Analysis on the Design of Japan FIT after Fukushima Disaster Using GIS and TIMES Integrated Model

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Abstract: This study aims to illustrate the Japanese electricity supply system after the earthquake with consideration of Japanese uniqueness including its 10 separate grids with weak connections between them and the geographical gap between renewable potential and electricity consumptions using GIS data for a TIMES model. We take FIT (feed-in-tariff) as a policy measure to promote renewables. To consider policies to promote renewables, we need a modelling approach where the electricity system of the entire country is represented with extremely disaggregated information on existing stock and future potentials of renewables. By building up technology models based on detailed disaggregate information on existing stocks and future potentials of renewables at the sub-regional level, we can develop renewables-related policies which reflect more realistic conditions. According to the simulation results, high FIT prices do not guarantee more introductions of renewables. High FIT prices make the huge potential of renewables commercially viable, but at the same time, they limit the maximum introduction of renewables. In addition, a high FIT budget does not guarantee more renewable introduction.

Key words: Energy technology model, renewable energy, nuclear, Japan.

1. Introduction

Nuclear power generated more than a quarter of Japan’s electricity over the past few decades (Fig. 1). More power plants were planned until the beginning of 2011, when the Fukushima disaster eroded people’s confidence in nuclear to the extent that, according to one scenario, all nuclear plants were forced to shut down in 2012. Maintaining a steady electricity supply at reasonable prices is the primary challenge the country faces today.

Among the energy issues facing Japan, energy independence and carbon emissions are two important policy targets. Most fossil fuels are imported and the energy self-sufficiency rate is merely 4% (18% if nuclear power is included) in Japan. The Japanese government aims to increase the self-sufficiency rate from the current 18% (including nuclear) to as much as 40% [1]. In addition, the Japanese government has GHG mitigation targets of 25% below 1990 levels by 2020 and 80% by 2050. Before the earthquake of March 11th, 2011, nuclear was expected to play a major role in achieving energy self-sufficiency and carbon mitigation targets by increasing the availability factor to about 90% and building 14 new nuclear power stations. After the earthquake and the accidents at the Fukushima Dai-ichi nuclear power station, nuclear has become an unacceptable option [2].

The Japanese electricity system is comprised of 10 grids with very limited inter-connection [3]. Further complicating matters is the fact that 3 grids use 50 Hz and 7 grids use 60 Hz [4]. According to the MOE (ministry of the environment) study on the potential of renewable energy in 2011, most potential renewable energy, especially wind turbines, exists in the north-most region, which is far from demand centres [5]. Grid expansion would be an important part of any plan to increase efficiency.
WWF (world wildwife fund) Japan unveiled a proposal for Japan to convert to a 100% renewable energy supply system [6], but the proposal does not consider cost issues, and as a result, the costs of realizing this system are not estimated. The ratio of the sum of PV and wind turbine electricity generation to electricity consumption is expected to be 308.41% in Hokkaido in 2050. To achieve such a high ratio, grid connection expansions are necessary, but the study does not take Japan’s current, uniquely limited grid connections into account.

The NIES (national institute of energy studies) researched a path towards an 80% carbon dioxide reduced society by 2050 [7]. A model used by the study employs very rich information on technologies including renewable energy and demand-side technologies and simulates under least cost conditions. However, no potential and location data of renewable energy and energy consumptions are applied in the model, although renewable potential exists in the north part of Japan and most significant electricity consumption is in the centre of Japan.

This study aims to illustrate the Japanese electricity supply system after the earthquake with consideration of Japanese uniqueness including its 10 separate grids with weak connections between them and the geographical gap between renewable potential and electricity consumptions using GIS data for a TIMES model. We take FIT (feed-in-tariff) as a policy measure to promote renewables.

2. Materials and Methods

2.1 Model Structure

Japan has 10 electricity grids with weak connections between grids as shown in Fig. 2. In addition, there are two different electricity frequencies, 50 Hz and 60 Hz, with frequency converters to convert one frequency to another.

