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Can Japan Improve on its INDC-based Target for CO_2 Intensity in the Electricity Sector?

Estimation of Renewable Electricity and Nuclear Power in 2030

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Key Findings

- On the assumption that the interconnection capacity of the current grid, comprising ten separate electricity systems, remains unchanged, the CO_2 intensity of the electricity sector could be reduced to 0.36 $kgCO_2$/kWh. This would be achieved through 334 TWh generated from renewable energy sources (representing about 40 percent of Japan's total renewable electricity potential) and 130 TWh from nuclear power (Scenario A). Adding 46 TWh of offshore wind power would further reduce the intensity to 0.34 $kgCO_2$/kWh (Scenario B). (See Table below)
- The electricity sector emissions intensity of 0.36 $kgCO_2$/kWh is equal to the intensity that can be calculated to result from the emissions intensity of fossil-fuel power technology and the energy mix that is targeted in Japan's Intended Nationally Determined Contribution (INDC). This is slightly lower than the voluntary emission intensity target put forward by electricity power companies, which is 0.37 $kgCO_2$/kWh.

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- The opportunity exists to further promote the use of renewable electricity in Hokkaido and Tohoku, sites of high wind power potential, but this would require expanding the grid interconnection capacity from Hokkaido to Tohoku as well as from Tohoku to Tokyo. It would also require the development of offshore wind power and solar power sites close to large electricity consumption areas served by the Tokyo grid or Kansai grid system.
- In addition, investment in technologies to stabilize the electricity system, for example, storage batteries, pumped storage hydropower, and electric vehicle batteries (EVB), would be necessary to enhance renewable electricity capacity especially in Hokkaido and Tohoku. This would entail consideration of issues such as investment costs, as well as effective disposal and treatment of wastes.

Table of Renewable Electricity and Nuclear Power in 2030

	Grid-connected electricity from renewables [TWh], (Share of 1,065 TWh)	Grid-connected electricity from nuclear power plants [TWh], (Share of 1,065 TWh)	CO_2 emissions intensity of electricity in 2030 [kgCO_2/kWh]	CO_2 emissions from electricity sector in 2030 [Mt CO_2]
INDC	234-256 (22-24%)	213 – 234 (20-21%)	0.36	383
Voluntary target	NA	NA	0.37	NA
Scenario A:	334 (31%)	130 (12%)	0.36	389
Scenario B:	380 (36%)	130 (12%)	0.34	361

Abstract

This paper assesses the potential for improving the CO_2 intensity of Japan's electricity sector—the units of carbon dioxide emitted per units of electricity generated—by examining the potential for the feasibility of restarting nuclear power plants and increasing renewable electricity generation by 2030. The analysis shows that, utilizing these two strategies, it is possible to achieve the intensity that can be calculated from the emissions intensity of fossil-fuel power technology and the energy mix of Japan's Intended Nationally Determined Contribution (INDC), and to exceed the voluntary emissions-intensity target announced by Japan's electricity companies, under the current level of investment in electricity grid facilities. The paper focuses only on the energy mix in the generation projected for 2030, using total electricity generation estimates in the INDC and electricity demand estimates from the Long-term Energy Supply and Demand Outlook (LTESDO).

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Abbreviations and Acronyms

AMeDAS	Automated Meteorological Data Acquisition System
ANRE	Agency for Natural Resources and Energy
BWR	Boiled Water Reactor
CO_2	Carbon dioxide
DBJ	Development Bank of Japan
EIA	Energy Information Administration
EVB	Electric Vehicle Batteries
FEPC	Federation of Electric Power Companies
FIT	Feed-in Tariff
GHG	Greenhouse gas
GIS	Geographic Information System
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
INDC	Intended Nationally Determined Contribution
JOGMNC	Japan Oil, Gas and Metals National Corporation
JWPA	Japan Wind Power Association
LTESDO	Long-term Energy Supply and Demand Outlook
MAFF	Ministry of Agriculture, Forestry and Fisheries
METI	Ministry of Economy, Trade and Industry
MILT	Ministry of Land, Information, Transport and Tourism
MOE	Ministry of the Environment, Japan
NEDO	New Energy and Industrial Technology Development Organisation
NRA	Nuclear Regulation Authority
OCN	Open Climate Network
PIRR	Project Internal Rate of Return
PV	Photovoltaics
PWR	Pressurized Water Reactors
RPS	Renewable Portfolio Standard
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
WACC	Weighted Average Cost of Capital
WRI	World Resources Institute

01 Background and Objectives

The CO_2 intensity of electricity in Japan from 1996 to 2002 was about 0.35–0.38 kgCO_2/kWh. It gradually worsened from 2003 to 2007, due to the use of coal-fired and gas-fired plants to meet electricity demand. The electricity landscape underwent a drastic change in 2011 following the Fukushima Daiichi nuclear power plant accident—after which almost all nuclear power plants were shut down. Electricity supply from gas-fired and oil-fired plants increased by 38 per cent and 86 per cent, respectively, to compensate for the reduction in nuclear power generation (figure 1). As a result, in 2012, the CO_2 intensity of electricity rose to 0.57 kgCO_2/kWh, the highest level in the last two decades.

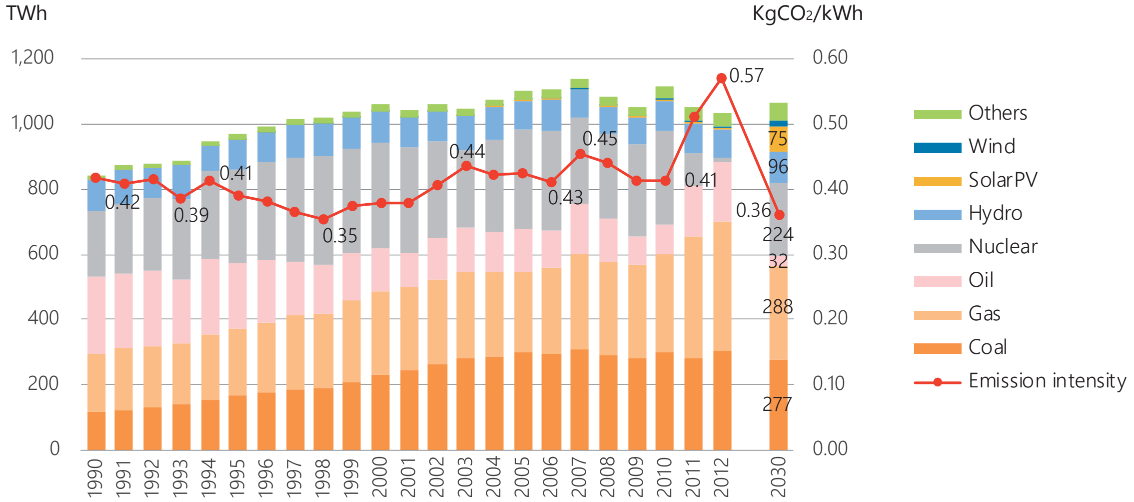

Figure 1. Electricity Generation by Source and CO_2 Intensity of Electricity
Source: FEPC (2014); METI (2015a); UNFCCC (2015)

It is in this context that the Intended Nationally Determined Contribution (INDC) submitted by the Government of Japan in July 2015 under the United Nations Framework Convention on Climate Change (UNFCCC) proposed a 26 per cent reduction in CO_2 emissions by 2030 relative to 2013 levels (equal to a 25.4 per cent reduction from 2005 levels) (UNFCCC 2015). The INDC specifies an intended 2030 electricity mix of: 20–22 per cent from nuclear, 26 per cent from coal, 3 per cent from oil, 27 per cent from natural gas, and 22–24 per cent from renewables. Although the INDC states the intended electricity mix in 2030, it does not mention a CO_2 emissions intensity target for electricity. On the same day that the INDC was submitted, however, 35 electricity companies (covering 99% of electricity sales in Japan) jointly announced an intensity target of 0.37 kgCO_2/kWh by 2030, as a voluntary action plan (FEPC 2015).

Neither the INDC nor the electricity company voluntary target clearly indicates how Japan will achieve the 2030 targets. There are plans to construct a large number of coal-fired plants that may negatively impact not only the 2030 electricity CO_2 intensity but also other longer-term targets, such as achieving an 80 per cent reduction in Japan's GHG emissions by 2050. It is important to examine energy investment plans for the national energy mix based on a long-term perspective and strategies aimed at reducing CO_2 emissions in 2030. Therefore, to promote discussion of an appropriate policy framework, this paper provides an analysis of how much of Japan's electricity supply in 2030 could be generated by renewable and nuclear energy, in order to improve the electricity sector's CO_2 emissions intensity. This paper aims to assess the feasibility of restarting nuclear electricity plants and the potential for renewable electricity in Japan in 2030.

It focuses only on the energy mix in the electricity sector, and disregards electricity demand. The paper uses total electricity generation estimates from the INDC and electricity demand estimates from Long-term Energy Supply and Demand Outlook (LTESDO) (METI 2015b),[1] although the authors are aware of the potential to reduce the final electricity demand compared to LTESDO. An analysis of the electricity demand reduction potential will appear in a subsequent study.

The paper is structured as follows. Section 2 examines Japan's INDC and the voluntary target announced by electricity companies. Section 3 identifies the feasible capacity of nuclear-powered electricity in 2030 if plants were to be restarted by 2030. Section 4 examines the feasible capacity of renewable electricity in 2030 and identifies the gap between potential renewable electricity generation and electricity demand in an electricity utility area[2] under the current electricity system. Section 5 examines the electricity supply-demand balance in 2030 based on the results of the analyses in the preceding sections. It also assesses how to balance electricity supply and demand in regions given the constraints of interconnection grid capacity in Japan's present electricity systems, as well as the minimum electricity supply needed from fossil-fuel power plants to stabilise the electricity system. A conclusion then summarizes the analysis presented in this paper.

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[1] The INDC is based on the result of LTESDO.

[2] In line with Japan's electricity system, the ten electricity utility supply and distribution areas (under the responsibility of Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, Kyushu, Okinawa Electricity Power Companies) are called regions in this paper ("Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, Kyushu, Okinawa regions").

02 INDC and Voluntary Target of Electricity Companies

According to Japan's INDC energy mix target, electricity supply from fossil-fuel power plants will be 596 TWh (of 1,065 TWh total electricity generation). The INDC provides no estimate of CO_2 electricity emissions intensity; however, on the basis of the projected energy mix we estimate it to be 0.36 $kgCO_2/kWh$ in 2030 (see Appendix 1 for the equation). However, 0.36 $kgCO_2/kWh$ will be feasible only if fossil-power plants operating for more than 40 years in 2030 are replaced with more efficient new power plants. (25% of existing fossil fuel power plants will have reached their 40-year life expectancy by 2030, and it is assumed these will be replaced with new power plants (2020 plant model) shown in Appendix 1.) If fossil-fuel power plants were to operate beyond their 40-year life expectancy, the emissions intensity would be an estimated 0.375 kgCO2/kWh in 2030. As of 2013, 20 per cent of fossil-fuel power plants in Japan had surpassed 40 years of operations (METI 2014a).

At an intensity level of 0.36 $kgCO_2/kWh$, CO_2 emissions from electricity in 2030 will be 214 $MtCO_2$ (total CO_2 emissions in the INDC are projected to be 972 $MtCO_2$). If the CO_2 emissions intensity of electricity is 0.37 $kgCO_2/kWh$—the voluntary target proposed by the the electricity companies— CO_2 emissions will be 221 $MtCO_2$. However, as mentioned above, to achieve the target indicated in the INDC and voluntary reduction in CO_2 emission intensity of electricity, Japan needs to replace fossil fuel plants beyond their life expectancy of 40 years with new plants and cannot build new ones, or to go beyond the target, Japan needs to decommission them and increase alternative energy sources.

Currently, no clear framework for electricity companies to achieve the CO_2 intensity target exists. In addition, according to the Development Bank of Japan (DBJ 2015) and publicly available construction plans of electricity producers, the additional capacity of planned fossil-fuel power plants exceeds 38.5 MW (18 MW for coal-fired plants, 20.5 MW for gas-fired plants). Furthermore, deregulation of Japan's household electricity market after April 2016 will likely add to uncertainty over whether the electricity sector can achieve its voluntary intensity target without any regulatory framework. Because households will be able to choose their electricity supplier, this may trigger demand for cheaper electricity, and therefore tempt investors into building more coal-fired plants,[3] which could raise the CO_2 emission intensity. Adding additional uncertainty, Japan's power generation and transmission sectors are scheduled to be separated in 2020, as part of electricity system reform measures (METI 2013a). Taking all this into account, Sections 3 and 4 below examine the feasiblity of re-starting nuclear power plants and increasing renewable electricity by 2030, respectively. Section 5 examines the electricity supply-demand balance in 2030 and assesses how to balance electricity supply and demand in regions given the current constraints of interconnection grid capacity in Japan.

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[3] According to a METI electricity-generation cost estimate, electricity generated by coal- and LNG-fired plants is cheaper than renewable energy (METI 2015e).

03 Nuclear Power Potential

This section examines potential electricity supply from the standpoint of individual nuclear power reactors. Under Japan's INDC, nuclear power is expected to supply 20–22 per cent of total electricity in 2030. However, as of October 2015, all nuclear power plants other than the unit 1 reactor at Sendai nuclear power station in Kagoshima prefecture are offline. To restart any nuclear power reactor several obstacles must first be overcome. These include a conformity check carried out by the Nuclear Regulation Authority (NRA), approval from the local mayor and prefectural governor, confirmation of plant operating life, and potential litigation involving local residents. Given the particular circumstances of each reactor, therefore, this section analyses the inherent risks at the level of the individual reactor to estimate electricity power supply.

3.1 Data and Methodology Used to Estimate Nuclear Electricity Generation

The amount of power generation from nuclear power is calculated using equation (1).

$$E = \sum_i^n P_i * 24 * 365 * \xi_i * \varphi_i \quad ......(1)$$

where E denotes electricity supply (TWh), P denotes generation capacity (TW), ξ[4] denotes capacity factor, φ1 denotes status of the operation for each reactor by 2030 (1 or 0), i denotes all nuclear power reactors in commercial operation (including the Shimane nuclear power plant unit 3[5] reactor).

