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## Article

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Energy Reports

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Elsevier

*Suggested Citation:* Zhu, Danmei; Mortazavi, Seyed Mostafa; Maleki, Akbar; Aslani, Alireza; Yousefi, Hossein (2020) : Analysis of the robustness of energy supply in Japan: Role of renewable energy, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, pp. 378-391, <https://doi.org/10.1016/j.egyr.2020.01.011>

This Version is available at:

<https://hdl.handle.net/10419/244041>

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## Research paper

## Analysis of the robustness of energy supply in Japan: Role of renewable energy

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## ARTICLE INFO

## Article history:

Received 16 August 2018

Received in revised form 11 December 2019

Accepted 29 January 2020

Available online xxxx

## Keywords:

Energy supply

Energy security

Energy policy

Energy efficiency

Renewable energy

## ABSTRACT

Today, the security of energy has become one of the primary concerns of all the countries around the world due to the limited energy sources, increasing population, energy prices fluctuations and limitations in energy supply. Japan is considered as one of the largest energy consumers and energy importers throughout the world which almost 96% of its primary energy supply in national level relies on the imports from other countries. After experiencing several harsh energy supply conditions over the last 40 years, Japan realized the sensitivity of its energy supply and decided to fundamentally restructure its energy supply and rely more on energy mix diversification, renewable energies, energy efficiency improvement, and carbon emissions reduction. In this article the energy security improvement and the government actions to boost diversification of energy by focusing more on renewable energies and reducing energy intensity, increasing energy efficiency and decreasing energy import dependency in Japan is studied. In addition, various renewable energy technologies as a substitute source of energy and promising ways of domestic energy supply as well as the factors to improve the security of energy supply are studied thoroughly. Moreover, it was realized that the most primary energy sources in Japan are biofuel and waste energy followed by hydropower and geothermal energy respectively.

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## 1. Introduction

Constant supply of various types of energies is essential for all human societies throughout the world which guarantees the existence of creatures and civilizations. The consumption of energy as a result of rapid growth of population around the world and also improvement of life quality has been increased considerably that proper access to different energy resources is completely essential for human beings (Hoppe et al., 2016). The total energy consumption in the whole world during the years 1950 to 2010 has increased from the amount of  $85 \times 10^{18}$  J or 86 Exajoule (EJ) to 503 EJ although the Growth Domestic Product (GDP) had the same growth rate and also it has been predicted that the global energy consumption will be extended up to 1000 EJ in 2050. In addition, high dependence of developed countries around the world on nonrenewable resources like different kind of fossil fuels reduces not only these conventional reserves but also leads to

many unfavorable environmental effects such as CO<sub>2</sub> emission that has increased considerably from 310 ppm in 1950 to 390 ppm in 2010 which causes air pollution and climate change that is dangerous for the human health (Hoppe et al., 2016; Moriarty and Honnery, 2012; Sovacool, 2012; Zhang et al., 2019a; Li et al., 2000; Zhang et al., 2019b).

Moreover this intense consumption of various energies including fossil fuels to supply vital services for human societies like heating and lightening not only has caused a serious climatic changes but also brings about several energy security risks in the case of unexpected energy cuts which might affect human life unfavorably and jeopardize the future of next generations (Erdal, 2015).

Oil crisis in the 1970's as well as the oil prices fluctuations during these years has intensified the importance of the security of energy supply which has attracted many attention throughout the world (Frondel and Schmidt, 2000). Basically the reliable access to various type of energy at all times and in adequate amounts and rational prices which does not have any negative impact on the environment and the economy is commonly considered as the energy security definition (Knox-Hayes et al.,

