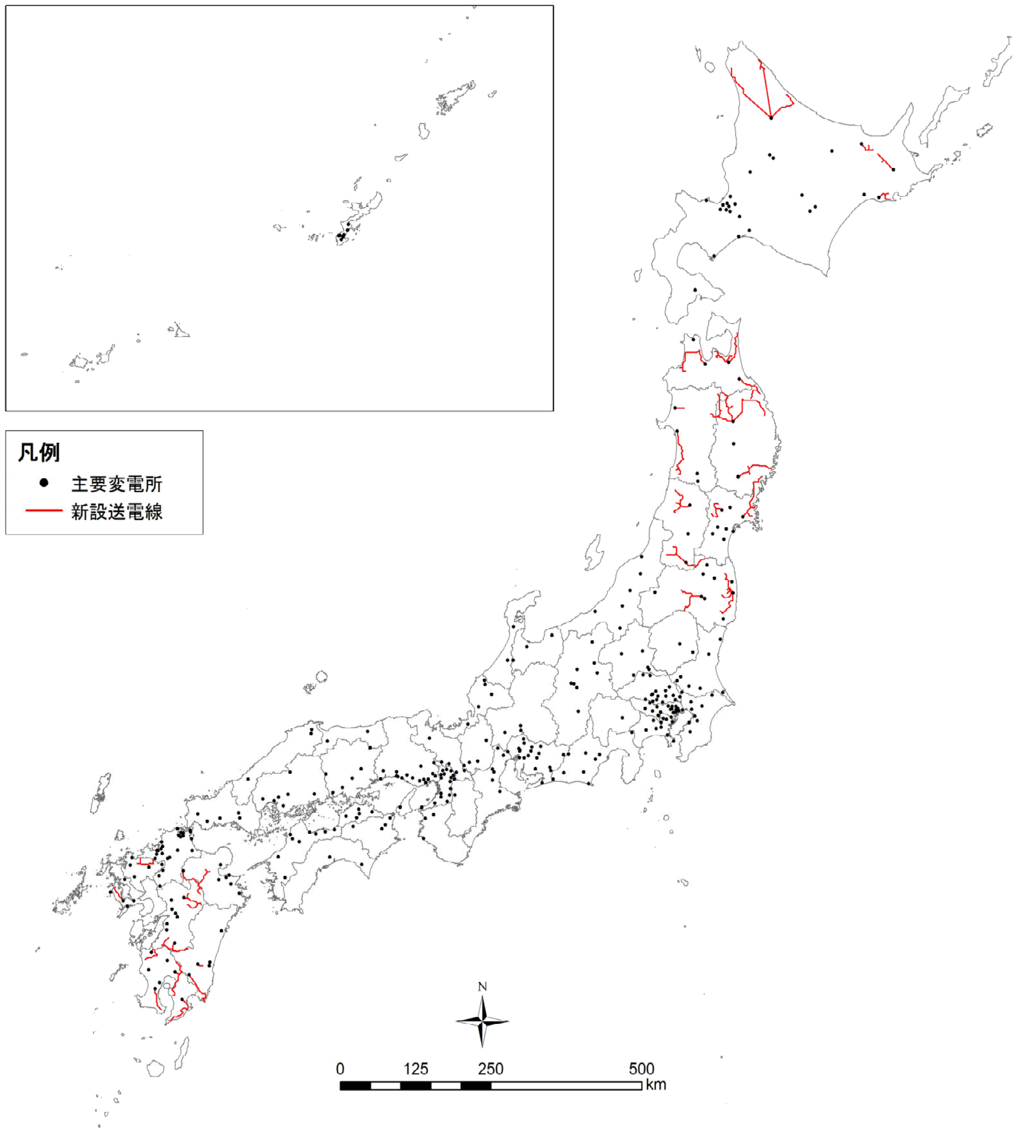

Figure 5　Layout of the network with Shin-Fukushima utilization case in basic scenario

③　**Evaluation of power flow and voltage profiles**

In order to evaluate the power flow and the voltage profiles in the new transmission networks, AC power flow calculation was applied to the basic transmission line layouts calculated in the previous process.

In the case of the operation of constant power factor to 1 for all wind farms, the values of voltage could be in the allowable ranges within 95 % - 105 % of basic voltage, therefore it showed the proper construction in the new transmission networks.