Information on nuclear power reactors, that is, starting dates of operation, type of reactor, generation capacity, was taken from the NRA web page (NRA 2015a). For capacity factors, this paper uses an average number for the 30 years prior to the Great East Japan Earthquake (ANRE 2014). More information is available in Appendix 2.

φ (operating status in 2030) is the most important factor in estimating potential nuclear power electricity supply for 2030 and is determined by two criteria. The first criterion represents technical aspects, that is, conformity assessment by NRA, operating years up to 2030, type of reactor, and existence of active geological faults (see Appendix 3 for more details). Using this criterion (see Appendix 4 for a more detailed description of the reason to set up technical criteria and social risks), reactors are classified into seven categories (A1, A2, B, C, D, E, F) as shown in table 1. The second criterion consists of four social elements—litigation, local consensus, evacuation plan, and installation of non-flammable cables.

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[4] ξreflects the operation interval by periodically checking on reactors annually.

[5] Construction is 93.6% complete (Chugoku Electric Power 2011).

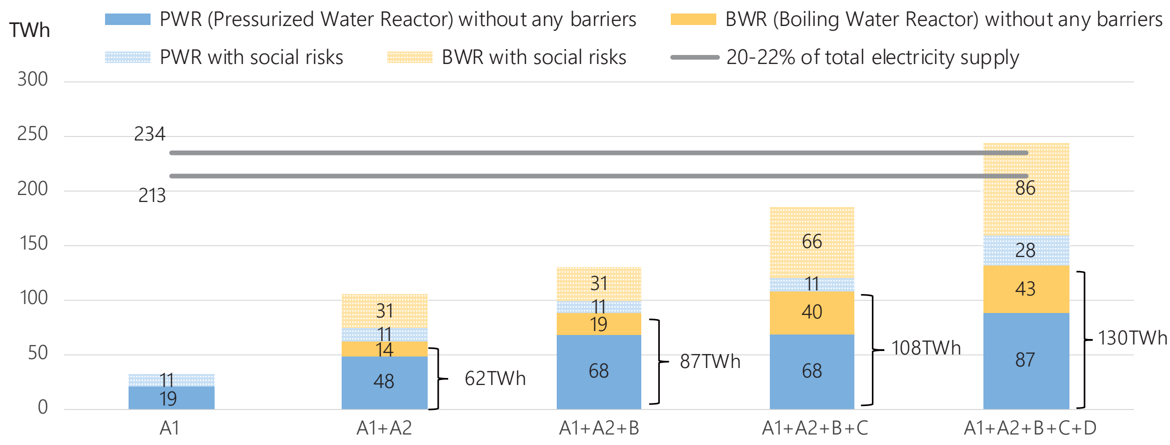
Table 1. Technical Criteria and Social Risks in Assessing Nuclear Reactor Operation to 2030

	Group	Description
Technical criteria	A1	Reactors permitted to restart operation after passing NRA conformity check
	A2	Reactors undertaking the conformity check and will operate for less than 40 years by 2030
	B	Reactors undertaking the conformity check and to operate for more than 40 years by 2030
	C	Reactors that have not applied for the conformity check and will operate for less than 40 years by 2030
	D	Reactors that have not applied for the conformity check and will operate for more than 40 years by 2030
	E	Reactors located on active seismic faults or at the Fukushima II station
	F	Reactors to be decommissioned
Social risks		Approval from city mayor and prefectural governor
		Litigation
		Evacuation plan
		Installation of non-flammable cables

3.2 Estimation of Electricity Supply from Nuclear Power

Our estimates of electricity supply from nuclear power reactors are shown in figure 2. Electricity supply is shown as a cumulative total and categorised by technical criteria and social risks.

The nuclear power reactors in Group A1 have passed the conformity assessment and have the potential to supply 30 TWh of electricity in 2030. After passing the assessment, the power companies running the reactor need to develop evacuation plans for residents living within 30 km of the power plant. Under this process, some nuclear power reactors would still be exposed to litigation risk. For example, Fukui District Court has passed a judgment prohibiting a restart of reactor units 3 and 4 of the Takahama nuclear power plant. Excluding the reactors exposed to social risk, the electricity generation from the power reactors in Group A1 would be 19 TWh, which would account for 1.8 per cent of the electricity supply expected under the INDC.



A1: Approved by conformity check
A2: Under the conformity check, <40yr
B: Under the conformity check, >40yr
C: Before the conformity check, <40yr
D: Before the conformity check, >40yr

Figure 2: Electricity Supply Based on Power Potential and Exposure to Risks

A2 is the group of reactors undergoing the conformity assessment; they have 73 TWh of potential electricity. Assuming that power companies have gone to great lengths to ensure that these reactors pass the conformity assessment, the possibility of being operational in 2030 is relatively high. However, several steps still remain, such as building consensus with residents and developing evacuation plans in the event of accidents. In particular, Oma nuclear power plant (unit 1) is exposed to litigation risk from Hakodate City (Hakodate City 2014). Hamaoka nuclear power plant unit 4 and Kashiwazaki-Kariwa nuclear power plant units 6 and 7 are facing difficulties in building consensus with the residents due to their location and, in the wake of the Fukushima Daiichi nuclear power plant accidents, the low status of nuclear power (see Appendix 4 for social constraints on restarting reactors). Thus, the total potential electricity supply from the nuclear power reactors in Groups A1 and A2, excluding the reactor that has social risks, would be 62 TWh, which accounts for 5.8 percent of the electricity supply under the INDC.

The nuclear power reactors in Group B are also undertaking the conformity assessment, but the operating period for these reactors will be over 40 years. Therefore, even if these reactors pass the conformity check, a further assessment is required to extend their period of operation. They represent an additional potential 25 TWh of supply. Since there are no reactors with social risk in Group B, the potential total electricity supply from the reactors in Group A1, A2, and B would be 87 TWh.

The nuclear power reactors in Group C are all of the Boiled Water Reactor (BWR)[6] type. They have not been subject to the conformity assessment and the operating period by 2030 will be less than 40 years. This could be because power companies recognize the level of uncertainty over BWR passing the conformity checks, which include installation of a bending filter. In addition, 63 per cent of potential electricity supply from Group C reactors involves social risk relating to operational restarts because these reactors are in Kashiawazaki-Kariwa and Hamakoa nuclear power plants. If nuclear reactors with risk exposure are excluded from Groups A1, A2, B, and C , the potential electricity supply would be 108 TWh, which accounts for 10.1 per cent of the electricity supply under the INDC.

The nuclear power reactors in Group D have not been subject to the conformity assessment and the operating period by 2030 will be more than 40 years. Therefore, more funding would be needed for regulatory checks and seismic durability enhancement to operate such reactors for more than 40 years. As a result, there is a relatively low possibility that these reactors will be operational in 2030. In addition, flame-retardant cables in Tokai Daini nuclear power plant unit 1 reactor, Mihama nuclear power plant unit 3 reactor, and Takahama nuclear power plant unit 1 and 2 reactors need replacing, which could involve high costs. Group D also has reactors in Kashiawaki-Kariwa and Hamakoa nuclear power plants. If nuclear reactors with risk exposure are excluded from Groups A1, A2, B, C, and D, the potential electricity supply would be 130 TWh, which accounts for 12.2 per cent of the electricity supply under the INDC. Nuclear power reactors in Group E and F are excluded from the estimation because restarting operation of those reactors is unrealistic under current social and geographical condition and regulation.

Given these circumstances, this paper works with two estimates of electricity supply from nuclear power reactors (see Section 5). The first estimate, 108 TWh, is plausible because this amount of electricity could be supplied by reactors in Group A1, A2, B, and C, which are without risk exposure and are likely to come back online. The second, 130 TWh, adds electricity supplied by reactors in Group D that are without risk exposure. Although it is much more uncertain whether reactors in Group D will be restarted, it is a possibility, given that some of the reactors in Group D are located in areas with relatively few alternative sources of electricity supply, compared to other areas of the country (METI 2015c) .

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[6] Type of light water nuclear reactor. The reactor directly generates steam that drives a steam turbine.

04 Renewable Electricity Potential

Under Japan's INDC, the target share of renewable electricity in the national power generation is 22–24 per cent in 2030. This section assesses the feasibility of the target by focusing on the potential and availability of renewable electricity in 2030.

4.1 Data and Methodology Used to Estimate Renewable Electricity Generation

To examine the renewable electricity generation potential for 2030, three different sets of data are collected: potential renewable energy sources (termed "potential renewable"); current level (as of July 2015) of renewable electricity (termed "2015 renewable"); and anticipated renewable electricity capacity under the Feed-in Tariff (termed "FIT 2015 data").

To estimate the "potential renewable", we use research published by governmental institutions, including the Ministry of the Environment, Japan (MOE), the Ministry of Economy, Trade and Industry (METI), and the New Energy and Industrial Technology Development Organisation (NEDO) (see Appendix 5). These reports define "potential renewable" as the maximum installed potential of renewables on available lands and locations.[7] It should be noted that "potential renewable" does not consider the financial barriers associated with installing renewables. Detailed descriptions of social, environmental, and locational conditions are listed in Appendix 6. Based on a comparison of different levels of "potential renewable" estimated by the various government reports, we selected a "potential renewable" for each renewable energy source/ technology analysed in this paper (see Appendix 7 for the comparison results).

This paper estimates "2015 renewable"—the current level of renewable electricity generation as of July 2015—by first assessing the total installed capacity of electricity in Japan using the Geographic Information System (GIS) published by the Ministry of Land, Information, Transport and Tourism (MILT). In the case of solar PV, we use data published under the FIT system because GIS data do not recognise small electricity producers of less than 10 kW installed capacity[8] (including households). Specifically, we use "installed capacity" and "transferred installed capacity" from the FIT data, with the latter referring to the capacity installed under a renewable portfolio standard (RPS) system initiated in 2002 and transferred to the FIT system to sell the generated renewable power to electricity companies at a procurement price determined by the FIT. FIT data have been collected by the government of Japan on a monthly basis at city and prefecture levels since July 2012, when the FIT was initiated.

Using this estimate of installed capacity, the "2015 renewable" (current) level of electricity generation is calculated by applying average capacity factors for each renewable power technology. To estimate electricity generation from solar PV, an average capacity factor at the prefecture level (47 prefectures)[9] is used. For wind generation, we use an average capacity factor based on average wind speed.[10] For geothermal electricity generation, we use a 70 per cent capacity factor for installations of less than 5,000 kW, 75 per cent for installations of 5,000–20,000 kW[11] and 80 per cent for installations of more than 20,000 kW. Hydropower electricity generation (TWh) is estimated by the METI hydropower database,[12] and we use these data. Biomass electricity generation (TWh) is estimated from oil equivalent (kl) electricity generation published in a METI research report (METI 2013b).

The "FIT 2015 data" are estimated by adding "approved capacity" of renewables in the FIT as of July 2015 to the "2015 renewable" dataset. "Approved capacity" of renewables means renewable capacity as calculated by applicants (individual electricity producers or electricity businesses) who are planning to install renewable electricity and who have obtained FIT[13] approval from METI and electricity companies. However, such renewable electricity is not yet installed. Since "approved capacity" is registered in the FIT system and requires government approval, the relevant data are collected by the government[14].

The "FIT 2015 data" are calculated using equation (2). To estimate electricity generation, the same capacity factors used to estimate "2015 renewable" for solar PV and wind are applied to "FIT 2015 data," and a capacity factor of 80 per cent is used for biomass.[15] Small- and medium-sized hydropower is estimated with a capacity factor of 60 per cent.[16]

$$\mathrm{FIT}_{2015}data=\sum_{i=1,\,j=1}^{47} I_{i,j}\times F_{i,j}+\sum_{i=1,\,j=1}^{47} R_{i,j}\times F_{i,j} \quad ......(2)$$

where FIT_{2015} data is total electricity generation of FIT data as of July 2015, $I_{i,a}$ is "2015 renewable" (current installed capacity of renewable) technology *j* in prefecture *i*, $F_{i,a}$ is the capacity factor of renewable technology *j* in prefecture *i* and $R_{i,a}$ is the "approved capacity" under the FIT of renewable technology *j* in prefecture *i*.

4.2 Estimation of Potential Renewable Energy Generation in 2030

4.2.1 Estimates of Renewable Energy Generation in 2030

To estimates the potential renewable electricity generation in 2030, the "FIT 2015 data" are used for **solar PV, small to medium hydropower, and biomass power**. Although the future installed FIT "approved capacity" is unknown, it can be used as an indication of willingness and plans to invest in renewable electricity by 2030. While FIT approval for these technologies, especially solar PV, is comparatively easy under the current FIT system, the approval process for wind and geothermal power producers, including procurement cost approval, is substantially more time-consuming due to the need for environmental assessments; implementation usually takes several years.[17] Because only three years have passed since the start of the FIT in 2012, the "FIT 2015 data" including "approved capacity" do not reflect investment decisions of electricity producers of wind and geothermal power.

To estimate **wind power generation** in 2030, therefore, we consider the Project Internal Rate of Return (PIRR) of potential renewable electricity at the regional level. For onshore wind power, we use the wind power data estimated by the METI (2011) report. We base wind power generation on a 3.3 per cent PIRR[18] after tax[19] and a willingness to install wind power under an assumed FIT system. Although a PIRR of 3.3 per cent is too low to operate a wind power business, it is assumed that wind technology costs in 2030 will be lower than 2009 levels, considering the learning effect (IEA 2012). The analysis, based on a 3.3 per cent PIRR, indicates 96 TWh of onshore wind power generation. We also estimate offshore wind power generation, based on a PIRR of 3.3 per cent, willingness to install wind power under an assumed FIT system indicated in METI (2011), as well as social acceptance. Our analysis indicates 119 TWh of offshore wind power generation.

In the case of **geothermal projects**, it takes more than 10 years to move from the initial ground investigation to the start of actual operations: two years for the ground and excavation investigation, three years for exploration, three to four years for the environmental assessment, and three to four years for excavation of the production well and construction (METI 2015d).

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7 The available lands and locations are under a minimum restriction of current policies, regulations and locational conditions (including installation in some national parks).

8 Although some solar PV installed before FIT were not transferred from the renewable portfolio standard (RPS) to the FIT system, we assume this is the current level of installed capacity (as of 2015) of solar PV in Japan

9 Although we use different average capacity factors at the prefecture level, we are aware that even in the same prefecture the capacity factor varies due to factors such as location, daily natural conditions (solar radiation, wind speed), and type and duration of installed technology.

