Quantitative analysis for regional potentials of on-grid wind power towards low-carbon electricity sector in Japan

Shuichi ASHINA and Junichi FUJINO
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, JAPAN
E-mail ashina.shuichi@nies.go.jp

(1) Overview

The purpose of this study is to identify regional potentials of on-grid wind power plants in Japan, and to define each utility's role for achieving low carbon electricity sector, based on quantitative evaluation using a multi-regional generation planning model which has been developed to model both distribution of electricity demands and location of power plants. For this purpose, this study looks at changes in capabilities of load frequency control (LFC) by the hour from the year 2000 to 2030. In order to figure the future potentials, it was assumed that the electric utilities in Japan would make a choice between CO_2 reduction scenario and business as usual scenario (BAU, non-CO_2 reduction). The results show that, without any CO_2 reduction strategies (BAU scenario), CO_2 emissions will raise from 86.8 Mt-C in 2000 to 137.9 Mt-C in 2030. However, potentials of on-grid wind power increase to 55 GW, and lead to the 21.6 Mt-C of CO_2 reductions in 2030. Although promoting CO_2 reduction strategies, such as installation of nuclear power and CCS-equipped natural gas combined cycle as newly-built options lead to the drastic reduction of CO_2 emissions in the 2030, both LFC capabilities and potentials of on-grid wind power will drop.

(2) Methods

Regional potentials of on-grid wind power were evaluated based on minimum annual amount of capability of load frequency control (LFC), which was determined both by capacity and by hourly outputs of fossil-fueled power plants. Both capacity and outputs of power plants were set by using a multi-regional optimal generation planning model (Ashina and Fujino, 2008). Fig.1 shows the configurations of the model. In this model, Japan divided by prefecture in to 60 regions. In each region, a single demand node representing electricity demand in that region and multiple power generation nodes representing power plants were established. Between the demand nodes in adjacent regions, hypothetical power transmission lines based on the actual power transmission network were established. The horizon of analysis for the model was from year 2000 to 2030 (each period of five-year length), and the objective function was the minimization of total generation cost during the entire horizon.

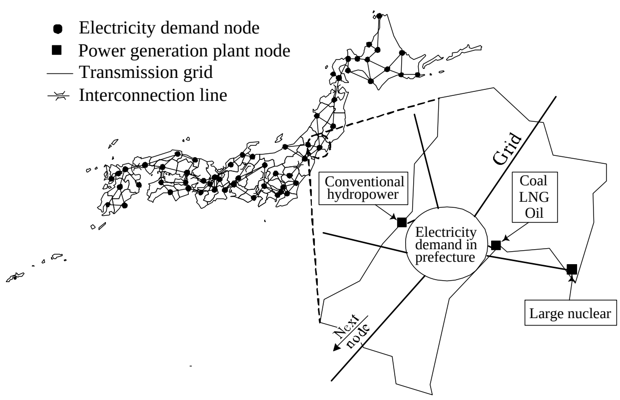

Fig. 1: Schemes for Multi-regional optimal generation planning model

(3) Results

In this study, we have set two scenarios in terms of CO_2 reduction targets. First, as the Business As Usual (BAU) scenario, a scenario in which no restrictions are imposed on CO_2 emissions in the year 2030 in the electricity sector was established. Next, as a CO_2 reduction target for the year 2030, 50 Mt-C, which is half of 1990 level, was introduced.

Table 1 summarizes the results under the BAU scenario from 2000 to 2030. In this scenario, CO_2 emissions continue to increase. From a level of 87.3 Mt-C in 2000, CO_2 emissions increase to 138.0 Mt-C in 2030.

Potentials of on-grid wind power also rise from 26.3 GW in 2000 to 55.0 GW in 2030. If all utilities allow wind generators to connect their grids as always on grid style, the electricity sector offsets 21.6 Mt-C of CO_2 emissions in 2030.

Table 1: Summary of the main results under the BAU scenario

	Total capacity	CO_2 emissions	On-grid wind power		CO_2 reduction potential	Total CO_2 emissions with on-grid wind power
			Potential	% of total capacity		
(Yr.)	(MW)	(Mt-C)	(MW)	(%)	(Mt-C)	(Mt-C)
2000	246,190	87.3	26,260	12.3	17.8	69.5
2005	246,520	94.7	26,680	12.4	19.0	75.7
2010	267,350	108.8	38,510	17.4	23.6	85.2
2015	295,470	125.2	52,540	22.3	21.7	103.5
2020	308,520	130.5	52,320	21.0	20.6	109.9
2025	314,020	133.6	53,060	21.0	20.8	112.8
2030	320,970	138.0	54,970	21.2	21.6	116.4

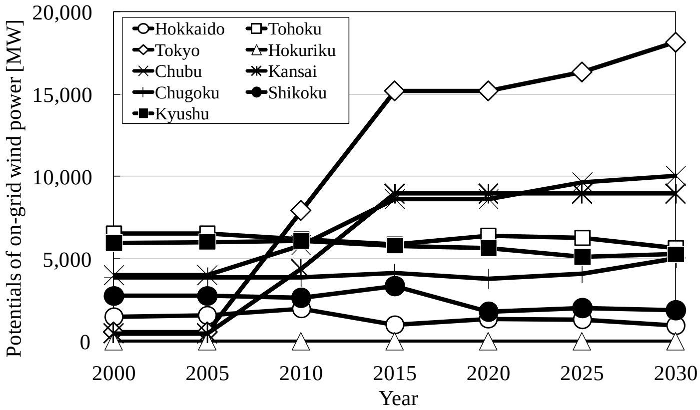

Fig. 2: Potential of on-grid wind power by utility

Figure 2 shows the potentials of on-grid wind power by utility. We see from the figure that potentials of on-grid wind power will increase at area of Tokyo, Chubu and Kansai electric company. In contrast, other utilities keep amount of potentials through analytical periods.

In 50 Mt-C of reduction target scenario, although CO_2 emissions in 2030 declines due to installation both of nuclear power and of CCS-equipped natural gas combined cycle (CCS-NGCC) as newly-built options, potential of on-grid wind power becomes zero. Since nuclear power in Japan are required to operate at full load and have no LFC capabilities, additional nuclear power leads to the cutting the potentials. Output of CCS-NGCC depends on hourly fluctuation of electricity demand and, during both peak and off-peak demand, the plant couldn't keep enough margins for LFC capabilities, resulting in the reduction of the potential.

(4) Conclusions

On-grid wind power would play a key role in achieving low-carbon electricity in Japan. In order to take full advantage of on-grid wind, electric utilities are required to keep certain amounts of LFC capabilities as a countermeasure for mitigation of output fluctuation of wind power. It was found from the results that, if electric utilities do no CO_2 reduction strategies in the future, they could reserve enough LFC capabilities, resulting in the installation of 55.0 GW of on-grid wind, which account for 21% of total capacities in the electricity sector. In contrast, CO_2 reduction strategy in the electricity sector causes the reduction both of LFC capabilities and of the potential of on-grid wind power.

Acknowledement

This research was made possible by a Global Environmental Research Fund (GERF/S-3) of Ministry of the Environment, Japan. The authors would like to thank all who made this research project possible.

References

Ashina, S. and Fujino, J. (2008): "Simulation analysis of CO_2 reduction scenarios in Japan's electricity sector using multi-regional optimal generation planning model", *Energy and Resources*, 29(1), 1-7.