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System Analysis of Japanese Renewable Energy

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Abstract

Nuclear power generated more than a quarter of Japan's electricity over the past few decades. The Fukushima disaster eroded people's confidence in nuclear to the extent that all nuclear plants may be forced to shut down by the end of 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. Japan imports most of its fossil fuels and its energy self-sufficiency rate is a mere 4% (18% if nuclear power is included). The Japanese government aims to increase the self-sufficiency rate from the current 18% (including nuclear) to as much as 40%. In addition, the government has GHG mitigation targets of 25% below 1990 levels by 2020 and 80% by 2050[1]. Before the earthquake of March 11, 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. Hence, renewables are expected to play a major role. The Japanese electricity system is comprised of 10 grids with very limited inter-connection. Further complicating matters is the fact that 3 grids use 50Hz and 7 grids use 60Hz. The uniqueness of Japan's electricity market and the instability of a renewable-generated electricity supply will be big burdens to making the most use of renewable potential in Japan. The objective of this paper is to characterise the renewable potential in Japan and to study its interactions with competitors under some key policies and technology scenarios.

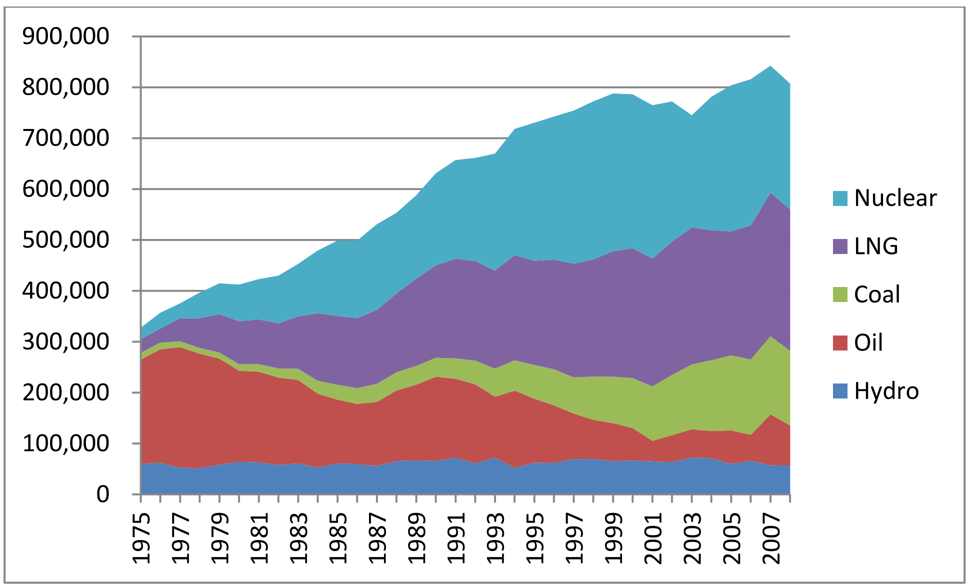
Key Words: Renewable, Nuclear, Technology Model

[1] The carbon mitigation target was set by the previous DPJ administration and at present, new target/mitigation actions have been under review by the current LDP.

CONTENTS

Introduction

Nuclear power generated more than a quarter of Japan's electricity in the past few decades (Figure 1). More power plants were planned till the beginning of 2011. However the Fukushima disaster has eroded people's confidence in Nuclear to the extent that in one scenario, all the nuclear plants may be forced to shut down by the end of 2012. Maintaining a steady electricity supply, at reasonable prices, is the first challenge the country faces today.



Source: The Institute of Energy Economics (2011), Handbook of Energy & Economic Statistics in Japan

Figure 1: Japanese Electricity Structure (million kWh)

To discuss energy issues in Japan, energy independence and carbon emissions are two important policy targets. Most of fossil fuels are imported and energy self-sufficiency rate is mere 4% (18% if include nuclear power) in Japan. Japanese government aims to increase the self-sufficiency rate from current 18% (includes nuclear) to some 40%. In addition, Japanese government has GHG mitigation targets, 25% below 1990 by 2020 and 80% by 2050. Before the earthquake occurred on 11th March, 2011, nuclear was expected major role to achieve energy self-sufficiency and carbon mitigation targets by increasing availability factor to about 90% and 14 new nuclear PowerStations. After the earthquake and Fukushima Dai-ichi nuclear PowerStation accidents, nuclear has become an unacceptable options.

Japanese electricity system comprises 10 grids with very limited inter-connections. Further complication is that 3 grids use 50Hz and 7grids use 60Hz. According to Ministry of the Environment (MOE) study on the potential of renewable energy in 2011, most renewable potential, especially wind turbine, exists in the north-most region that is far from demand centres. Grid expansion would be an important part of the efficient plan.

After Fukushima disaster, many countries have started to review their energy policy. In general, countries which rely on import fuels are active player to promote nuclear power same as Japan. In addition, nuclear are expected as a key technology to reduce carbon emissions. Japan is not a unique case, many countries may face similar situations in foreseeable future. It is not a sustainable option to keep dependent on fossil fuels.