10 We use the capacity factor of average wind speed due to factor variations of 16.2% to 54% in speed (m/s) and 2000kW or 5000kW in capacity (METI 2011a).

11 Data from MOE (2013).

12 METI database http://www.enecho.meti.go.jp/category/electricity_and_gas/electric/hydroelectric/database/energy_japan003/

13 FIT website: http://www.fit.go.jp/statistics/public_sp.html

14 Although equipment such as solar panels is not necessarily purchased at this approval level, documents on manufacturers and model numbers of such equipment to be installed need to be registered. Prior to April 2015 when regulations changed, approval from a regional electricity company to connect generated renewables to its grid was not needed. Further, for solar PV, a certified copy of land registration and a legal installation procedure status report for the site were not required, and there was no regulation on the time period from approval to installation . Since April 2015, 1) all renewable electricity producers need approval not only from the government but also from electricity companies to connect their produced electricity to the grid, 2) solar PV electricity producers of more than 50 kW installed capacity need to submit a certified copy of land registration, legal procedure status report of installation site and procurement document of equipment within 180 days (maximum extended days is 360 days), otherwise face expiry of the registered "approved capacity" and obtained procurement price. See the following METI site for information on the FIT (METI 2014c). http://www.enecho.meti.go.jp/category/saving_and_new/saiene/kaitori/nintei_setsubi.html

15 A fixed capacity factor of 80% as published by METI (2013b) was used to estimate biomass electricity generation (TWh) from installed capacity (kW), and for the estimation from calorific value (PJ) an electricity generation efficiency figure of 20% was used with a 15% allowance for loss at the plant and 5% loss due to electricity transmission.

16 A fixed capacity factor of 60% was used (as published by MOE (2013)) to estimate small-medium hydropower electricity generation (TWh) from installed capacity (kW).

Obtaining FIT approval for geothermal projects requires environmental assessments, among other procedures. Further, if public discussion and coordination with local communities are needed, another five years may be required, meaning that a project designed to begin operation in 2030 should begin public consultations today. Although this assumption might be too conservative[20], we use the current available information because there is no available data to estimate expected geothermal power generation in 2030. Using the information and data collected from the Japan Oil, Gas and Metals National Corporation (JOGMNC),[21] as well as company announcements regarding the start of public consultations,[22] this paper calculates the expected total installed capacity of geothermal power in 2030. From this, it estimates feasible geothermal power generation in 2030 to be 10 TWh.[23]

Our estimates of solar, hydropower, and biomass power generation, based on "FIT 2015 data," a PIRR of 3.3 per cent for onshore wind, and anticipated levels of geothermal power generation in 2030 (called here "2030 renewable without offshore wind") indicate that Japan could generate 372 TWh of renewable electricity in 2030 (figure 3). If offshore wind power generation is included, using a PIRR of 3.3 per cent and socially accepted levels of installation ("2030 renewable"), the total electricity generation from renewable electricity will be 491 TWh. According to the INDC and LTESDO (METI 2015b), Japan will generate 1,065 TWh of total electricity supply in 2030 and have an electricity demand of 981 TWh. Our two estimates, "2030 renewable without offshore wind" and "2030 renewable" would provide 35 per cent and 46 per cent, respectively, of the total electricity supply in 2030 as estimated by the INDC.

When our results are compared with research on the 2030 renewable electricity potential conducted by MOE (2014), "2030 renewable without offshore wind" is slightly higher than the MOE's estimated highest level of renewable potential for 2030 of 357 TWh. On the other hand, Energy Basic Plan 2010[24] indicates that primary renewable energy in 2030 will be 486 TWh (METI 2012a). Although the data for Energy Basic Plan 2010 are for primary renewable energy, our estimate of renewable electricity including offshore wind in 2030 ("2030 renewable") is roughly the same, at 491 TWh.

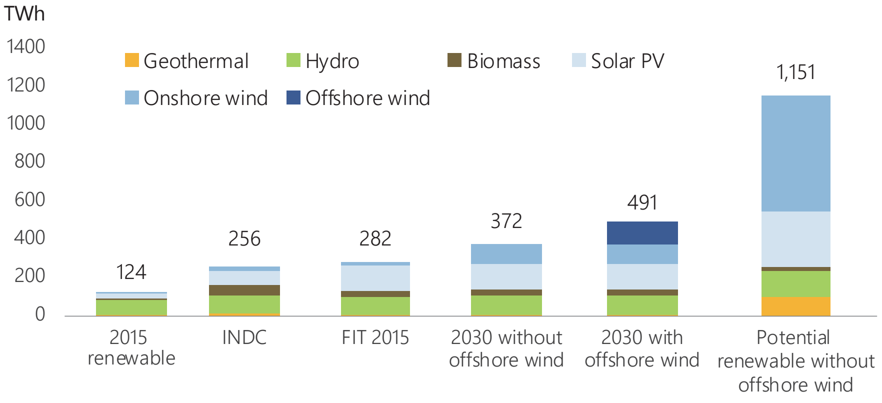

Figure 3. Renewable Electricity Generation Options

2015 renewable: Current level of electricity generation as of 2015

INDC: Japanese INDC renewable energy generation target in 2030

FIT 2015: Adding "approved capacity" of renewables in the FIT as of July 2015 to the "2015 renewable"

2030 without offshore wind: Estimates of solar, hydropower, and biomass power generation, based on "FIT 2015 data," a PIRR of 3.3 per cent for onshore wind, and anticipated levels of geothermal power generation in 2030

2030 with offshore wind: Adding offshore wind power generation using a PIRR of 3.3 per cent and considering socially accepted levels of installation to the "2030 renewable without offshore wind"

Potential renewable without offshore wind: Maximum installed potential of renewables on available lands and locations in Japan

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[17] Wind power, in general, takes about 5–7 years including half a year to select the development site, 1.5–2 years of wind condition investigation, half a year of evaluation and decisions for feasibility of commercialisation and 4–5 years of environmental assessment. If evaluation and decision of the propriety of commercialisation of wind power, and acquisition of approval and license of land is made, power producers can apply for FIT registration.

[18] PIRR is used to evaluate whether a project can be feasibly operated and to determine whether the project will be a success or not. If PIRR is larger than the weighted average cost of capital (WACC), operation is usually feasible with a return on investment expected . For instance, WACC is about 4.7–7.5% for onshore wind while about 6.8–9.7% for offshore wind in some European countries and the USA (IEA 2011).

[19] Before tax, PIRR is 4.3–4.5%, depending on the FIT price per kWh (METI 2014a).

[20] Currently there is a plant to shorten environmental assessment processes to register wind and geothermal in the FIT system. In addition, eased regulations for parts of national parks could promote installations of geothermal power plants. Thus, there is a possibility to increase more geothermal power generation in 2030 than that estimated in this paper.

[21] Japan Oil, Gas and Metals National Corporation (JOGMNC) http://geothermal.jogmec.go.jp/

[22] There is no information on anticipated installed capacity of geothermal power plants in public consultations, thus this paper assumes sites located in hot spring areas are 500 kW (minimum installed capacity of medium-scale geothermal); those in national parks are 30,000 kW (large scale geothermal is more than 15,000 kW); and others are 2,000 kW (maximum installed capacity of medium-scale geothermal). Data is based on a JOGMEC report (JOGMEC 2013).

[23] Includes sites in national parks. In October 2015, MOE announced

eased regulations for parts of national parks, meaning development of geothermal power generation is possible for some sites (source: Asahi Shimbun newspaper (6 October 2015); http://www.asahi.com/articles/ASH7Z46TVH7ZULBJ005.html).

[24] This paper refers to Energy Basic Plan 2010 and not 2014 because the latter gives no data breakdown for renewables (METI 2014d).

4.2.2 Comparison of our Estimates and the INDC

Based on the dataset presented in Section 4.1, this paper estimates "2015 renewable" (current installed renewable electricity generation) at 124 TWh. However, if the "approved capacity" of renewable electricity generation is added, the total expected amount of renewable electricity generation ("FIT 2015 data") amounts to 282 TWh, which is greater than the renewable generation indicated in the INDC of 256 TWh (figure 3). On the other hand, the estimated "potential renewable" electricity generation in Japan is much higher, at 1,151 TWh (see methodology described above and Appendix 7).

Our analysis finds that, while solar PV according to energy mix in the INDC is 7 per cent of total electricity supply at 75 TWh, solar PV generation of actual FIT "installed capacity" is only about 27 TWh as of July 2015. However, solar PV of "FIT 2015 data" including approved FIT solar PV electricity generation (not installed) provides 136 TWh. If this "approved capacity" of solar PV under the FIT were actually installed, 48 per cent of solar PV out of the "potential renewable" solar PV could be generated.

Hydropower generation under "2030 renewable" is 99 TWh, which is similar to that of the INDC (98 TWh at 9.2 per cent of total electricity generation). The 98 TWh exceeds 40 per cent of the "potential renewable" hydropower generation. Hydropower generation of "2015 renewable" is already 93 TWh.

Biomass power generation is estimated at 4.6 per cent of total electricity generation in the INDC (which means 49 TWh out of 1,065 TWh). Biomass power generation of "FIT 2015 data" indicates 28 TWh, which is much lower than the INDC.

For wind power generation, the INDC indicates 18 TWh (1.7 per cent of total electricity generation), which means additional 10 TWh is needed by 2030 from wind power generation of "2015 renewable". On the other hand, this paper estimates wind power generation in 2030 as 96 TWh in "2030 renewable without offshore wind". The 96 TWh is still 16 per cent of "potential renewable" wind power generation.

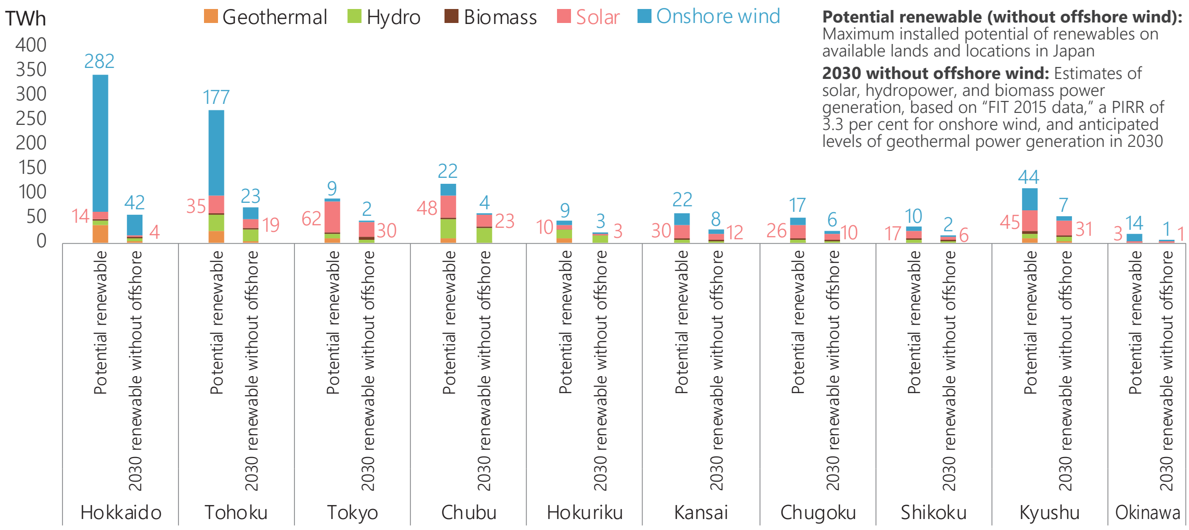
Our estimate for geothermal generation in 2030 (10 TWh) is slightly lower than that of still only the INDC, in which geothermal accounts for 1 per cent of total electricity supply, which equates to 10.09 TWh of geothermal power generation out of 254 TWh of total renewable generation (based on renewable electricity accounting for 24 per cent of the total electricity generation of 1,065 TWh).

4.2.3 Renewable Electricity Potential in 2030 by Region

The current electricity system in Japan, which comprises supply and distribution, is dominated by 10 regional companies: Hokkaido, Tohoku, Tokyo, Chubu, Shikoku, Kansai, Chugoku, Kyushu and Okinawa Electricity Power Companies[25]. Each regional company is responsible for supplying electricity and operating electricity systems for each geographical region in Japan. The responsible areas of the regional electricity companies are demarcated as shown in Appendix 8. Although this system is set to be reformed in 2020 because Japan's power generation and transmission sectors are set to be split as mentioned above, this study looked at the current demarcation of electricity supply and demand.

This sub-section examines the renewable electricity generation in 2030 ("2030 renewable without offshore wind"), by region and by technology, and analysis of electricity supply and demand by region is following in next sub-section. By region, "2030 renewable without offshore wind" equates to nearly 40 per cent of the "potential renewable" in Hokuriku, Chugoku and Shikoku regions (figure 4). In Tokyo, Chubu and Kyushu regions, "2030 renewable without offshore wind" exceeds 40 per cent of the "potential renewable" in each region (figure 4). From the analysis of renewable electricity in 2030, "2030 renewable without offshore wind" and "2030 renewable", our analysis indicates high renewable electricity potential in Hokkaido and Tohoku regions, relative to other regions.

[25] The 10 power companies are in charge of regional power supply services as general electricity utilities and are responsible for supplying electricity from power generation, to distribution to the consumers in their respective service areas (FEPC 2015). General electricity utilities supply about 84% of electricity demand and sell 96% of electricity in Japan (as of 2014) (METI electricity research and statistics database: http://www.enecho.meti.go.jp/statistics/electric_power/ep002/results.html#headline2) .