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2013). The energy availability which is one of the essential aspects of energy security is defined as the physical existence of various energy resources in a most sustainable manner. Although because of the price fluctuations over the time, the affordability as one of the energy security aspects cannot be defined precisely, reliability as another aspect can be defined as the constant and sufficient supply of energy can fully meet all the global economy needs that without any disruption. Moreover the energy security definition also has a social aspect which in terms of environmental concerns defines the acceptability of different energy sources which is one of the most important aspects (Erdal et al., 2015; Wonglimpiyarat, 2009; Von Hippel et al., 2011). Different countries around the world are trying to promote their energy security in different ways such as reducing the energy intensity by investing more on the advanced technologies which is one of the most efficient ways to reduce the consumption of energy and production costs (Erdal, 2015; Felgenhauer and De Bruin, 2009). In addition, increasing the energy efficiency and decreasing the dependency on energy imports as well as increasing domestic energy supply potentials and diversifying the energy mix by focusing more on boosting renewable resources as a substitute sources of energy are the factors to improve the security of energy supply (Balat, 2010; Uchiyama, 2002). Reducing the risks of energy market disruptions by diversifying energy resources is an essential way of enhancing the energy security (Lesbirel, 2004). Therefore different energy policy methods such as diversification of energy supply via alternative suppliers and alternative routes, industrial globalization and also diversifying fuel types and using renewable and sustainable energies as a new types of energies is essential for those countries that are highly dependent on foreign energy resources (Neff, 1997). Moreover enhancing the self-sufficiency of energy and reducing the energy import is very important for energy importing countries (Chen et al., 2014). In addition, energy diversification by increasing the use of renewable energy and also reducing the share of fossil fuel generation reduces the greenhouse gas emissions (Awerbuch et al., 0000). Expanding the economy and also achieving to the sustainable development goals for the most industrialized nations and any developing countries is highly dependent on energy sufficiency (Lu et al., 2016). Therefore, renewable energy resources as the green energy resources by prospering the path of sustainable development can have a considerable role to solve the environmental issues (Kumar et al., 2017). In addition, renewable energies as a clean and domestic energy sources by having the slightest environmental impacts can be the best substitutes for the fossil fuel resources such as coal, natural gas and oil which are the main sources for many non-renewable energy systems such as coal powered power plants and hydrocarbon combustion engines that produce a large amount of greenhouse gases which adversely affect the environment and global warming (El-Farra and Christofides, 2017).

Fig. 1 shows the conceptual framework of the analysis. As can be seen, various renewable energies like wind energy, biofuel and waste energy, solar energy, hydropower energy and geothermal energy have all the qualities of energy security which are availability, affordability and sustainability and it simply improves the energy security in different countries.

In this study a comprehensive analysis on more than ten years research and study on the energy supply in Japan is presented. In addition, the importance of promoting diversification of energy, increasing energy efficiency and also reducing energy intensity as a main policy for dealing with energy security problems in Japan was studied. Furthermore, different government actions to boost diversification of energy and increase renewable energies by providing different incentive systems are presented. Moreover, various renewable energy technologies such as biofuel energy,

hydro power energy, solar energy, geothermal energy and wind energy as an alternative source of energy and favorable ways of domestic energy supply as well as the energy supply security promoting factors are reviewed. Moreover, the importance of decreasing carbon dioxide emission because of increasing use of fossil fuels in Japan is mentioned.

The remainder of the paper is prepared as follows. In Section 2, the framework of energy supply in Japan is presented. Section 3 presents the main objectives and importance of diffusing renewable energies in Japan. A thorough overview of renewable energy sources are presented in Section 4 and discussion and conclusion are presented in Sections 5 and 6 respectively.