The world is now watching Japan; no longer able to depend upon nuclear power, how it can raise its energy self-sufficiency ratio and reduce its GHG while maintaining the highest energy efficiency in the world.

Model Structure

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

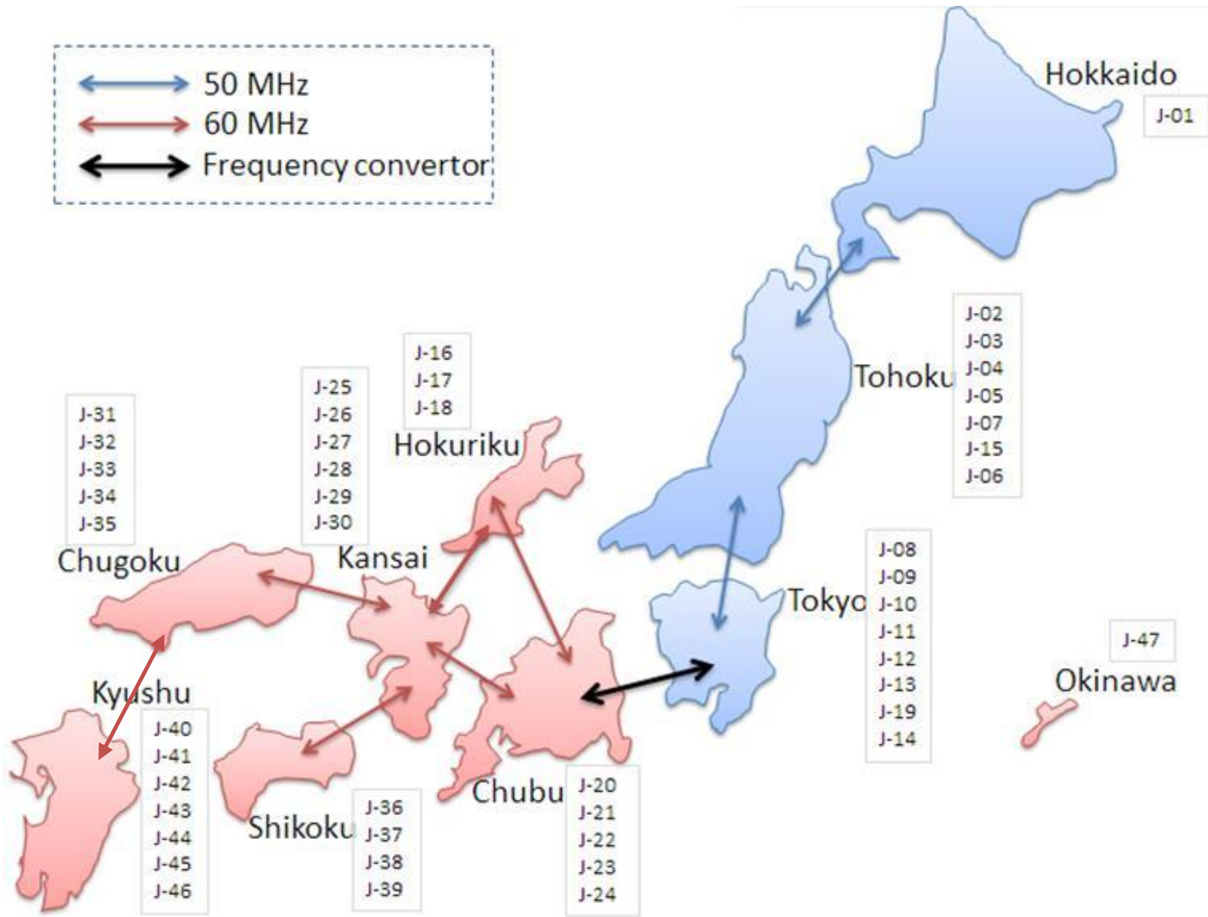


Figure 2: 47 prefectures with the electricity grids and interties

Figure 3 represents the energy system of the model. The model focuses mainly on electricity supply and existing PowerStation and pumped storage data are in the model. As new technologies, the model assumes conventional PowerStation (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, photovoltaic (PV), Geothermal and small hydro).