Potential renewable (without offshore wind): Maximum installed potential of renewables on available lands and locations in Japan

2030 without offshore wind: Estimates of solar, hydropower, and biomass power generation, based on "FIT 2015 data," a PIRR of 3.3 per cent for onshore wind, and anticipated levels of geothermal power generation in 2030

Figure 4. Comparison of "Potential renewable" and "2030 renewable without offshore wind" by region and by technology

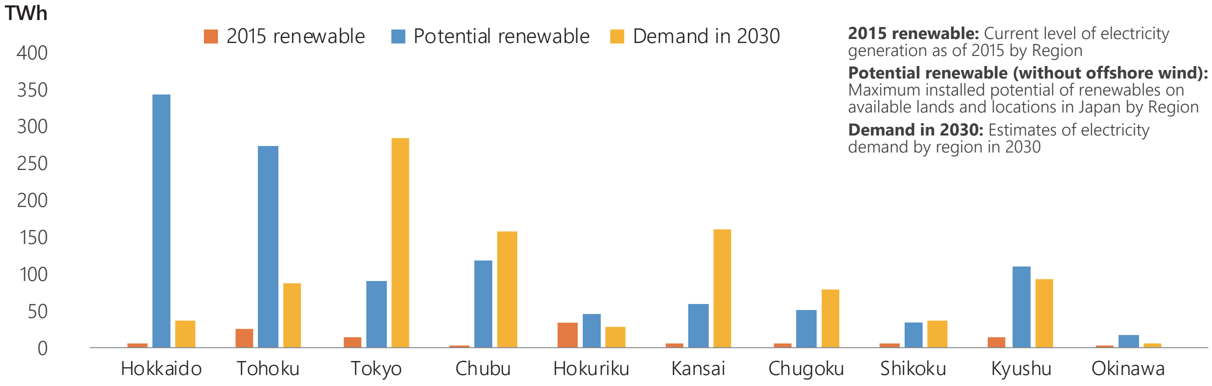
4.2.4 *Electricity Supply and Demand Balance*

This paper now examines the electricity supply and demand balance under the current Japanese electricity system. This is because feasible renewable electricity should be utilised by considering electricity demands by region.

To estimate the electricity supply and demand balance by region, we estimate electricity demand for each region in 2030 using the LTESDO total electricity demand in 2030. The percentage share of total electricity demand for each region is calculated using electricity demand data from METI from 1990 to 2012 and these percentages are applied to total electricity demand for 2030 (980.8 TWh in the LTESDO). According to the population forecast for Japan, total population will decline by 15 million between 2015 and 2030 (approximately 8–18%, depending on the region[26]). This paper ignores regional differences and uses an average percentage share for total electricity demand from 1990 to 2012. As shown in Figure 5, there is a gap between renewable electricity supply and total electricity demand in each region.

Compared to electricity demand in 2030 by region as calculated from expected total electricity demand stated in the LTESDO, the "potential renewable" electricity sources in Hokkaido and Tohoku have a huge surplus beyond the demands of the region (Figure 5). Conversely, Tokyo, Chubu, and Kansai regions have high demands for electricity. Therefore, in these regions, reductions in electricity usage are needed to balance supply and demand as well as further increases in renewable electricity generation.

[26] Excluding Okinawa, population declines range from 8% in Tokyo region and 17–18% in Hokkaido, Tohoku and Shikoku regions.



2015 renewable: Current level of electricity generation as of 2015 by Region

Potential renewable (without offshore wind): Maximum installed potential of renewables on available lands and locations in Japan by Region

Demand in 2030: Estimates of electricity demand by region in 2030

Figure 5. "Potential Renewable" Supply and Electricity Demand in 2030 by Region

05 System Analysis: Estimation of Energy Balance and CO_2 Intensity in the Electricity Sector in 2030

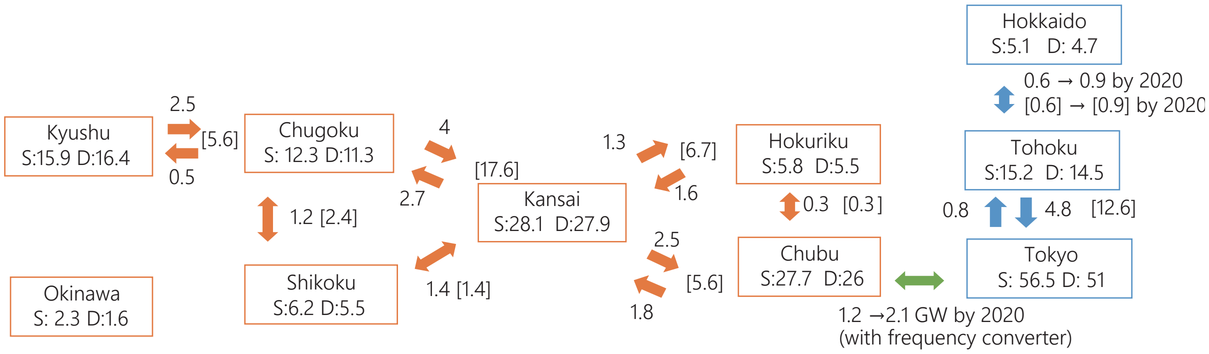
This section discusses how much of the nuclear and renewable electricity generation identified in Sections 3 and 4 could actually be supplied in the current electricity system. In Section 4, we highlighted the gap between renewable supply and electricity demand in regions under Japan's current electricity system. Although reforms are due in 2020, issues such as grid connection and potential renewable electricity in different regions will remain. This paper therefore examines the feasible CO_2 emission intensity in 2030 under the current electricity system and draws inferences regarding the kinds of technologies requiring investment if more renewable potential is to be realized.

5.1 Method Used to Analyze Japan's Electricity System

For this study, a model is developed for analyzing electricity systems to determine electricity supply sources on an hourly basis. The model is described in Sections 5.1.1 to 5.1.4. It should be noted that the installed facilities and technologies in the electricity system, such as the capacity of interconnection grids and pumped hydro power plants, are fixed at the current level in order to highlight the barrier in transmitting electricity from one region, with a large renewable potential, to another. It also helps to identify the need for accelerating technology development and investment in order to expand the availability of access to renewable electricity in different regions. The limitations of this method are, first, that this model applies only to a single electricity supply trend for each electricity generation source, that is, wind and solar power but, in actual systems, renewable electricity supply would be more complex due to differences in trends and locations. Second (although this issue chiefly affects only Hokkaido and Tohoku regions), this model does not calculate the level of wind power curtailment needed to satisfy the supply-demand balance.

5.1.1 Setting the Capacity of Interconnection Grids and Pumped Storage Hydropower

To stabilize the supply and demand balance in a given region, this paper considers the transmission of surplus electricity in one region to other regions. In the estimate, we first consider the capacity of interconnection grids. Japan's transmission lines are interconnected with neighboring electricity systems (except for the Okinawa electricity system), but the capacity of the interconnections is limited (Figure 6). In particular, increasing the capacity of interconnections between Hokkaido and Tohoku is key to realizing increased use of renewable electricity in Japan: a large renewable electricity potential exists in Hokkaido, from where surplus electricity needs to be transmitted to the Tokyo region through Tohoku. The interconnection grid is planned to expand from 0.6 to 0.9 GW (according to METI (2015c)), but this capacity would still not be sufficient to support the transmission load that could result if Hokkaido's wind power potential is fully realized.



The numbers in boxes show maximum demand [GW] on August, 2014 and electricity supply capacity [GW] in 2014
The numbers outside boxes show transmitting capacity [GW] and heat capacity (maximum transmitting capacity without any technical constrains) [GW]

Figure 6. Map of Grid Interconnections Source: METI (2012b)

Furthermore, two different electricity distribution lines exist in Japan—50 Hz in the east (Hokkaido, Tohoku, and Tokyo) and 60 Hz in the west (rest of the country). Therefore, substations with frequency converters have been installed at the interface between Tokyo and Chubu electricity systems. The Government of Japan is currently investing in upgrades to provide a capacity of 2.1 GW by 2020 to enhance electricity system stability, as well as taking measures to ensure efficient utilization of power plants (METI 2015c). An additional 0.9 GW of grid interconnection between Tokyo and Chubu is also planned.

5.1.2 Setting Electricity Supply and Demand Curves

To investigate how each electricity system can satisfy fluctuating electricity demand with an intermittent renewable electricity supply, we develop electricity demand and supply curves for each electricity source. For electricity supplied by solar and wind power, hourly basis curves are created based on data from 1,300 points throughout Japan that are fed into the Automated Meteorological Data Acquisition System (AMeDAS) and made available via the Japan Meteorological Agency web site. From the AMeDAS data, we used data from around 50 solar radiation stations and 484 wind speed stations located in potential wind power sites. For electricity demand curves, hourly demand curves for 2014 were used. The procedure is described in detail in Appendix 9.

5.1.3 Setting the Dispatch Order of Each Electricity Source

We use the following electricity priority dispatch order to estimate the essential electricity supply required to meet demand in each regional electricity system. The first order is to estimate the base load electricity, that is, nuclear power, hydropower, geothermal, and biomass power, in each region. The second order is the minimum amount of fossil-fuel power generation for the peak load. Regional electricity companies[27] publish the minimum required amounts of fossil-fuel power generation based on METI methodology (METI 2014b). For regions where electricity companies do not publish specific figures, the minimum amount of electricity generated by fossil-fuel power plants is identified with existing base-load practices in several countries.[28] The third order is to estimate electricity from solar and wind power generation. The generation patterns are determined by the process described in section 5.1.2. The fourth order is electricity supply by pumped hydropower plants. The fifth order is to estimate electricity generated by fossil-fuel power plants to fill the gap in electricity demand in a region. Appendix 9 shows the algorithm used for this calculation and an example of hourly output of electricity system analysis.

5.1.4 Inputting Data to the System Analysis Model

Table 2 shows the input data for the electricity system model, based on the estimated electricity supply from nuclear power generation estimated in Section 3, renewable electricity generation identified in Section 4, and minimum fossil-fuel power generation calculated using the methodology described in Section 5.1.3. Input data of the modal is estimated at prefectural level and aggregated as total electricity supply by each power source, and based on the input data, three scenarios are set up, as shown in Table 2. Since the potential of offshore wind power is less certain than that of other renewable energy sources, Scenario A shows the amount of electricity supply by renewables excluding offshore wind ("2030 renewable without offshore wind"). Scenario B shows the amount of electricity supply by renewables including offshore wind ("2030 renewable"). As shown in Section 3, there are two options for the nuclear power estimation of electricity supply, and the impact of this differentiation can be seen between Scenarios A and B, which give 130 TWh, and Scenario C, which gives 108 TWh.

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[27] Reports are submitted to METI by Hokkaido, Tohoku, Hokuriku, Chugoku, Shikoku, Kyushu, and Okinawa electricity power companies to indicate the amount of renewable electricity capacity they can handle.

[28] The concept of base load differs by country. This paper uses the definition used in Europe and America: "The minimum amount of electric power delivered or required over a given period of time at a steady rate" (U.S. Energy Information Administration (EIA) Glossary). We assume base load as 60% of total electricity supply referring documents such as METI (METI 2015f) and Environmental Business online (http://www.kankyo-business.jp/column/010237.php).

Table 2: Potential Sources of Electricity Supply in 2030 (TWh)

	Geothermal hydropower, biomass	Solar	Onshore wind	Off- shore wind	**Total renewable supply**	Nuclear	Minimum Fossil Fuel
Scenario A	137	139	96	0	**372**	130	374
Scenario B	137	139	96	119	**491**	130	374
Scenario C	137	139	96	119	**491**	108	374

5.2 Results of Estimation

Using the data and methodology in Section 5.1, this paper estimates the potential electricity supply by considering the hourly fluctuation in electricity demand and electricity supply from renewable sources for all regions, i.e., Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, Kyushu, and Okinawa.

Figure 7 shows the results of the electricity mix in Scenarios A, B, and C on a yearly basis and regional level. In the east of the country, the surplus of renewable electricity in Hokkaido and Tohoku is transmitted to meet the high electricity demand in the Tokyo region. However, not all of the excess electricity supply from Hokkaido can be transmitted to the Tohoku grid due to the low capacity of the transmission lines between the two systems (max. 0.9 GW in 2030). Therefore, a huge dependency on fossil-fuel electricity generation remains in regions such as Tokyo and Chubu.

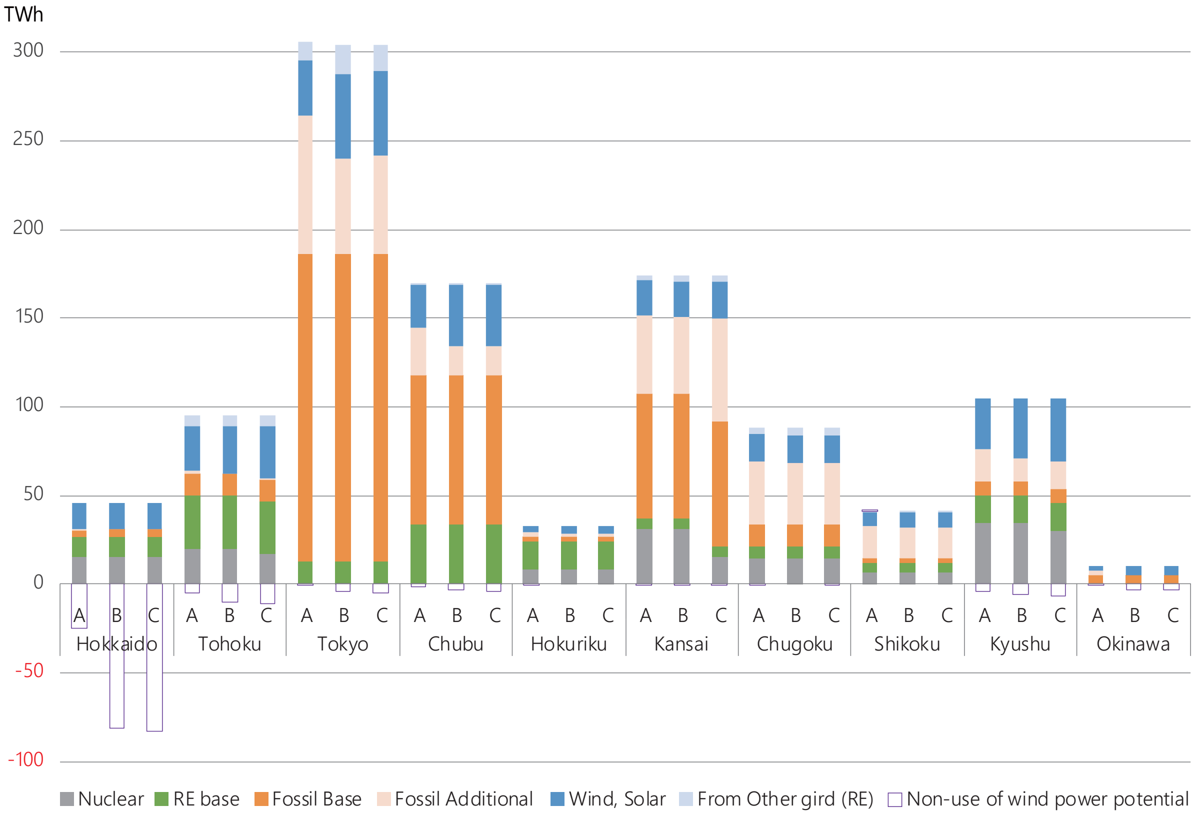

Figure 7. Electricity Supply and Demand in 2030 by Region and Scenario
(See the detailed description of Scenarios in Table 2)

After examining electricity supply and demand on a regional basis, we repeat the analysis at the national level. Figure 8 shows the results of estimating the electricity mix in 2030. Japan increases its share of renewable electricity to 334 TWh by 2030 in Scenario A. Table 2 indicated a renewable electricity supply (Scenario A) of 372 TWh. However, 38 TWh of renewable electricity surplus cannot be supplied to the grid due to the limited capacity of the electricity system. In this case, renewable electricity will be 31 per cent (334 TWh) of the total electricity supply under the INDC, and 90 per cent of total renewable supply in Scenario A is used for electricity demands (10 per cent is not used). Nuclear power generation provides only 12 per cent of the energy mix with 130 TWh, and fossil-fuel power provides 57 per cent (603 TWh) (Table 3).