Fig. 3 represents the energy system used in the model. The model focuses mainly on electricity supply, and existing power stations and pumped storage data are included therein. The model assumes conventional power stations (USC (ultra-super critical)), IGCC (integrated gasification combined combustion), GTCC (gas turbine combined cycle), and nuclear) and renewable (biomass, on-shore and off-shore wind turbine, PV (photovoltaic), geothermal and small hydro) as new technologies.
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Fig. 2 47 prefectures with electricity grids and interties.

Fig. 3 Energy system.

USC: Ultra-super Critical
IGCC: Integrated Gasification Combined Cycle
GTCC: Gas Turbine Combined Cycle
2.2 Database

Table 1 shows data sources which were used for the model in this study.

In this model, a year is divided into four seasons: spring (March-June), summer (July-September), autumn (October-December) and winter (January-February), and a day is divided into three sections: day (8-14 h, 16-24 h), peak (14-16 h) and night (0-8 h).

MOE’s renewable potential GIS data contain geological, capacity, and cost information. For example, on-shore wind turbine GIS data includes location (latitude and longitude), wind speed, distance from road, and distance from electricity grid on a 1 km² mesh (Fig. 4). From these data, we calculate capacity, availability factor, investment, and O & M (operational and maintenance) cost and create a new data set as shown in Fig. 5.

For TIMES [8], we make clusters categorised by investment cost and availability factor and the same clusters are applied to each prefecture. The upper limit of capacity installed in each cluster is applied based on the GIS dataset as shown in Fig. 6.

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3. Results and Discussion

The Fukushima disaster has eroded people’s confidence in nuclear to the extent that all of Japan’s nuclear plants were forced to stop operation on May 5th, 2012. In this current situation, renewable energy is expected to play a major role in supplying electricity, and in fact, the Japanese government decided to introduce FIT (feed-in-tariff) in July 2012.

In this study, we have tried to identify the relationship between FIT price and amount of electricity generated by renewables under four budget constraints. Electricity generated by PV is costly compared to other renewable sources, and hence FIT price for PV is set at twice that of other renewables. Maximum FIT prices for PV and other renewables are assumed to be 40 cents/kWh and 20 cents/kWh, respectively, and we have done sensitivity analysis on FIT prices from 10% of maximum price to maximum price under four annual budgets constraints: 5, 10, 15 and 20 billion USD.

In all budget constraints except 5 billion USD, electricity generation by renewables peaks at 20% of maximum FIT price and sees a sharp drop afterward.

| Categories                  | Description                                      | Sources                                                                 |
|-----------------------------|--------------------------------------------------|-------------------------------------------------------------------------|
| Existing power stations     | Capacity, generation                             | Agency for natural resources and energy, Overview of electricity demand and supply 2009 (Japanese source) |
|                            |                                                  | Federation of Electric Power Companies of Japan, Handbook of electricity business 2010 (Japanese source) |
| Power stations under construction | Capacity                                   | Agency for natural resources and energy, Prefecture energy consumption statistics, Institute of Energy Economics |
| LNG port                    | Capacity                                         | Tex Report, Gas Annual Report 2010 (Japanese Source)                     |
| Renewable energy            | On-shore wind turbine, off-shore wind turbine, PV, geothermal, small hydro | Ministry of the environment (2011), Survey on potential of renewable energy |
|                            | Biomass                                          | NEDO (new energy and industrial technology development organization), Biomass potential and available biomass estimation (Japanese source) |
|                            | Potential                                        | IEA (international energy agency), World Energy Outlook 2008             |
|                            | Cost                                             | IEA (international energy agency), World Energy Outlook 2008             |
| Conventional power generation | Coal, gas, oil, nuclear and hydro               | Agency for natural resources and energy, Prefecture energy consumption statistics (Japanese source) |
| Electricity consumption     | Electricity consumption by prefecture            | Federation of Electric Power Companies of Japan, Nuclear and Energy Drawings (Japanese source) |
Fig. 4  Offshore/onshore wind and geothermal potential on a 1 km² grid.