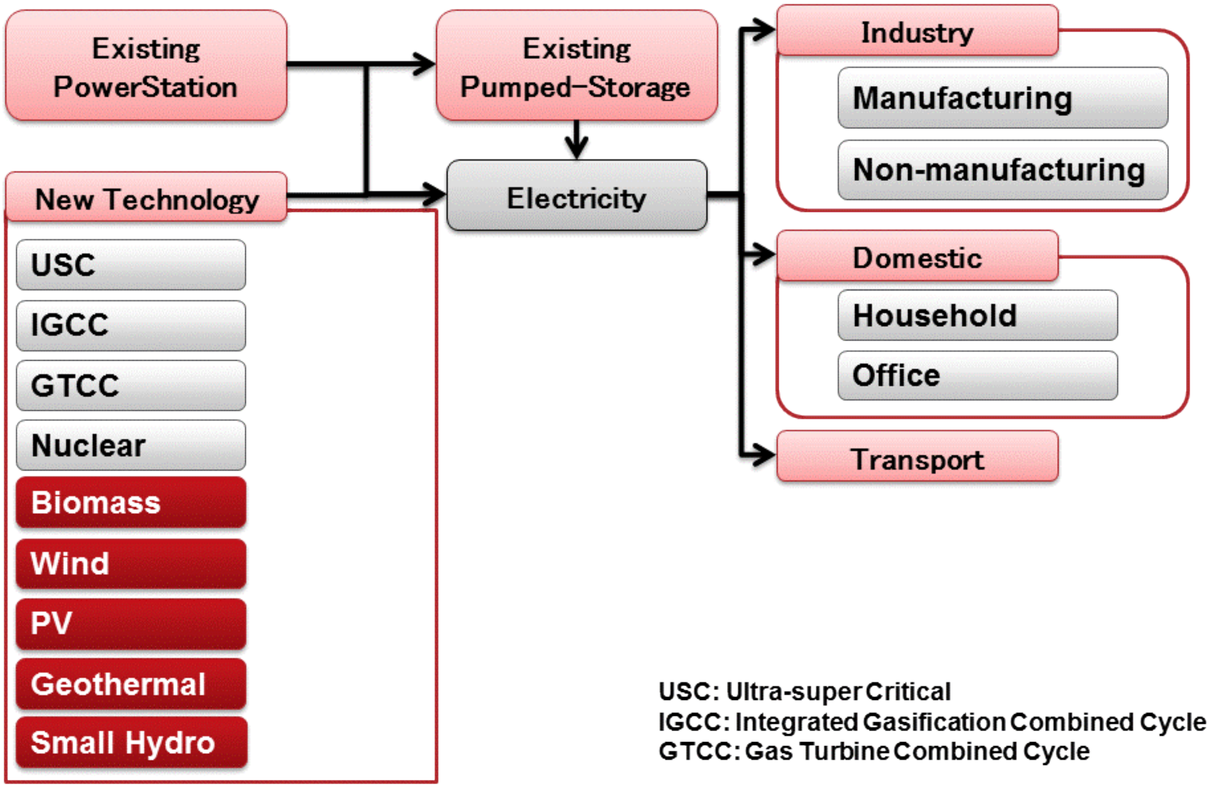


Figure 3: Energy Systems

Model data

Table 1 is data sources which are used for the model used for this study.

Table 1: Data Sources

Categories		Description	Sources
Existing PowerStation		Capacity, Generation	Agency for Natural Resources and Energy, Overview of Electricity Demand and Supply 2009[2] Federation of Electric Power Companies of Japan, Handbook of Electricity Business 2010[3]
PowerStation 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[4]
Renewable Energy	On-shore Wind Turbine, Off-shore Wind Turbine, PV, Geothermal, Small Hydro	Potential and Cost	Ministry of the Environment (2011), Survey on Potential of Renewable Energy,
	Biomass	Potential	New Energy and Industrial Technology Development Organisation (NEDO), Biomass Potential and Available Biomass Estimation[5]
		Cost	International Energy Agency (IEA), World Energy Outlook 2008
Conventional Power Generation	Coal, Gas, Oil, Nuclear and Hydro	Cost	International Energy Agency (IEA), World Energy Outlook 2008
Electricity Consumption		Electricity Consumption by Prefecture	Agency for Natural Resources and Energy, Prefecture Energy Consumption Statistics[6]
Electricity Load Curve			Federation of Electric Power Companies of Japan, Nuclear and Energy Drawings[7]

[2] 経済産業省資源エネルギー庁電力・ガス事業部編、「電力需給の概要　2009」

[3] 電気事業連合会統計委員会編、「電気事業便覧」（平成 22 年版）

[4] テックスレポート、「ガス年鑑」（2010 年版）

[5] 新エネルギー・産業技術総合開発機構、「バイオマス賦存量・有効利用可能量の推計」

[6] 経済産業省資源エネルギー庁、「都道府県別エネルギー消費統計」2009 年度版、http://www.enecho.meti.go.jp/info/statistics/regional-energy/index.htm

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, Day (8 - 14hr, 16-24hr), Peak (14-16hr) and Night (0-8hr).

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, distances from road and distance from electricity-grid on 1 sq km mesh (Figure 4). From these data, we calculate capacity, availability factor, investment and operational and maintenance (O&M) cost and create new data set as shown in Figure 5.