The CO_2 emissions from electricity generation are 389 MtCO2, which is very slightly higher than emissions estimated in the INDC (see Section 2). CO_2 emissions intensity under Scenario A is 0.36 $kgCO_2/kWh$ (Table 3). In addition, if Japan can increase its renewable electricity in Scenario B (other factors being the same as in Scenario A), the total renewable electricity generation including offshore wind power will be 380 TWh. In this Scenario, there is 111 TWh of unused wind power potential (23 per cent is not used) and the share of renewables in the electricity supply mix in 2030 would be 35.7 per cent. Nuclear supply is the same as in Scenario A at 130 TWh. Fossil-fuel power generation provides 554 TWh. CO_2 emissions from electricity are 362 $MtCO_2$, yielding an emissions intensity of 0.34 $kgCO_2/kWh$, which is similar to but slightly lower than that of the INDC estimate. Even though the electricity supply by nuclear power generation provides 108 TWh in Scenario C (other factors being the same as in Scenario B), an emission intensity would be 0.35 $kgCO_2/kWh$ with 554 TWh of fossil-fuel power generation, which is still lower than the INDC target.

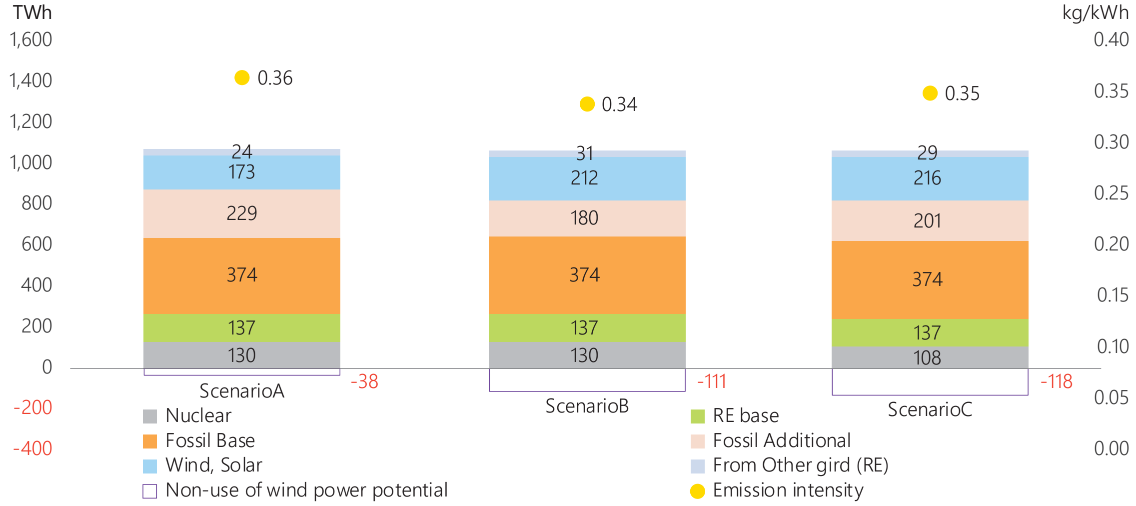

Figure 8. Electricity Supplied via the Electric Grid System and CO_2 Intensity, 2030

Table 3. Result of Each Scenario for 2030 Target

	Grid-connected electricity from renewables [TWh], (Share of 1,065 TWh)	Grid-connected electricity from nuclear power plants [TWh], (Share of 1,065 TWh)	CO_2 emissions intensity of electricity in 2030 [$kgCO_2/kWh$]	CO2 emissions from electricity sector in 2030 [Mt CO_2]
INDC	234-256 (22-24%)	213 – 234 (20-21%)	0.36	383
Voluntary target	NA	NA	0.37	NA
Scenario A:	334 (31%)	130 (12%)	0.36	389
Scenario B:	380 (36%)	130 (12%)	0.34	361
Scenario C:	382 (36%)	108 (10%)	0.35	373

5.3 Discussion

Based on our estimation of the total electricity supply to each grid electricity system in 2030, we discuss in this section the following three points: 1) achievement of the emissions intensity target for the electricity sector through the scenarios described in Sections 5.2 and 2); actions required to strengthen the emission intensity target; and 3) limitations of this study.

5.3.1 Achievement of Emissions Intensity Target for Electricity Sector

The CO_2 emissions intensity of electricity generation in 2030 could be 0.36 kgCO_2/kWh in Scenario A, 0.34 kgCO_2/kWh in Scenario B, or 0.35 kgCO_2/kWh in Scenario C. It might therefore be possible to achieve both INDC's and corporate voluntary emission intensity target for the electricity sector at the current level of investment in renewable electricity, together with considerably ramped-up use of nuclear power plants. The scenarios assume that in 2030 the amount of electricity from solar, biomass and hydro is at the same level as that already approved by the FIT; the amount of electricity supply derived from wind and geothermal power is developed under the assumption that project developers could invest in such power plants at reasonable cost; and that the amount of electricity via nuclear power plants could be met using only reactors with low associated operational risks if restarted. Based on these assumptions, 601 TWh of electricity supply by fossil fuel power plants would be required in 2030. In particular, 153 TWh of electricity would be supplied by replaced fossil fuel power plants, which would incur the "lock-in-effect" on Japan's long-term emission reduction target. Therefore, it is necessary to further invest in low CO_2 emitting electricity sources and, in particular, renewable electricity in regions where a large amount of electricity is generated by fossil fuel power plants. Indeed, since the amount of renewable electricity assumed in the analysis is only around 40 per cent of its true potential, this leaves room to promote additional renewable electricity.

5.3.2 Actions Required to Strengthen the Emissions Intensity Target

In order to increase use of renewable electricity, it is crucial to be able to supply power to areas of high demand. This could be done through the following actions.

- Expand the interconnection grid capacity: this is a key investment in order to realize greater use of renewable electricity. As shown in Figure 7, the renewable electricity potential in Hokkaido and Tohoku is under-utilized, while the grid in the Tokyo region requires a large amount of fossil-fuel power—the enhancement of which would be costly.[29]
- Invest in solar power: solar PV can be directly used by households and factories in high-demand areas, such as Tokyo, Kansai, and Chubu. If PV panels are installed on house roofs or near high-demand areas, project developers need not be concerned about limitations to the interconnection grid capacity.
- Utilize offshore wind power plants: this could have an impact on increasing renewable electricity in Tokyo and Chubu, where great potential exists.
- Introduce technology for stabilizing electricity systems supplied by renewable electricity, such as pumped storage hydropower, storage batteries and demand-response[30] that can store surplus energy until it is needed. For example, electricity supply in the Tokyo region, under Scenario B and C (Figure 7), suffers from curtailment of wind power due to the limited wind power capacity in the region, the constraints of interconnected grid from Tohoku to Tokyo and the limited capacity of electricity storage, even though additional power generation are required to supply electricity. This is because the electricity system cannot store the surplus wind electricity, which exceeds demand at certain hours.

5.3.3 Limitations of this study

The limitations of this study are as follows. First, this paper considers only a single scenario of electricity demand under the INDC. Multiple demand-side scenarios could be addressed in future work. Second, the necessity of nuclear power plants should be seriously questioned from the regional perspective. For example, Hokkaido and Tohoku regions have abundant renewable electricity potential. On the

[29] According to (METI 2012b), it would cost around 500 billion JPY (4.2 billion USD) to add 1.8 GW capacity of interconnection between Hokkaido and Tohoku.

[30] Changes in electric usage by end-users in response to changes in the price of electricity over time, or to incentive payments by reducing electricity use at times of peak demands or high wholesale market prices.

contrary, potential of renewable electricity in western Japan, including Kansai, Chugoku and Shikoku would not be sufficient to meet the electricity demand in 2030. Third, more detailed analysis is needed of the minimum electricity supply provided by fossil-fuel power plants, although this paper refers to METI (2014b). Fourth, the impact of the diminishing cost of solar PV and wind power generation over time needs to be further elaborated. In fact, even since Japan's current solar capacity was installed, solar power technology has developed much more rapidly than was predicted in several earlier studies (METI 2014e). Fifth, the model used for analysis of the electricity system needs to be updated to better reflect the actual situation, in which electricity is supplied via several different electricity sources.

06 Conclusion

This paper has discussed the potential electricity supply from nuclear power reactors and renewable electricity under the current electricity system. The analysis supports three main findings:

Electricity supply from nuclear power generation in 2030 is estimated to be 108–130 TWh. This means that electricity supplied by nuclear power plants would account for 12 per cent of total electricity supply in 2030. Further increases in nuclear power generation are unlikely due to the limited acceptance of local stakeholders, active faults around power plants, and the cost of extending operating periods beyond 40 years.

It is possible to achieve the renewable electricity target under the INDC, where renewable electricity supplies 234–256 TWh of total energy supply. The amount of renewable electricity capacity estimated by this analysis ("2030 renewable without offshore wind") indicates that solar PV power will equate to 137 TWh, which exceeds 40 per cent of "potential renewable" electricity (which is 115 TWh). However, the capacity of wind power, 96 TWh, is much less than its potential (only 16 per cent of "potential renewable"). The potential of renewable electricity differs according to region: while high potential, especially for wind power, exists in Hokkaido and Tohoku regions, the Tokyo region has a very low renewables potential compared to electricity demand.

The potential of renewable electricity cannot be fully realized without investment in grid interconnections. Under the current electricity system, although "2030 renewable without offshore wind" will provide an estimated 371 TWh, renewable electricity actually used for electricity supply is 334 TWh; the remaining 38 TWh cannot be used due to the transmission limitations—that is, the inability to transmit the electricity from one region with a surplus electricity supply to another with a shortage. Therefore, even though renewable electricity supply can be increased with offshore wind power, "2030 renewable" indicates that, while 491 TWh of renewable electricity is generated, only 380 TWh is actually usable, with a surplus of 111 TWh that cannot be supplied or invested in for electricity use. With "2030 renewable without offshore wind," an intensity target of 0.36 kgCO_2/kWh can be achieved. If offshore wind power electricity generation is included ("2030 renewable,") the CO_2 intensity in the electricity sector could decrease to 0.34 kgCO_2/kWh.

Although it is beyond the scope of this paper, these results above lead to the implication that, in order to increase the overall renewable electricity potential supplied to the grid system within and between regions, technological innovation, such as storage systems (pumped-storage hydropower generation and storage batteries) and enhancement of transmission lines are required. In addition, although this paper focuses only on the electricity supply side, it is important to discuss some demand-side measures, such as energy efficiency and demand-response technology, to reduce the level of electricity demand—981 TWh in 2030— that is indicated in the INDC.

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Appendix 1.
The Equation to Estimate CO_2 Intensity of Electricity in 2030

The equation to estimate CO_2 intensity of electricity generation is as follows:

$$C_{2030}=C_{2012,coal}\times E_{2030,coal}+C_{2012,oil}\times E_{2030,oil}+C_{2012,lng}\times E_{2030,lng}+C_{2012,renewable}\times E_{2030,renewable}+C_{2012,nuclear}\times E_{2030,nuclear} \quad ......(1)$$

Where C is CO_2 intensity of the entire electricity sector in 2030, $C_{2012,coal}$ is CO_2 intensity of existing coal plants (Table A1.1), $E_{2030,coal}$ is the share of total electricity supply from coal plants in 2030 that is estimated from Japan's INDC (277 TWh, 26% of total electricity supply). $C_{2012,oil}$ is CO_2 intensity of existing oil plants (Table A1.1), $E_{2030,oil}$ is the share of total electricity supply from oil plants in 2030 that is estimated from the INDC (32 TWh, 3% of total electricity supply). $C_{2012,lng}$ is CO_2 intensity of existing LNG electricity plants (Table A1.1), $E_{2030,oil}$ is the share of electricity supply from LNG plants in 2030 that is estimated from the INDC (288 TWh, 28% of total electricity supply). $C_{2012,renewable}$ and $C_{2012,nuclear}$ that indicate CO_2 intensity in renewable and nuclear is zero. $E_{2030,renewable}$ is the share of electricity supply from renewables and $E_{2030,nuclear}$ is the share of electricity supply from nuclear power.