## 2. Analytical framework of energy supply in Japan

Japan by being consisted of more than 6850 islands and the land area of 378 000 square kilometers is a country located in the Pacific Ocean in East Asia that mountainous regions account for about 70% of the its total area. Japan has a temperate climate and a population of 127 million that is predicted to be reduced to 124 million by the year of 2021. After the three countries of China, the United States and Germany, Japan is considered as the fourth biggest exporter in the world. The main export goods are engines and machines, vehicles, and electronic equipment. Unemployment rate of 3.4% in Japan is very low in 2015 (IMF, 2015; Maeda and Kamada, 2009c). According to the International Monetary Fund in 2015, the amount of its GDP was 4.1 trillion US Dollar. Relying more on import of the considerable amount of primary energy supply and industrial raw materials as well as expenditures is one of the critical issues in Japan which has few mineral resources and is one of the largest energy consumers and importers in the world (IEA, 0000). Imported energy consists of 96% of the total domestic energy consumption in Japan which makes this country highly dependent on imported energy resources. In 2015, import of energy accounted for 434 million tons of oil-equivalent (Mtoe) and exports to 19 Mtoe. Imported crude oil and different oil products by the amount of 215 Mtoe; coal by the amount of 120 Mtoe and natural gas by 99 Mtoe accounted for the total imported energy resources which respectively contain 49.5%, 27.7% and 22.7% of the total energy consumption of Japan. Among various sectors, transportation by 37.5% and industry by 30.9% accounted for total demand of Japan's consumption. The Total Primary Energy Supply (TPES) and energy production of Japan between the years 1973 to 2015 is shown in Fig. 2. As it is shown in Fig. 2.a, due to the great earthquake which hit the east part of Japan in March 2011 and its subsequent impacts there has been a sudden reduction of total energy consumption. Fig. 2.b shows the energy production in 2015 that biofuels and waste by 37.5% are the most amount of energy production in Japan and after that, hydro energy by 24.1%, natural gas by 8.5%, nuclear energy by 8.1%, solar energy by 11%, geothermal energy by 7.8%, oil by 1.6% and wind energy by 1.5% are respectively the main energy productions in Japan.

In the year of 2010 and before the earthquake disaster nuclear energy, renewable energies and natural gas and oil accounted for 75.9%, 20.2% and 3.9% of the domestic energy production, respectively. However after since 2010, solar energy technologies, biofuels and waste have had a noticeable growth of 207.8% and 19.7%, respectively (IEA, 0000; Sheng et al., 2013).

The situation of energy supply in Japan after the nuclear disaster in Fukushima on March 11, 2011 changed and Japanese government tried to substitute the loss of nuclear energy in power sector which was facing the –62.9% reduction in production rate with additional low Sulfur crude oil, natural gas and fuel oil (Fig. 3) (Energy White Paper, 2012).

As shown in Fig. 3, Fukushima nuclear power plant disaster in 2010 and 2011 changed the primary energy distribution of

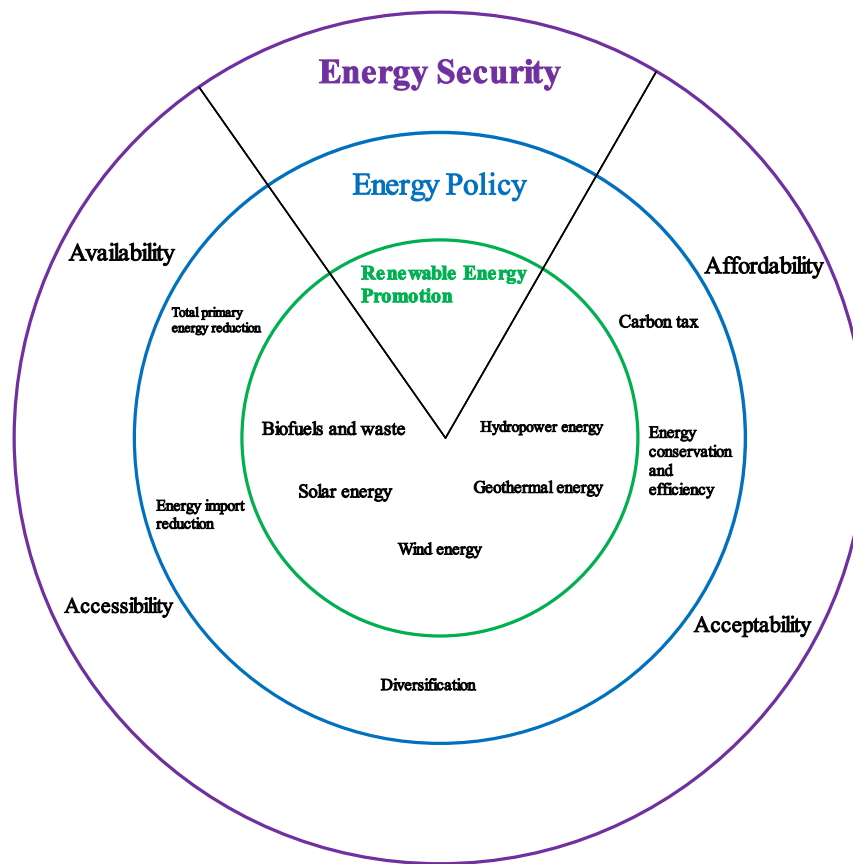


Fig. 1. Conceptual framework of research.