[7] 電気事業連合会、「原子力・エネルギー図面集」

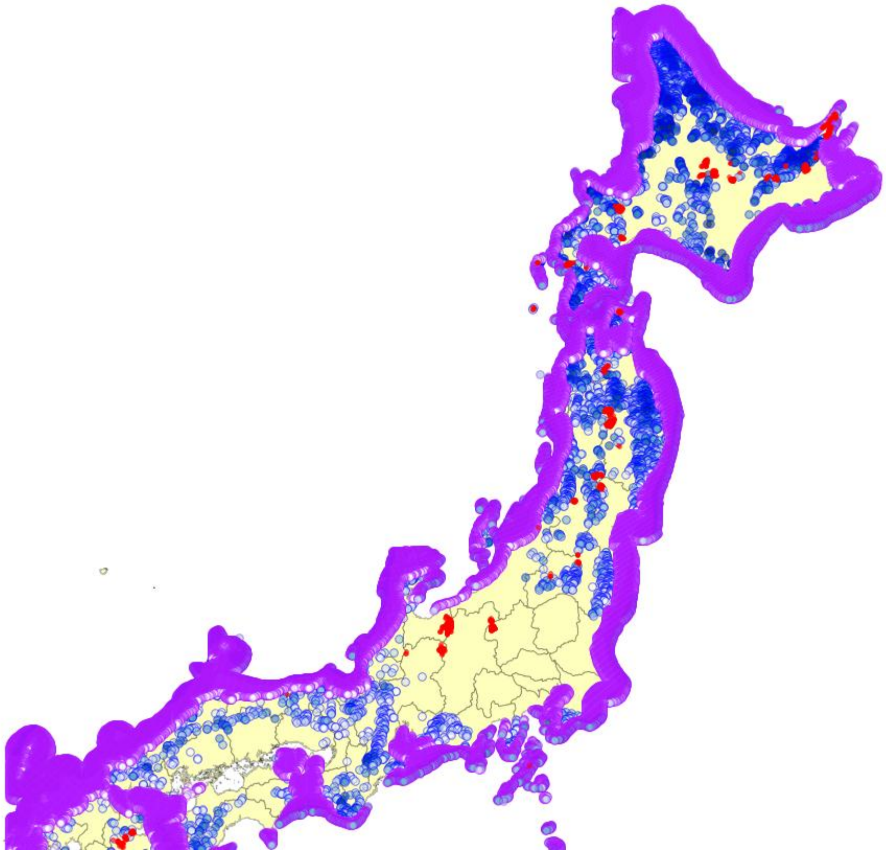


Figure 4: Offshore/onshore wind and geothermal potential on a 1 sq km mesh

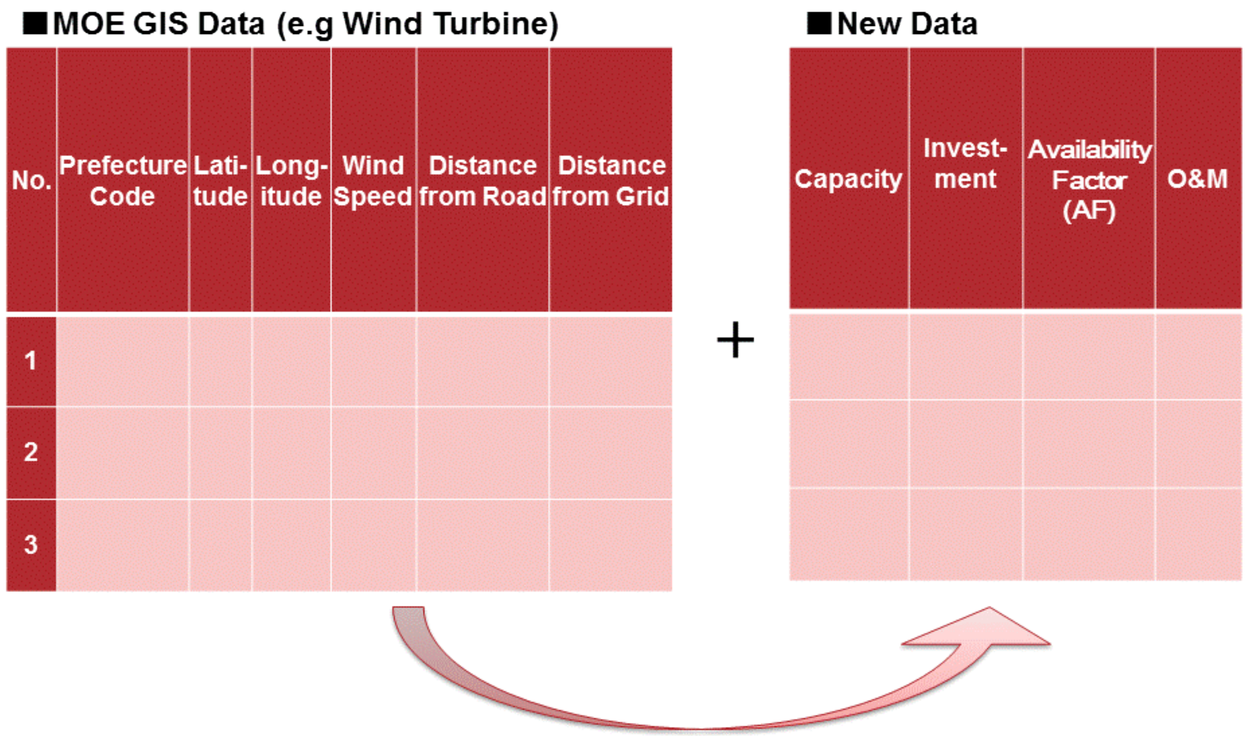


Figure 5: MOE GIS Data and New Data

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

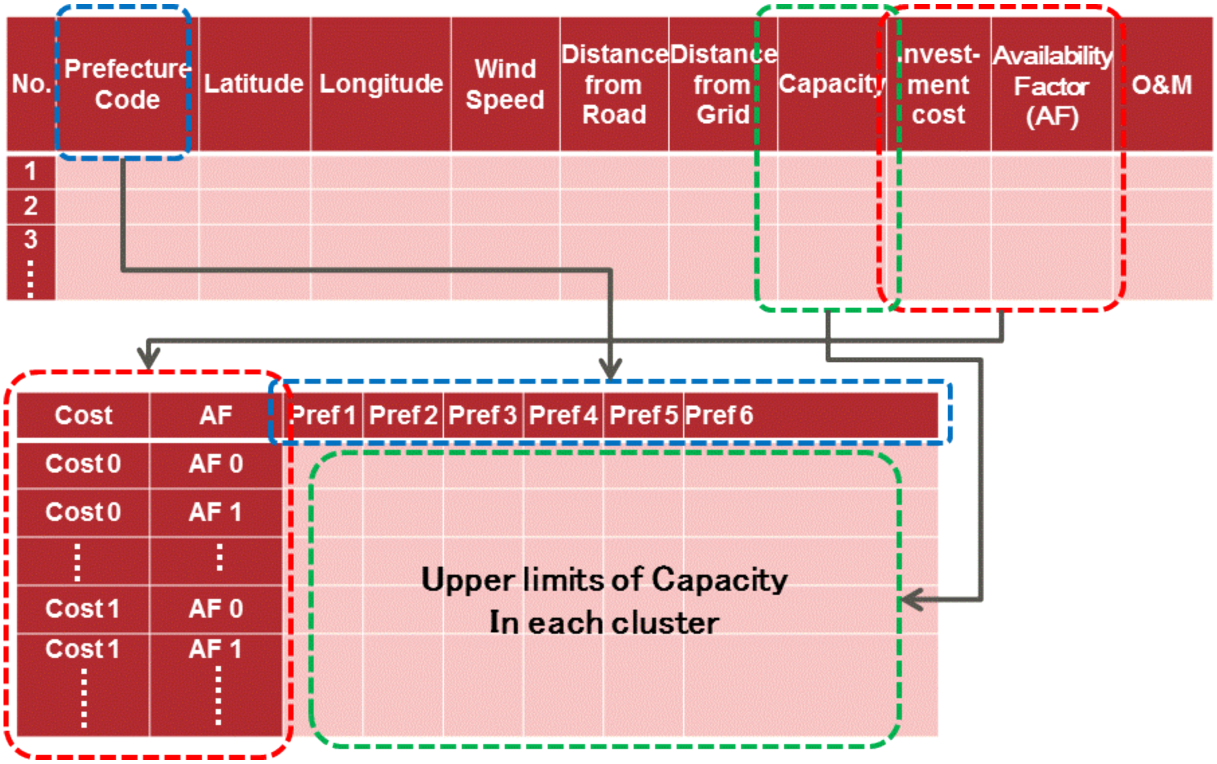


Figure 6: Conversion GIS data to TIMES

In the most of technology (or bottom-up model), one technology has only one technology information, for example, investment cost and availability factor.

Simulation Design

CCS, biomass and renewable can help in the climate objective. However, renewable is the only option that would take Japan towards self-sufficiency.

The objective of this paper is to characterise the renewable potential in Japan and to study its interactions with competitors under some key policies and technology scenarios.

These supply curves shown in Figure 7 have been computed using used 1km2 mesh GIS data for onshore and offshore wind, and for solar PV. More than 1000 Twh seems be available for well under 15 cents/kwh based on this figure. However these costs and availabilities ignore very important spatial and temporal issues, which we propose to address using systems analysis.