Table A1.1. Fossil-Fuel Power Plants: Available Technologies

		Existing plant (as of 2012)	2015 plant model	2020 plant model
Coal	CO_2 intensity	0.91kgCO_2/kWh	0.83kgCO_2/kWh	0.75kgCO_2/kWh
	Thermal efficiency	36%	42%	46%
	Technology		USC (ultra-supercritical)	IGCC (Integrated gasification combined cycle) A-USC (Advanced USC)
Oil	CO_2 intensity	0.66kgCO_2/kWh		
	Thermal efficiency			
	Technology			
LNG	CO_2 intensity	0.44kgCO_2/kWh	0.36CO_2/kWh	0.33CO_2/kWh
	Thermal efficiency	40%	52%	57%
	Technology		CC (Combined cycle) / ACC (Advanced CC)	Gas turbine (1700°C)

Source: IEA (2014); MOE (2012); Kuriyama & Kuramochi (2015)

Appendix 2.
Capacity Factor for Nuclear Power Plants Operated by Electric Companies

Company Name	Average capacity factor during past 30 years before the Fukushima Daiichi Nuclear Power Accident
Hokkaido Electric Power Company	0.848
Tohoku Electric Power Company	0.698
Tokyo Electric Power Company	0.676
Hokuriku Electric Power Company	0.713
Chubu Electric Power Company	0.7
Kansai Electric Power Company	0.749
Chugoku Electric Power Company	0.761
Shikoku Electric Power Company	0.831
Kyushu Electric Power Company	0.834

Source: ANRE (2014)

Appendix 3. List of Nuclear Power Plants in Japan

Nuclear power plant name	No. of reactors	Type of reactor	Capacity (MW)	Operating years at 2030	Located electricity system	Possibility of restart	Other specific risk
Tomari	1	PWR	579	41	Hokkaido	B	
Tomari	2	PWR	579	39	Hokkaido	A2	
Tomari	3	PWR	912	21	Hokkaido	A2	
Oma	1	BWR	1383	NA	Tohoku	A2	Litigation
Higashidori	1	BWR	1100	25	Tohoku	C	
Onagawa	1	BWR	524	46	Tohoku	D	
Onagawa	2	BWR	825	35	Tohoku	A2	
Onagawa	3	BWR	825	28	Tohoku	C	
Fukushima I	1	BWR	460	59	Tokyo	F	Decommission
Fukushima I	2	BWR	784	56	Tokyo	F	Decommission
Fukushima I	3	BWR	784	54	Tokyo	F	Decommission
Fukushima I	4	BWR	784	52	Tokyo	F	Decommission
Fukushima I	5	BWR	784	52	Tokyo	F	Decommission
Fukushima I	6	BWR	1100	51	Tokyo	F	Decommission

Nuclear power plant name	No. of reactors	Type of reactor	Capacity (MW)	Operating years at 2030	Located electricity system	Possibility of restart	Other specific risk
Fukushima II	1	BWR	1100	48	Tokyo	E	Close to Fukushima I
Fukushima II	2	BWR	1100	46	Tokyo	E	Close to Fukushima I
Fukushima II	3	BWR	1100	45	Tokyo	E	Close to Fukushima I
Fukushima II	4	BWR	1100	43	Tokyo	E	Close to Fukushima I
Tokai II	1	BWR	1100	52	Tokyo	D	Need for flame-retardant cables
Kashiwazaki-Kariwa	1	BWR	1100	45	Tokyo	D	Local consensus
Kashiwazaki-Kariwa	2	BWR	1100	40	Tokyo	C	Local consensus
Kashiwazaki-Kariwa	3	BWR	1100	37	Tokyo	C	Local consensus
Kashiwazaki-Kariwa	4	BWR	1100	36	Tokyo	C	Local consensus
Kashiwazaki-Kariwa	5	BWR	1100	40	Tokyo	C	Local consensus
Kashiwazaki-Kariwa	6	BWR (ABWR)	1356	34	Tokyo	A2	Local consensus
Kashiwazaki-Kariwa	7	BWR (ABWR)	1356	33	Tokyo	A2	Local consensus
Hamaoka	1	BWR	540	54	Chubu	F	Decommission
Hamaoka	2	BWR	840	52	Chubu	F	Decommission
Hamaoka	3	BWR	1100	43	Chubu	D	Evacuation plan, possibility of active fault
Hamaoka	4	BWR	1137	37	Chubu	A2	Evacuation plan, possibility of active fault
Hamaoka	5	BWR (ABWR)	1380	25	Chubu	C2	Evacuation plan, possibility of active fault
Shika	1	BWR	540	37	Hokuriku	E	Active fault
Shika	2	BWR (ABWR)	1368	24	Hokuriku	A2	
Tsuruga	1	BWR	357	60	Kansai, Chubu, Hokuriku	F	Decommission
Tsuruga	2	PWR	1160	43	Kansai, Chubu, Hokuriku	E	Active fault
Mihama	1	PWR	340	60	Kansai	F	Decommission
Mihama	2	PWR	500	58	Kansai	F	Decommission
Mihama	3	PWR	826	54	Kansai	D	Need for flame-retardant cables
Oi	1	PWR	1175	51	Kansai	D	
Oi	2	PWR	1175	51	Kansai	D	
Oi	3	PWR	1180	39	Kansai	B	
Oi	4	PWR	1180	37	Kansai	B	

Takahama	1	PWR	826	56	Kansai	D	Need for flame-retardant cables
Takahama	2	PWR	826	55	Kansai	D	Need for flame-retardant cables
Takahama	3	PWR	870	45	Kansai	A1	Litigation
Takahama	4	PWR	870	45	Kansai	A1	Litigation
Shimane	1	BWR	460	56	Chugoku	F	Decommission
Shimane	2	BWR	820	41	Chugoku	B	
Shimane	3	BWR (ABWR)	1373	NA	Chugoku	C	
Ikata	1	PWR	566	53	Shikoku	E	Active fault
Ikata	2	PWR	566	48	Shikoku	E	Active fault
Ikata	3	PWR	890	36	Shikoku	A1	
Genkainada	1	PWR	559	55	Kyushu	F	Decommission
Genkainada	2	PWR	559	49	Kyushu	D	
Genkainada	3	PWR	1180	36	Kyushu	A2	
Genkainada	4	PWR	1180	33	Kyushu	A2	
Sendai	1	PWR	890	46	Kyushu	A1	
Sendai	2	PWR	890	45	Kyushu	A1	

Note
A1: Reactors permitted to restart operation after passing NRA conformity check
A2: Reactors undertaking the conformity check and operating for less than 40 years by 2030
B: Reactors undertaking the conformity check and operating for more than 40 years by 2030
C: Reactors that have not applied for the conformity check and operating for less than 40 years by 2030
D: Reactors that have not applied for the conformity check and operating for more than 40 years by 2030
E: Reactors located on active seismic faults or at the Fukushima II station
F: Reactors to be decommissioned

Appendix 4.
Criteria to Assess Operation of Nuclear Power Plants in 2030

A4.1 Technical Criteria

The technical criteria have been developed to classify the nuclear power reactors into seven categories based on five factors, namely, conformity assessment by NRA, type of reactor, operating life, active faults, and special circumstance of Fukushima Daini (Fukushima II) power stations.

The first factor is the conformity assessment by NRA. After the Fukushima Daiichi nuclear power disaster, the government established the Nuclear Regulation Authority (NRA) that conducts conformity assessment for all power reactors during periods of operation. In practice, power companies need to halt operations at nuclear power reactors for periodic inspection. All nuclear power reactors should be subject to the conformity check (NRA 2013a).

The second factor is the type of reactor—a pressurized water reactor (PWR) or a boiled water reactor (BWR). As of October 2015, five PWRs passed the conformity assessment but no BWR has passed the assessment. This is because a BWR needs additional measures for its restart and system to reduce the pressure of the reactor using portable power. Consequently, it takes time to assess the safety of such a system (Koike 2015).

The third factor is the operating period of nuclear power reactors that can be extended up to 60 years after examination by the NRA, although this is limited to 40 years in principle (NRA 2013b). NRA also requests the power company running a reactor that is in operation for more than 30 years to evaluate the deterioration of building structure and equipment. At the same time, it also requests the power company to develop and update a long-term maintenance policy every ten years.

The fourth factor is the existence of active earthquake faults under the reactors. NRA detected the evidence of an active fault under the Shiga nuclear power plant unit 1 reactor and under the Tsuruga nuclear power plant unit 2 reactor (NRA 2015b; NRA 2015c). Ikata nuclear power plant unit 1 and 2 reactors are difficult to restart even though the unit 3 reactor has passed the NRA's conformity assessment. These two reactors require an immense amount of investment to be reinforced because the two reactors have been operating for more than 30 years and Ikata nuclear power plant is located at a distance of 8km from Japan's largest active fault, "Median Tectonic Line fault zone."

The fifth factor is the special circumstances for Fukushima II nuclear power station, unit 1 to 4 reactors. The station is located only 12 km from Fukushima Daiichi (Fukushima I) nuclear power plant. Yuko Obuchi, the former Minister of Economy, Trade and Industry, stated on 25 September 2014 that "Fukushima II cannot be handled in the same context as other nuclear power plants." (Nikkei News Paper 2014a).

A4.2 Social Risks

Local consensus

Each reactor needs to receive the approval of both the mayor of the host city and the governor of the prefecture. The Governor of Niigata prefecture, Hirohito Izumida, is cautious about the decision to restart because he insists that completing the investigation of the accident at the Fukushima Daiichi power plant (Fukushima I) should be completed before any discussion can begin on the Kashiwazaki-Kariwa nuclear power plant (Reuters News Paper 2015). Therefore, it is largely uncertain whether all nuclear reactors in Kashiwazaki-Kariwa in Group A2 C and D will restart their operations.

Litigation

Even if both the city mayor and the prefectural governor approve the restart of nuclear reactor operations, the residents still have an option to get involved in litigation against its operation. For Takahama nuclear power plant unit 3 and 4 reactors, the Fukui District Court lodged a temporary injunction on 14 April that prohibits operations (Fukui District Court 2015). Going against this injunction, Kansai Electric Power, the plaintiff, filed an objection to this decree. If Fukui District Court makes a judgment to prohibit restarting Takahama power plant, it would be harder to operate the plant's unit 3 and 4 reactors in Group A1, due to strong opposition from residents. In the case of Oma nuclear power plant unit 1 reactor, Hakodate city is 30 km from the plant and began litigation on the decision to restart (Hakodate City 2014). Hakodate city is not the city hosting the Oma nuclear power plant, but it needs to develop an evacuation plan in the event of a serious accident. Therefore, Hakodate city insists that the power company running the Oma nuclear power plant should get approval from all cities within 30 km of the plant.

For these various reasons, Takahama nuclear power plant unit 3 and 4 reactors in Group A1, Oma nuclear power plant unit 1 reactor in Group A2, Kashiwazaki-Kariwa nuclear power plant unit 1 reactor in Group D, unit 2-5 reactors in Group C, and unit 6-7 in Group A2 would have difficulty restarting operations.

Evacuation plan

At the same time as requesting conformity assessment, a meeting on disaster prevention for nuclear power stations under the Cabinet Office requested that an evacuation plan for each nuclear power plant should be developed and approved. All local municipalities located within a 30 km radius from a nuclear power plant should develop evacuation plans.

For the Tahakama nuclear power plant, Fukui, Shiga and Kyoto prefectures are requested to develop their own evacuation plans. As shown in the example of Hakodate city above, even cities that are not located in the prefecture hosting a nuclear power plant have a mandate to develop evacuation plans. They may also have opposing opinions about the nuclear power reactor and can conduct litigation on any issues that are missing from the approval process.

For Hamaoka nuclear power plant, the evacuation plan would be very complicated because there are 0.96 million residents within a 30 km radius of the Hamaoka nuclear power plant. In addition, it is uncertain whether or not Hamaoka nuclear power plant would pass the conformity assessment because an evaluation of active faults for the peripheral site has not been concluded.

For these various reasons, Takahama nuclear power plant unit 3 and 4 reactors in Group A1, Hamaoka nuclear power plant in Group A2, C, and D would have difficulty in restarting operations.

Installation of Flame-Retardant Cables

When a nuclear power plant extends its operating period to more than 40 years, it is required to replace the flame-retardant cables, which is prohibitively expensive. Power companies have proposed the use of fire-protection paint as an alternative to replacing all cables, but it is unclear whether their claim is approved or how much it would cost (Nikkei News Paper 2014b).

This risk factor affects Tokai Daini nuclear power plant unit 1 reactor, Mihama nuclear power plant unit 3 reactor and Takahama nuclear power plant unit 1 and 2 reactor in Group D. This paper determines that it is still possible for the reactors in Group D with flame-retardant cables to be operational in 2030.

Appendix 5.
Data Sources for Potential Renewable Energy Sources

The table provides data sources used to plot different estimates of potential renewable energy in Japan.

Table A5.1. Data Sources for Potential Renewable Energy Sources

	Potential renewable energy
Solar PV	NEDO 2001 Research of solar power generation evaluation NEDO 2013 NEDO renewable energy technology white paper METI 2009 Research on dissemination of new energy METI 2011b Research report on New Energy promotion basic research (Survey on installed capacity of solar power and solar thermal) MOE 2014 Report on renewable energy zoning basic information*
Wind	METI 2011a Research report on New Energy promotion basic research (Survey on installed capacity of wind energy) MOE 2014 Report on renewable energy zoning basic information* JWPA 2014 Wind Power Energy Resources and Mid/Long term target
Geothermal	MOE 2010 Renewable energy potential survey FY2009 MOE 2011 Renewable energy potential survey FY2010 MOE 2013a Survey and analysis on installed capacity to the geothermal power generation*
Biomass	NEDO biomass database* MAFF 2012 Current Status and Issues surrounding the biomass METI 2002 Study of biomass energy development and utilization strategy
Hydro	METI hydropower database* MOE 2014 Report on renewable energy zoning basic information

Note: *data used as available renewable energy for the analysis in this report. * is at the medium level of the range of various data.

Appendix 6.
Social and Environmental Conditions of Potential Renewable Sources.

The Table below presents the list of conditions included in the estimation of potential renewable energy sources.

Table A6.1. Social and Environmental Conditions of Potential Renewable Energy Sources

	Potential renewable energy
Solar PV	Residential, non-residential, (public facilities, commercial buildings, industry facilities and office buildings, hospitals), low-use and unused land, abandoned farmland Installed in gable roof, north, east and west walls, and windows more than 10m^2
Onshore wind	Wind speed (more than 5.5 m/s) Altitude (less than 1200 meters) Maximum angle of inclination (less than 20 degrees) Less than 10km from roads more than 3 meters wide Laws and regulations (Distance from the residence (more than 50m)
Offshore wind	Same as onshore wind
Geothermal	Technically available density Geothermal temperature is more than 150 degrees centigrade: more than 10kW/km^2, 120~150 degree: more than 1kW/km^2, 53~120 degree: more than 0.1kW/km^2
Biomass	Theoretically generated and discharged amount in a year regardless of the use of biomass only eEconomically available efficiency amount of biomass considering availability to collect and access to biomassthe collection of biomass
Waste	Direct incineration obtained by subtracting the amount of resources from the general waste emissions

Source: MOE (2014); METI (2011b); METI (2011a)

Appendix 7. “Potential Renewable”

This Appendix describes how to define the potential renewable energy and to estimate the electricity generation referred to in this paper as “potential renewable.”