As the evaluation of the required reactive power and the power losses in the networks, the summary of the results was showed in Table 10 for the comparison of the constant operation for all wind farms and the adjusted operation in power factor for each wind farm.

When the power factor of the wind farms was adjusted to minimize the required reactive power from the existing power system to the new transmission networks rather than to minimize the power losses in the network, the values of power factor could be in the allowable ranges (Power factor allowable range: 0.90 - 1.00, both lag and lead). And also, the values of the required reactive power from the existing power system could be nearly 0 and the values of the power factor through each new transmission networks could be nearly 1.0. Therefore the additional facilities such as SVCs were not required as the countermeasures which compensated the reactive power.

Table 10 Reactive power compensation and transmission loss for each accesspoint (P_{loss} ([%]): ratio to total generating capacity)

Electricity supply area	Access point	Constant operation for all wind farms				Adjusted operation in power factor for each wind farm			
		Power factor 1.00		Constant voltage		Minimizing Q_{sys}		Minimizing P_{loss}	
		Q_{sys} [MVar]	P_{loss} [MW] ([%])	Q_{sys} [MVar]	P_{loss} [MW] ([%])	Q_{sys} [MVar]	P_{loss} [MW] ([%])	Q_{sys} [MVar]	P_{loss} [MW] ([%])
Tohoku	Iwate East route 842.8MW	291.4	56.5 (6.70)	171.8	56.6 (6.72)	113.9	52.5 (6.23)	121.6	52.4 (6.22)
	Shin-Fukushima South route 600.6MW	67.1	20.1 (3.35)	134.6	22.7 (3.78)	0.0	20.0 (3.32)	-02.1	19.8 (3.29)
Hokkaido	Memanbetsu 569.5MW	86.6	16.7 (2.93)	114.9	17.3 (3.14)	0.0	16.3 (2.86)	-20.4	16.2 (2.84)
Kyushu	Osumi 518.8MW	163.8	32.4 (6.25)	92.7	32.9 (6.34)	63.9	30.5 (5.88)	69.8	30.4 (5.86)
	Kumamoto 386.9MW	115.4	24.2 (6.25)	87.3	25.5 (6.59)	0.0	23.6 (6.10)	32.1	23.1 (6.02)

Ploss : active power loss, Qsys :reqired reactive power compensation from power system.

④ Setting of power system construction available area along with environmental investigation and outline design

For several areas of basic transmission line layouts with large connected capacity, power system construction available areas were set in view of land usage situations, legal systems and so on. “Power system construction available area” is corresponding to the outline route in a general transmission line investigation and design. Depending on the situation of each area, multiple plans were considered in case the places to be bypassed largely or the places feasible for construction of wind turbines were included in the area.

Also, as for these areas, consideration matters related to environment in transimission line construction were organaized on the basis of existing materials investigation, and field investigations such as landscape survey were conducted when needed. Furthermore, the outline designs were implemented assuming concrete construction method, and the approximate costs by the construction method were estimated. As for the area where multiple plans were considered, the environmental impacts and the approximate costs were compared between each plan.

Table 11 shows the selected areas for the outline route, and Table 12 shows the summary of results for the outline design in each area.

Table 11 Selected areas for outline route

	Hokkaido (1 area)	Tohoku (5 areas)	Kyushu (2 areas)
Area	Memanbetsu	Aomori, Iwate, Akita, Miyagi, Hamadori	Kumamoto, Osumi

Table 12 Summary of results for outline design in eash area

No.	Area	Voltage Class (kV)	Result of outline design (Plan A)				Result of outline design (Plan B)				Result of basic transmission line layouts			
			Total length (km)	Total construction cost (billion yen)	Construction cost (million yen /km)	Ratio of mountains (%)	Total length (km)	Total construction cost (billion yen)	Construction cost (million yen /km)	Ratio of mountains (%)	Connected capacity (MW)	Total length (km)	Total construction cost (*) (billion yen)	Construction cost (million yen /km)
1	Memanbetsu	110	32.4	11.05	341.0	58%	30.5	10.06	329.8	49%	570	34.1	11.38	333.7
2	Aomori	154	94.8	34.10	359.7	47%	92.6	33.47	361.4	46%	824	95.7	33.23	347.2
3	Akita	154	98.1	36.61	373.2	54%	94.2	34.90	370.5	51%	848	94.8	33.42	352.5
4	Iwate	154	100.5	40.07	398.7	85%	100.6	39.82	395.8	85%	843	99.6	35.08	352.2
5	Miyagi	154	107.5	41.43	385.4	85%	105.7	40.81	386.1	84%	822	109.1	37.51	343.8
6	Fukushima	154	50.2	19.27	383.9	91%	44.5	16.66	374.4	90%	601	51.5	17.65	342.7
7	Kumamoto	110	66.0	22.83	345.9	78%	-	-	-	-	582	69.4	22.63	326.1
8	Osumi	110	66.8	24.29	363.6	83%	65.6	23.86	363.7	83%	519	72.8	23.94	328.8