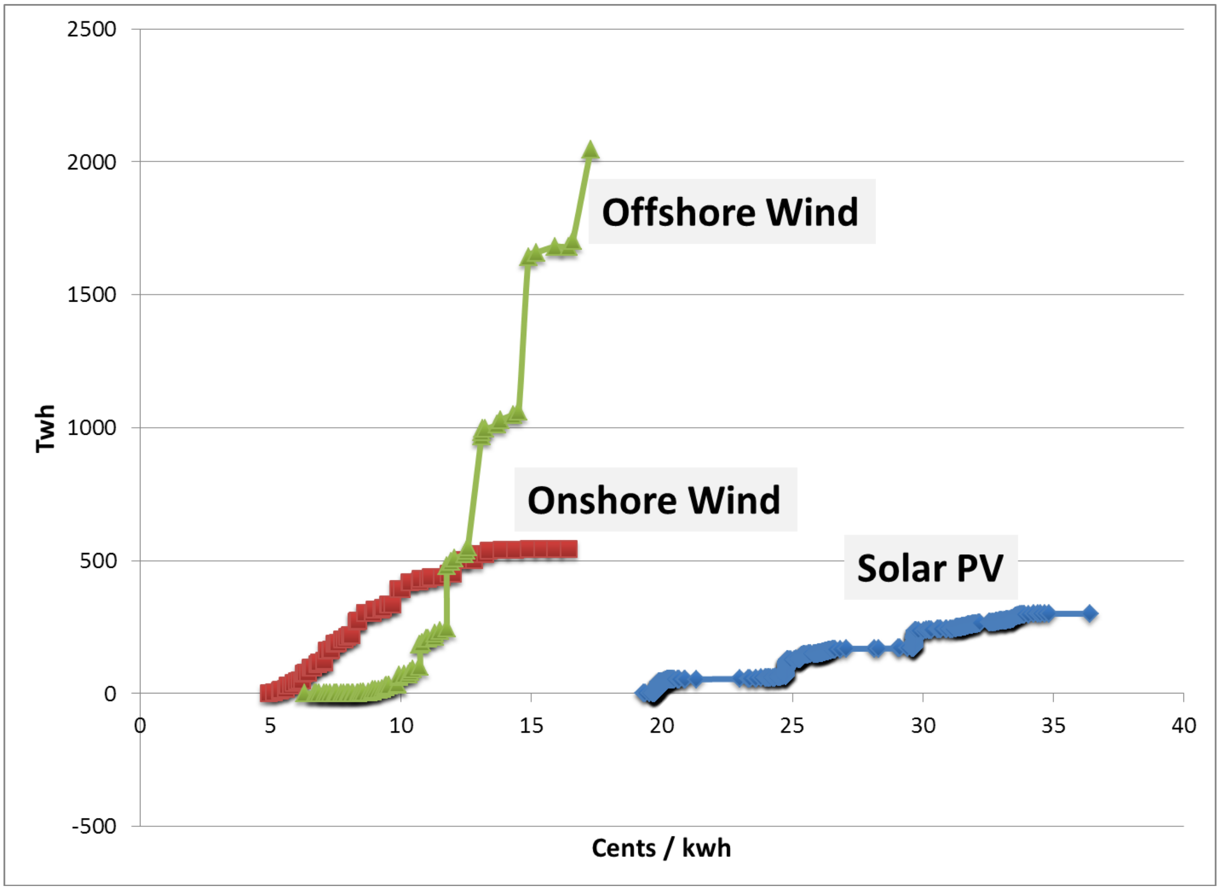


Figure 7: Supply Curves of Onshore and Offshore Wind and Solar PV

We start with highly disaggregated GIS data for onshore and offshore wind. An appendix will describe how this was interpreted. Estimates of roof top solar PV supply, disaggregated into three types - , comes from a government survey (MOE 2011).

There are two main reasons why the actual availabilities would turn out lower and prices would turn out higher, than what is shown above:

- The Japanese electricity system comprises 10 grids that have very poor interconnections. While the costs of connecting to the regional grids are included in above estimates, the cost of increasing inter-regional connections is not. We can see from Figure that renewable potential is not sufficiently high on the grids that have high demands. So, using the lower part of the above curves necessitates grid expansion.
- The above prices assume full utilization of power when it is available. However, due to seasonal and diurnal variation in demands, this is not possible and the actual utilization turns out lower than the potential.

Japan has 10 electricity grids with poor inter-connectivity. The demands and renewable resource potential in each grid region is shown in Figure 8. Regions with high wind potential are located far from regions with high demand. Solar is better distributed but the potential is small.