A7.1 Solar PV

1) Definition of potential solar PV electricity sources
Potential solar PV sources for individual households are estimated by including the maximum installation in available lands and spaces, considering the total number of households at the prefecture level, average installed capacity by building area, and physical limitations such as locations on rooftops occupied by other structural objects, rooftop area spaces (divided into nine types of area spaces (m^2)) and shapes (divided into three types of shapes). It also considers quake-resistance standards by households, vacancy factors, and solar irradiation time periods (less than 1 hour, 1-3 hours, 3-5 hours and more than 5 hours), weather conditions, access to grid system, and regulations.

2) Potential solar PV data used in this paper
The renewable solar PV data is compared in the building sector and unused land that are estimated in different government reports (Figure A5.1). Five different sources (NEDO 2001; NEDO 2013; METI 2009; METI 2011b; MOE 2014) (Appendix 5) are used. Solar PV for the building sector includes households, public and commercial buildings, and factories. The result indicates that potential solar PV for the building sector ranges from 54GW to 293GW (Figure A7.1). From this range, we use the MOE 2014 level 3 data[31] as potential solar PV because it is a mid-point of the range and includes data at the prefecture level. For the analysis of solar PV in 2030 in Section 4.2, we use power generation instead of installed capacity.

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[31] The level set up in each government report is different by conditions for available rooftop area spaces. Level 3 is maximum installed capacity while level 1 includes additional limiting conditions

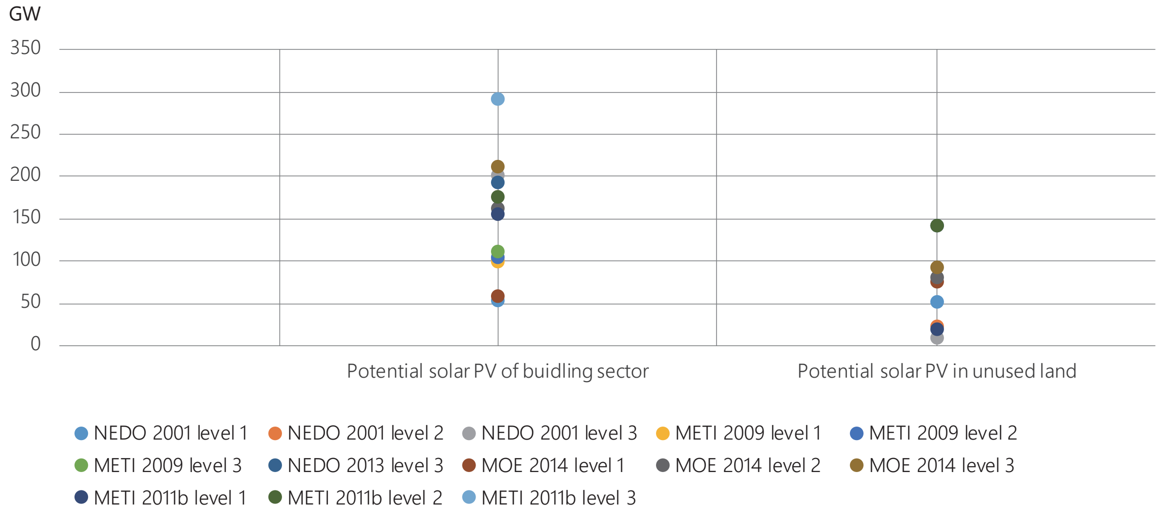

Figure A7.1. Comparison of Various Government Estimates of Potential Solar PV

A7.2. Wind

1) Definition of potential wind electricity sources

Potential wind power is defined as that which considers the natural conditions and social conditions such as regulatory conditions and land use conditions as listed in Appendix 6. Potential wind power is estimated by including the maximum installation in available lands and spaces, but excluding some technical issues such as wind power less than 5.5m/s of wind speed, and installation of wind power in specific areas such as protected areas and regulated areas (in case of MOE 2014 and METI 2011a). The detailed estimation methodology for potential wind power is shown in Appendix 7-2.

2) Potential wind data used in this paper

In the comparison of wind power capacity by government sources listed in Appendix 5, Figure A7.2 shows the range of potential onshore and potential offshore wind power. The range of potential onshore wind is 151GW–291GW. On the other hand, the range of potential offshore wind is 157GW–370GW. From comparison of the data, MOE (2014) data is used for potential onshore and offshore wind because it includes data at the prefecture level and is closer to the mid-point than other data such as METI (2011a). For the analysis of wind power in 2030, we use power generation instead of installed capacity (see the equation in Appendix 7-2).

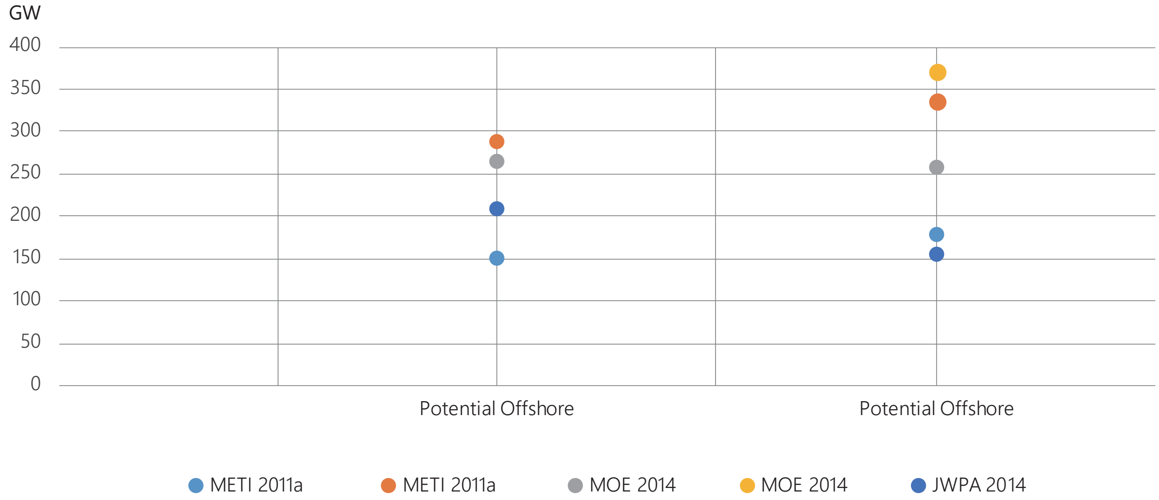

Figure A7.2. Comparison of Various Government Estimates of Potential Wind Power Installed Capacity

A7.3. Geothermal, Hydropower and Biomass

1) Potential hydropower, geothermal and biomass electricity data used in this paper

Data on availability of hydropower, geothermal, and biomass are limited to a few official reports. Available data estimates from different government sources is compared, as shown in Figure A7.3 and Appendix 5. We use METI data for potential hydropower electricity source, NEDO data for biomass, and MOE data for geothermal. METI collects hydropower capacity data every five years at the prefecture level, which includes existing hydropower, hydropower under construction, and unused water sources, therefore, the METI's official data (METI hydropower database) is used. On the other hand, NEDO has a database on biomass on the prefecture level. For geothermal, a MOE research report from 2013 (MOE 2013a) is used. In these reports, power generation data is available for hydropower and geothermal. For biomass, the data is available in joules; we converted from joules to TWh in order to estimate potential electricity data presented in Section 4.2.

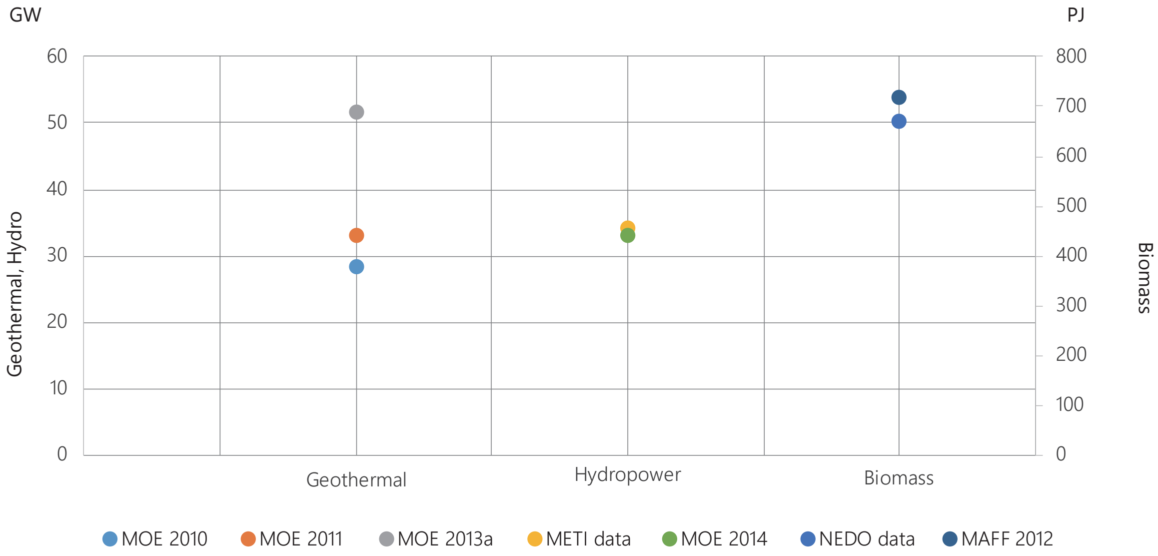

Figure A7.3. Comparison of Potential Geothermal, Hydropower and Biomass Energy from Various Government Reports

Appendix 7-1. Methodology to Estimate Solar PV Installation Capacity and Power Generation

According to a research report of METI (2011b), the methodology to estimate potential solar PV is as follows:

$$\sum_{i=47,m=9} E_i = \sum C_{i,m} \times \sum H_{i,m} \times K_1 \times K_2 \quad \text{......(A1)}$$

Where E_i is total potential solar PV installed capacity (kW) at *i* prefecture, $C_{i,m}$ is installed capacity of a household (kW/household) with *m* building area at *i* prefecture, $H_{i,m}$ is the number of households with *m* building area at *i* prefecture, K_1 is physical limiting condition (potential solar PV), and K_2 is other limiting conditions (potential solar PV). The potential solar PV data are estimated by 47 prefectures and nine types of building areas, and then aggregated as total installed capacity of solar PV in Japan.

Then, the electricity generation from solar PV is estimated using equation (A2):

$$E_{PM,i} = F_i \times P_{AS,i} \times \frac{H_{Am,i}}{G_{s,i}} \quad \text{......(A2)}$$

$E_{PM,i}$ indicates monthly system generation (kWh/month) at capital city at *i* prefecture; F_i is monthly design factor of solar PV at capital city of *i* prefecture, including variations in the output of the solar cell module, circuit losses, and losses due to equipment and temperature adjustment factor; $P_{AS,i}$ is system capacity (kW) which was estimated in equation (1) at *i* prefecture; $H_{AM,i}$ is the amount of solar radiation (kWh/m^2/month) at capital city of *i* prefecture; $G_{S,i}$ is solar radiation intensity in the standard test conditions at capital city of *i* prefecture.

F_i (monthly design factor of solar PV) is estimated using the following equation:

$$F_i=F_{PT,i}\times F_{HD}\times F_{PD}\times F_{PM}\times F_{PA}\times nINO \quad ......(A3)$$

Where $F_{PT,i}$ is monthly temperature correction factor at *i* prefecture, F_{HD} is annual insolation variation correction factor (0.97), F_{PD} is over-time changes correction factor of crystal-based solar PV (0.95) and amorphous solar PV (0.87), F_{PM} is array load matching correction factor (0.94), and F_{PA} is array circuit correction (0,97). nINO is power conditioner execution efficiency (0.99).

Appendix 7-2. Wind Installed Capacity and Power Generation Methodology

The equation of wind power installed capacity and power generation of METI (2011a) is estimated using the following equations:

$$\sum_{i=47}E_i = \sum(A_i\times CA) \quad ......(A4)$$

Where E_i is installed capacity of wind power at *i* prefecture, A_i is area (km^2) at i prefecture, CA is installed capacity per km^2, CA is estimated as 0.192km^2 for 2 MW windmill (80m of blade diameter) and 0.243km^2 for 3 MW (90m of blade diameter).

To estimate available area (km^2) for wind power to be installed at the prefecture level, this paper considers the following elements: wind condition including average wind speed and horizontal solution of 500m and ground height of 80m, altitude, maximum angle of inclination, distance from roads more than 3 meters wide, regulated areas including national parks etc; the distance from household, city planning areas, land use area, protected forest area, and grid availability.

The wind power generation from wind power is estimated as follows:

$$EG_i=E_i\times CF_p\times 24(h)\times 365(d) \quad ......(A4)$$

Where EG_i is electricity generation at *i* prefecture, CF_p is capacity factor of *p* annual average wind speed.

Appendix 8. Regional Demarcation

Table A8.1. Regional Power Companies

Regional power companies	Prefectures that can purchase electricity under the regional power companies
Hokkaido	Hokkaido
Tohoku	Iwate, Aomori, Iwate, Niigata, Miyagi, Fukushima, Niigata
Tokyo	Gunma, Tochigi, Ibaraki, Saitame, Chiba, Tokyo, Kanagawa
Chubu	Nagano, Shizuoka, Gifu, Aichi, Mie, Yamanashi
Hokuriku	Ishikawa, Toyama, Fukui
Kansai	Kyoto, Nara, Osaka, Hyogo, Shiga, Wakayama
Shikoku	Kagawa, Tokushima, Kochi, Ehime
Chugoku	Tottori, Shimane, Okayama, Hiroshima, Yamaguchi
Kyushu	Fukuoka, Saga, Nagasaki, Oita, Kumamoto, Miyagi, Kagoshima
Okinawa	Okinawa

Appendix 9.
Estimation of Electricity Supply to the Electric Grid System

This Appendix provides procedures to estimate electricity supply to an electric grid system, using the following three steps.