Fig. 5  MOE GIS data and new data.
With the 5 billion USD budget constraint, the amount of electricity generated by renewables decreases as the FIT price increases.

Under a fixed FIT budget, there is no linear relationship between FIT price and electricity generation by renewables. There is no guarantee that a higher FIT price leads to more electricity generation by renewables. 20% of FIT maximum price under a
billion USD budget is expected to generate more electricity from renewable sources than 50% of FIT maximum price under 20 billion USD budget (in Fig. 7).

Under FIT budget constraint, we allow grid expansion. Fig. 8 shows the benefits of grid expansion and by allowing grid expansion, more renewables are to be introduced, which means grid expansion make possible to access to cheap renewable potentials.

Table 2 illustrates comparison of electricity generation by renewable technology between no grid expansion and grid expansion scenarios. Fig. 9 shows on-shore wind generation by prefecture under 10bnUS$ FIT budget constraint and 30% of FIT price in 2020. Allowing grid expansion makes it possible to access to cheap on-shore wind potential in Hokkaido.

Japan has 10 electricity grids with poor inter-connectivity. The demands and renewable resource potentials in each grid region are shown here. Regions with high wind potential are located far from regions with high demand. Solar is better distributed but the potential is small (Fig. 10).

In most simulation models such as top-down and bottom-up models, one electricity generation technology has only one set of technology descriptions, for example, capital cost, O & M cost and availability factor. However, in this model, one renewable technology has combinations of capital cost and availability factor for wind-turbines and potential for wind-turbines at the prefectural level.

The cost of electricity generation by renewables, such as wind-turbines, differs by region, because wind-speed and distance from electricity grid and road differ by region.

4. Conclusions

After the earthquake and Fukushima Dai-ichi Nuclear Power Station accident, the Japanese government has to review energy and environmental policy. Before the earthquake, nuclear was expected to increase its share in total electricity supply by building new nuclear power stations and increasing their availability factor. Under current situations, it is very unlikely that this will happen, and Japanese energy and environmental policies will shift from nuclear to renewables. In fact, the Japanese government decided to introduce FIT in July, 2012. To consider policies to
promote renewables, we need a modelling approach where the electricity system of the entire country is represented with extremely disaggregated information on existing stock and future potentials of renewables.

By building up technology models based on detailed disaggregate information on existing stocks and future potentials of renewables at the sub-regional level, we can develop renewables-related policies which reflect more realistic conditions.

In this study, we have taken FIT as a renewable political measure and done sensitivity simulations on FIT using the above model. High FIT prices do not guarantee more introductions of renewables. High FIT

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**Table 2  Electricity generation by renewable under 10bnUS$ FIT budge constraint and 30% of FIT price in 2020.**

| Electricity generation (TWh) | With GE | Without GE | Differences |
|-----------------------------|---------|------------|-------------|
| Biomass                    | 24.9    | 19.4       | 5.5         |
| Geothermal                 | 10.4    | 4.6        | 5.9         |
| Small hydro                | 30.9    | 27.2       | 3.8         |
| PV                         | 0.0     | 0.0        | 0.0         |
| Offshore wind              | 27.7    | 33.8       | -6.1        |
| Onshore wind               | 117.8   | 85.1       | 32.7        |

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**Fig. 9  On-shore wind generation by prefecture under 10bnUS$ FIT budge constraint and 30% of FIT price in 2020.**

**Fig. 10  Electricity demand and wind potential.**
prices make the huge potential of renewables commercially viable, but at the same time, they limit the maximum introduction of renewables. In addition, a high FIT budget does not guarantee more renewable introduction. Twenty percent of FIT maximum price under a 10 billion USD budget is expected to generate more electricity from renewable sources than 50% of FIT maximum price under a 20 billion USD budget.

In designing FIT, we need to use a detailed disaggregated model, like the model we used for this study, as an evaluation tool and do sensitivity analysis of the combinations of FIT price and budget to discover the cost effectiveness of different combinations.

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