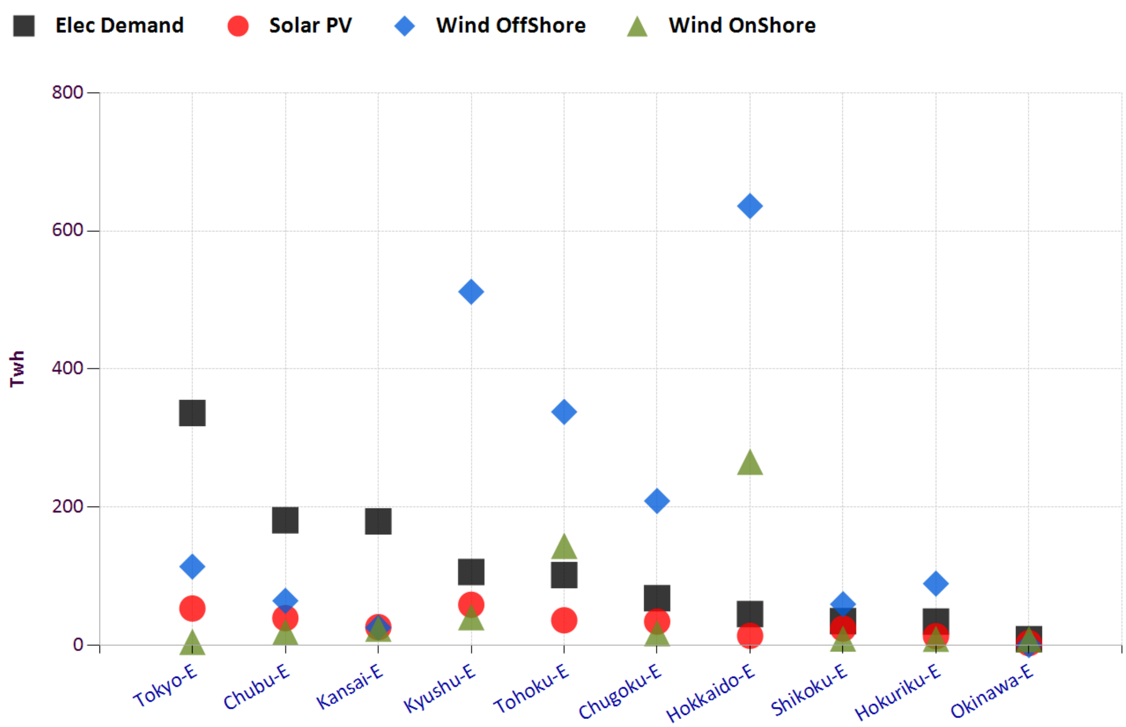


Figure 8: Renewable Potential Resources in Grid Region

We use the following scenario design to study the possible role of renewable electricity in Japan:

Table 2: Scenario Design

	Grid Expansion	CCS Availability	Storage Technology[8]
Ref	No	Yes	No
GE	Yes	Yes	No
GE NCCS	Yes	No	No
GE NCCS Sto	Yes	No	Yes

[8] Unlimited availability of a $2000/kw technology with storage EFF of 75% and charge/discharge rates suitable for day-night storage.

Nuclear power is discontinued starting in 2013 in each of these scenarios. 10 levels of CO2 prices ($100/ton CO2 to $1000, in equal steps) have been used in each scenario, to trigger low emission configurations.

These scenarios have been run on the Japanese multi-region TIMES model (JMRT) that works at the prefecture level. Existing power plants are modelled at the unit level, including life-extension options. The prefectures that are on the same grid trade freely among themselves. The existing inter-grid connections are represented via trade links in the model. New connections are possible at $200/kw when grid expansion is allowed. The renewable characterization has been done at the prefecture level.

Grid expansion almost doubles the onshore wind deployment and At this point, it is more competitive than CCS, as removing CCS does not draw more onshore wind.