Step 1: Calculation of electricity supply and demand for each hour

Step 2: Calculate export/import electricity between grids, electricity storage, additional electricity supply by thermal power plant and electricity surplus from renewable energies for each hour

Step 3: Calculate total electricity supply by each source for a year

Step 1: Calculation of electricity supply and demand for each hour

An hourly basis electricity supply and demand were calculated by the following equations:

Demand

$$d_{2030,i} = D_{2030} * \frac{d_{2014,i}}{\sum_{i}^{n} d_{2014,i}} \qquad \text{......(eq. A7-1)}$$

Where:

i: time of electricity demand

n: total number of hours in a year (8,760)

$D_{2030,i}$: Electricity demand for each grid for all power plants including distribution losses in 2030 (kWh)

$d_{2030,i}$: Electricity demand at hour i in 2030 (kW)

$d_{2014,i}$: Electricity demand at hour i in 2014 (kW)

Nuclear

$$e_{n,i} = E_n/8760 \qquad \text{......(eq. A7-2)}$$

Where:

$e_{n,i}$: Electricity supply capacity by nuclear power (kW)

$E_{n,i}$: Potential electricity supply in 2030 by nuclear power (kWh)

Hydro

$$e_{h,i} = \mathrm{E}_h/8760 \qquad \text{......(eq. A7-3)}$$

Where:

$E_{h,i}$: Potential electricity supply in 2030 by hydropower (kWh)

Biomass

$$e_{b,i} = \mathrm{E}_b/8760 \qquad \text{......(eq. A7-4)}$$

Where:

$E_{b,i}$: Potential electricity supply in 2030 by biomass power (kWh)

Geothermal

$$e_{g,i} = E_g/8760 \qquad \text{......(eq. A7-5)}$$

Where:

$E_{g,i}$: E Potential electricity supply in 2030 by geothermal power (kWh)

Thermal base load

$e_{Tb,i} = E_{Tb}/8760$ ……(eq. A7-6)

Where

$E_{Tb,i}$: Potential electricity supply in 2030 by thermal-based load (kWh)

Solar power

$$e_{s,i} = E_s * \frac{r_i}{\sum_i^n r_i}$$

$$r_i = \frac{\sum_i^m r_{i,j}}{m}$$

Where:

i : time of electricity supply
j : monitoring points
n : total number of hours in a year (8,760)
m : total number of AMeDAS monitoring points
$E_{s,i}$: Potential electricity supply in 2030 by solar power (kWh)
$r_{i,j}$: Solar radiation (MJ/m^2)

Wind power

$$v_{80i,j} = v_{10,i,j} \left(\frac{80}{10}\right)^{\beta_i} \quad \text{……(eq. A7-7)}$$

$$\begin{cases} f_{i,j} = \alpha v^{3}_{80_{i,j}} & \text{if } v \leq 14 \\ f_{i,j} = \alpha (14)^{3}_{80_{i,j}} & \text{if } 14 < v \leq 25 \\ f_{i,j} = 0 & \text{if } 25 < v \end{cases} \quad \text{……(eq. A7-8)}$$

$$f_i = \frac{\sum_j^m f_{i,j}}{m} \quad \text{……(eq. A7-9)}$$

$$e_{wi} = E_s * \frac{f_i}{\sum_i^n f_i} \quad \text{……(eq. A7-10)}$$

Where:

i : time of electricity supply
j : monitoring points that located at the place where wind power potential is observed
n : total number of hours in a year (8,760)
m : total number of AMeDAS monitoring points
E_{wi} : Potential electricity supply in 2030 by wind power (kWh)
$f_{i,j}$: Wind force at 80m height
$v_{10,i,j}$: Wind speed at 10m height
$v_{80,i,j}$: Wind speed at 80m height
α : Correction factor
β_i : Power exponent for each i, determined in the table below

Hour	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
β	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.05
Hour	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
β	0	0	0	0	0	0.05	0.1	0.2	0.2	0.25	0.3	0.3

Source: DeMarrais (1958); Adachi (1981)

Step 2: Calculate export/import electricity among grids, electricity storage, additional electricity supply by thermal power plant and electricity surplus by renewable energies for each hour

The procedure to calculate export/import electricity among grids, electricity storage, and additional electricity supply by thermal power plan for each hour is summarized in Figure A9-1.

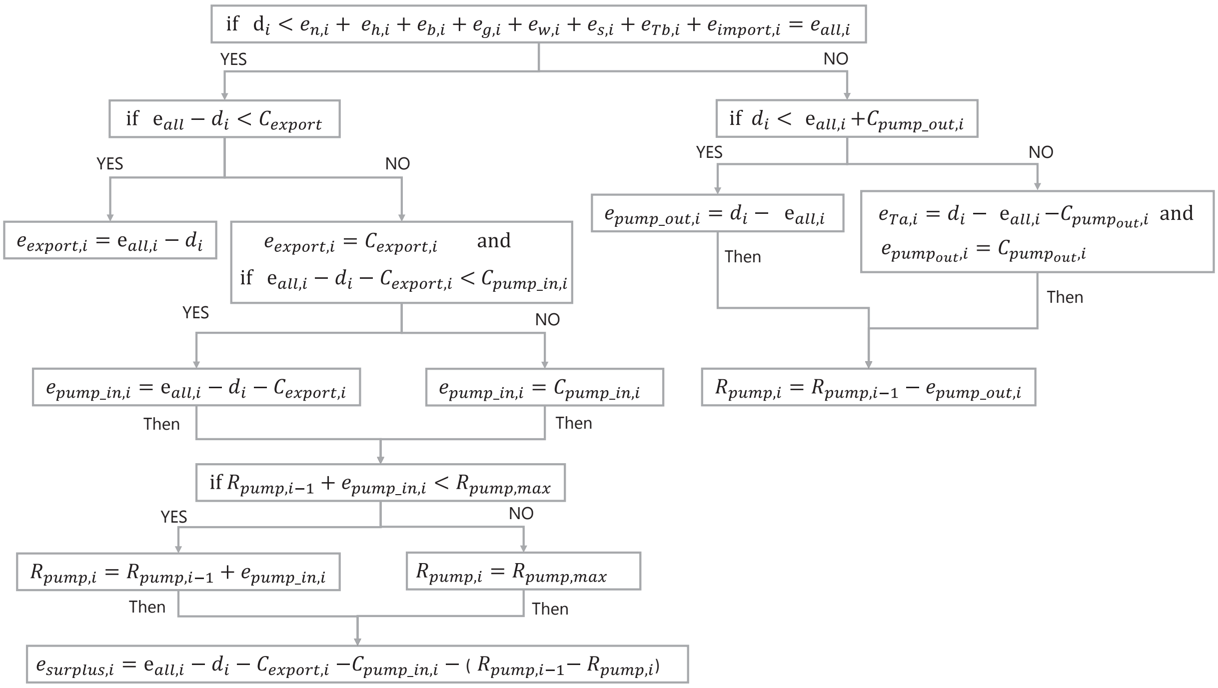

Figure A9-1. Procedures to Calculate Electricity Supply To the Grid

Where:

$e_{n,i}$: Electricity supply capacity by nuclear power at i(kW)
$e_{h,i}$: Electricity supply capacity by hydropower at i (kW)
$e_{b,i}$: Electricity supply capacity by biomass power at i (kW)
$e_{g,i}$: Electricity supply capacity by geothermal power at i (kW)
$e_{Tb,i}$: Electricity supply capacity of thermal base load at i (kW)
$e_{s,i}$: Electricity supply capacity of solar power at i (kW)
$e_{w,i}$: Electricity supply capacity of wind power at i (kW)
$e_{import,i}$: Import electricity from neighbouring grids at i (kW)
$e_{export,i}$: Export electricity to neighboring grids at i (kW)
$e_{pump\_in,i}$: Pumped storage capacity of hydropower at i (kW)
$C_{pump\_in,i}$: Maximum pumped storage capacity of hydropower at i (kW)
$e_{pump\_out,i}$: Pumping-out capacity of stored hydropower at i (kW)
$C_{pump\_out,i}$: Maximum pumping-out capacity of stored hydropower at i (kW)
$R_{pump\_,i}$: Amount of electricity storage of stored hydropower at i (kWh)
$R_{pump_{max},i}$: Maximum amount of electricity storage of stored hydropower (kWh)
$e_{surplus,i}$: Electricity surplus of wind and solar power at i (kW)

Step 3: Calculate total electricity supply by sources in 2030

The electricity supply by sources was calculated using the following equations.
We assume that electricity surplus is produced by renewable energies:

$$E_{nuclear} = \sum_{i}^{n} e_{n,i} \qquad \text{......(eq. A7-11)}$$

$$E_{Tb} = \sum_{i}^{n} (e_{Tb,i}) \qquad \text{......(eq. A7-12)}$$

$$E_{re\_base} = \sum_{i}^{n} (e_{h,i}+e_{b,i}+e_{g,i}) \qquad \text{......(eq. A7-13)}$$

$$E_{re\_wind\_solar} = \sum_{i}^{n} (e_{w,i}+e_{s,i}-e_{surplus,i}) \qquad \text{......(eq. A7-14)}$$

$$E_{Ta} = \sum_{i}^{n} (e_{Ta,i}) \qquad \text{......(eq. A7-15)}$$

Figure 9-2 shows an example of electricity supply capacity by the hour from 1 March to 14 March in the Tohoku region. It indicates that there is peak supply of electricity from solar PV around 13:00 (1.00 pm) although the amount of daily electricity supply from solar PV depends on the weather conditions. Electricity from wind power fluctuated more. Between March 6 and March 8, the electricity from wind power is generally higher than on the other days.

The result indicates that, even though a large amount of renewable electricity potential exists in the Tohoku region, if we use adjusted 30 per cent renewable scenario (Scenario A), not all electricity generated from renewables can be utilized and/or transmitted due to the capacity limitations of grid interconnection and electricity storage.

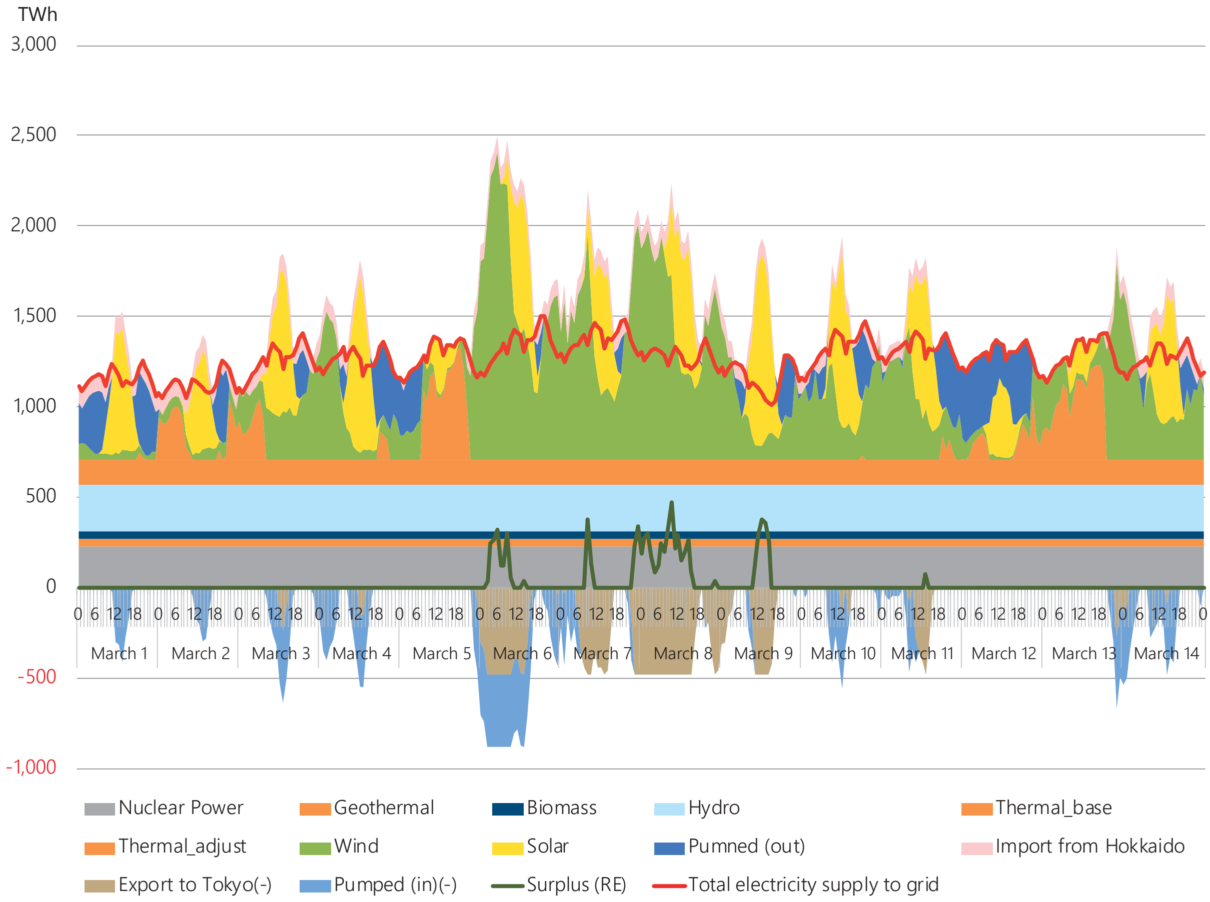

Figure 9-2. Example of Supply and Demand Balance in Tohoku Electricity System

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The Institute for Global Environmental Strategies (IGES), established under an initiative of the Government of Japan in 1998, is an international research institute conducting practical and innovative research for realizing sustainable development in the Asia-Pacific region. IGES research focuses on three issues of critical importance: climate change, natural resource management, and sustainable consumption and production. IGES also serves as the secretariat for various international initiatives and research networks, actively contributing to policy formulation in the form of information sharing and policy proposals.

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This working paper is part of an OCN initiative to inform the post-2020 GHG mitigation goals in Intended Nationally Determined Contributions under the United Nations Framework Convention on Climate Change. The OCN Secretariat, based at the World Resources Institute, is managing this multi-country effort. For more information regarding this initiative, contact openclimate@wri.org.

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