(*) Excluding cost for substations

3 Conclusion

3.1 Descussion for result

In this project, 3 areas of which introduction potential is large - Hokkaido (Northern Area and Eastern Area) , Tohoku, and Kyushu - were set as power system construction study areas. In total of these 3 areas, line length was estimated to 2,360 km and construction cost was estimated to 867.9 billion yen (Shin-Fukushima utilization case of basic scenario).

Because it requires about 850 billion yen to construct transmission lines for wind power generation of 20 GW in these 3 areas, the cost to construct transimission lines for wind power generation of 33.5 GW in all onshore areas is estimated to be 1.5 trillion yen by simple calculation (approximately 1.7 times as large as total of 3 areas). On the other hand, cost to develop wind power generation facilities of 33.5 GW is estimated to approximately 10 trillion yen assuming unit cost of 0.3 million yen per km. Therefore, cost to construct transmission lines is estimated to about 13 % of total cost to introduce wind power generation (11.5 trillion yen). Furthermore, transmission costs were calculated to be 1 to 2 yen per kWh. These are 10 to 20 % of wind power generation cost of 10 yen per kWh that is estimated in committee of National Policy Unit.

Because the main consideration in this project was the construction of new transmission lines, there are areas where new transmission line construction are not planned depending on the situation of power system construction, the wind farm scales and others. However, these areas include the places where the existing transmission lines are available or the places where small-scale wind farms can be constructed.

So far, there had been no study of planning the transmission lines for wind power generation on a nationwide scale. The result of this project is greatly hoped to be utilized for future transmission line construction.

3.2 Future challenges

Future challenges of this project are as below:

（1） For the future study

1) Installed capacities of power stations or substations were taken or estimated from latest published values. However, it is hoped that more realistic study will be done with future planned values to be taken into consideration. However, the study will become more realistic if future planned values are taken into consideration.
2) In this project, 3 areas with large introduction potential - Hokkaido (Northern Area and Eastern Area), Tohoku, and Kyushu - were set as areas for power system construction study. However, studies for other areas including optimization calculation are desirable to be conducted as well.
3) Only the existing substations were applied as access points in this project. However, because thermal power plants such as oil-fired and LNG-fired are possible for flexible power control, they are desirable to be applied as access points as well.
4) In islands connected to power systems such as Shodoshima Island and Amakusa Islands, there are promising areas for wind power generation. Therefore, these islands are also desirable to be taken into consideration.

（2） For the implementation of construction project

1) Transmission line layout plans were studied base on the promising areas for onshore

wind power generation, which were selected by confirming terrain condition using 1:40000 scale topographic map. However, when implementing projects for wind power generation or transmission line construction, it is necessary to grasp workability, landowner situations and others in the field enough.

2) When implementing projects for wind power generation, it is necessary to conduct field investigations of rare raptors, etc. which could be bypassing conditions when narrowing down the routes.

3) When planning construction of the concrete transmission lines, it is important to consider the way to reduce transmission line construction cost more, by promoting coordination between wind farm construction process and transmission line construction process (e.g., sharing of haul roads, efficient use of construction equipments, sharing of environmental information about rare raptors and others).

(３) About the offshore wind power generation

1) The offshore wind power generation is the developing technology. Therefore, the construction method, the transmission method (AC or DC), the installation plan for transmission lines including offshore substations and others are subjects of future investigation.

2) Considering mainly onshore wind power generation, wind condition data was prepared at 80 m above ground level or sea level in this project. However, as wind turbines for offshore wind power generation are getting larger (e.g., 5 MW, 7 MW), wind condition data on the ocean is desirable to be prepared at about 100 m.