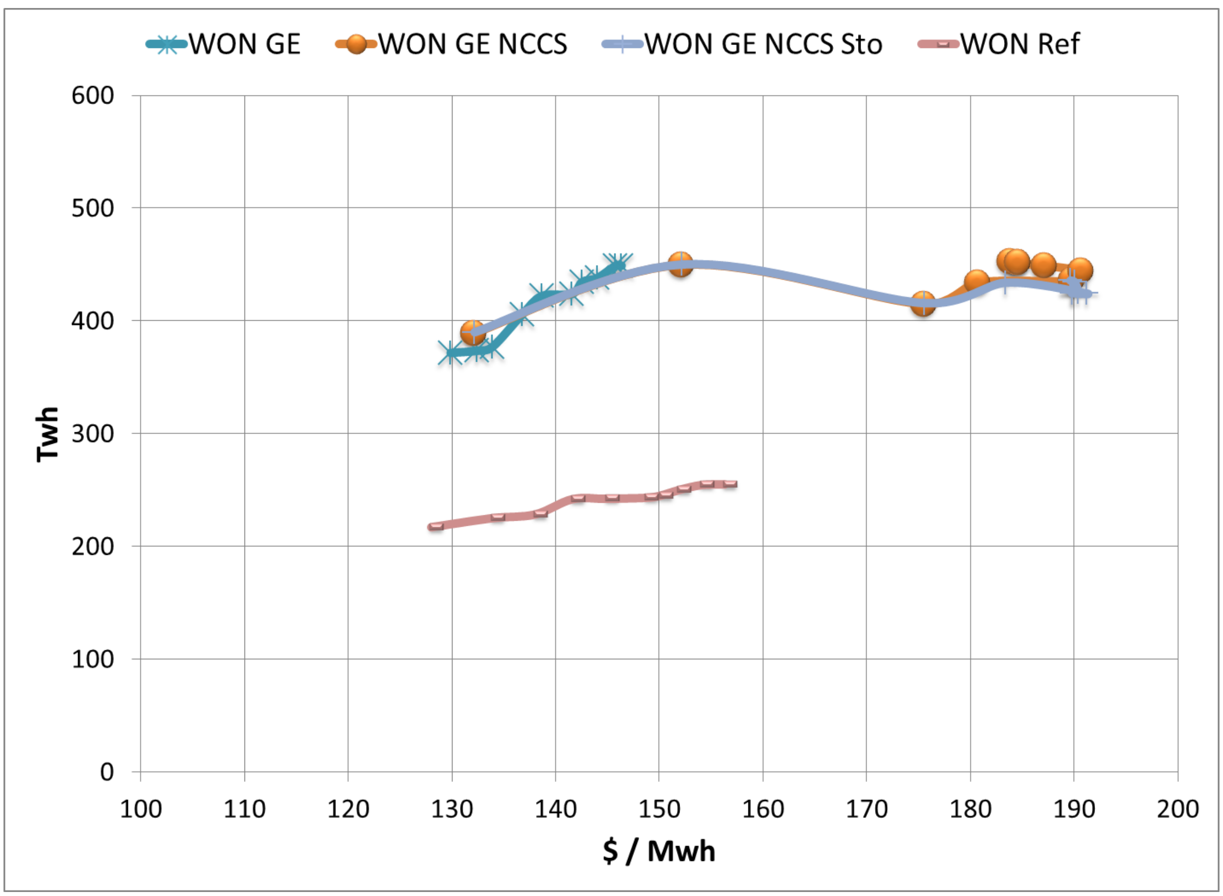


Figure 9: Penetration of onshore wind in 2040 under 4 scenarios

Grid expansion has a similar but smaller impact compared to onshore wind. This is partly because offshore wind is distributed more evenly compared on onshore, which is almost entirely in Hokkaido – the northern tip of Japan. Offshore wind competes with CCS and no CCS almost doubles the penetration. Storage adds another 100 Twh under extreme configurations.

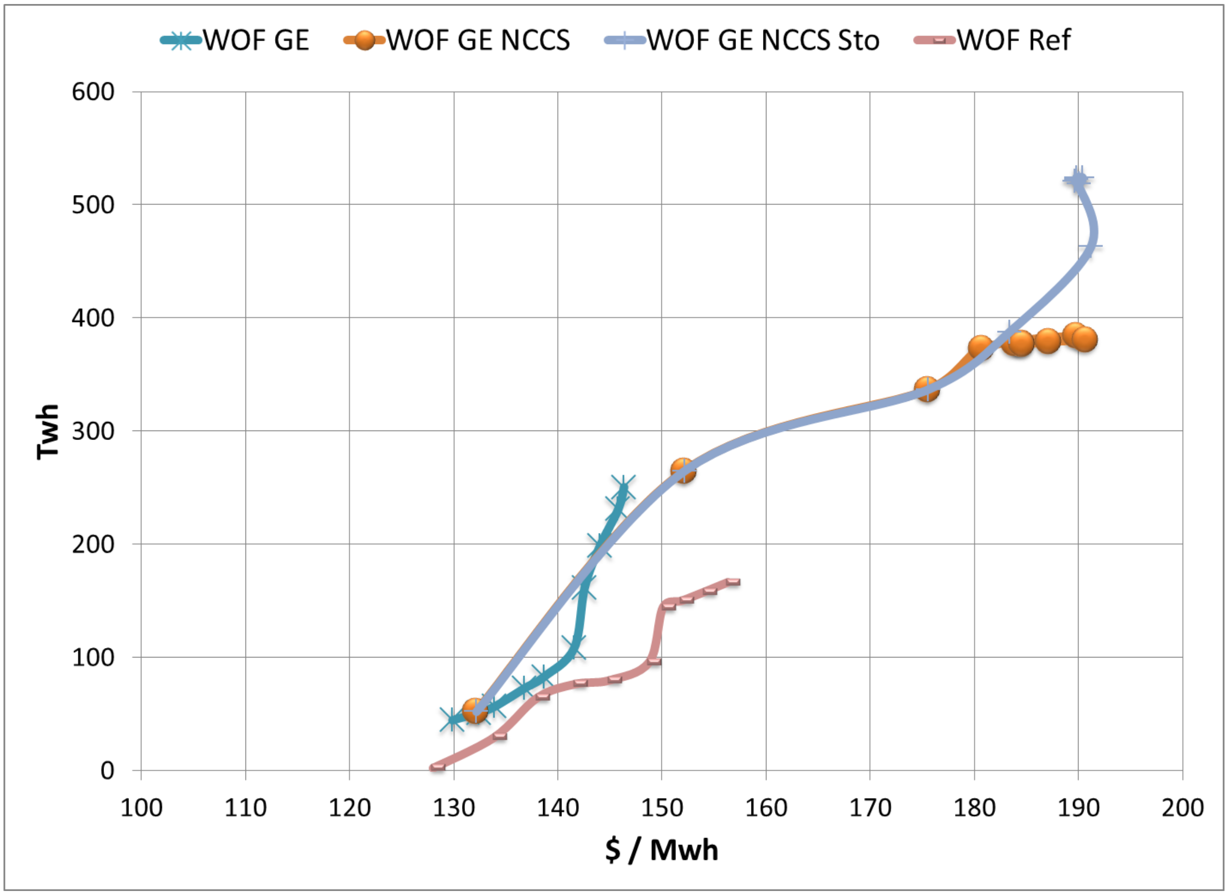


Figure 10: Penetration of offshore wind in 2040 under 4 scenarios

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