Japan and by declining the nuclear energy production by 64.5%, natural gas driven thermal power plants increased their energy production levels to deal with the power shortage and as a result of this heavy operational load CO<sub>2</sub> emission levels increased by 4.1% from 2011 to 2012 (METI-Japan, 2013; Amagai et al., 2014; Mclellan et al., 2013).

As nuclear energy supplies only 13% of the overall primary energy consumption of the country before the accident, Japan for reducing its dependency on oil and also achieving a stable and environmentally safe energy supply, was highly dependent on nuclear power as the energy basis for its central energy security strategy. Therefore the Fukushima accident in 2011 brought a new outlook on the energy security challenges in Japan and made the reliability of nuclear power plants highly questionable (Erdal et al., 2015).

Japan after the Fukushima disaster decided to change its energy system structure fundamentally by 2030 and by focusing more on diversifying its energy mix (more relying on renewable energies, less fossil fuels consumption and restarting its nuclear power plants when announced that they are safe) and restraining its carbon emissions, reconsider its energy policies (Vivoda, 2012). The government by building on these plans after these serious energy challenges has outlined the aspiring goals to reduce 26% of its greenhouse gas emissions between the years 2013 and 2030 (IEA, 0000). Therefore, the possibility of potential energy crisis for the country by diversifying the types of primary energy consumed and also the geographic distribution of the supplying energy sources can be reduced immensely (Vivoda, 2012).

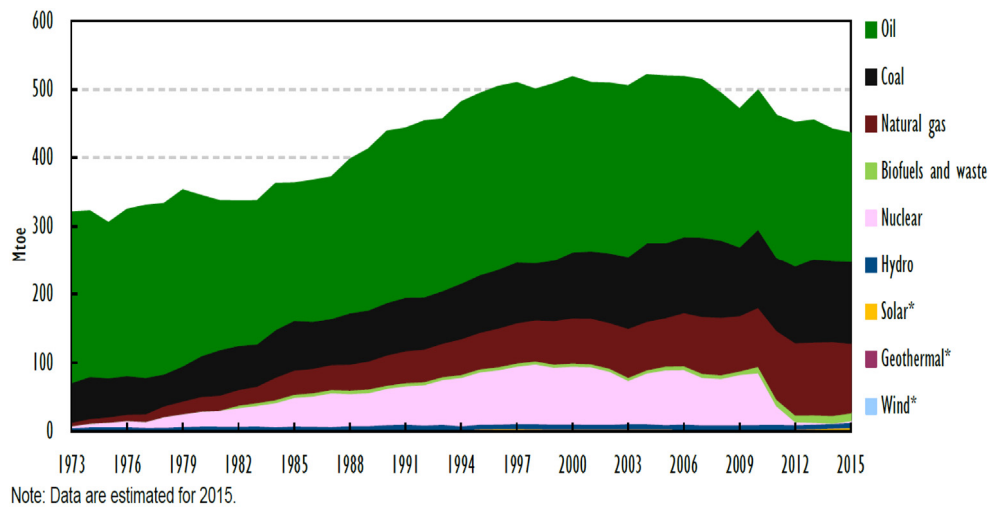
In addition, energy resource diversification helps in responding to external price changes and minimizes the susceptibility of a single energy source. After the great oil crisis during 1970s, Japan designated a planned energy policy in order to reduce

its dependency on energy imports, especially on Middle Eastern oil. Besides reducing energy import dependency, the diversity of the energy mix and source were the primary energy concern for the country. Japan, like many other countries, has regarded diversification of energy supply as an effective policy measure for sustainable growth and energy security (Ozkan et al., 2016). Therefore, based on revised energy policy plans, four possible energy mix strategies including nuclear supply share from 10% to 35% for the three different pathways each coupled with a considerable portion of renewable energy and fossil fuels to replace nuclear and also one totally nuclear-free pathway has been considered for the future of energy supply of Japan (Hong et al., 2013).

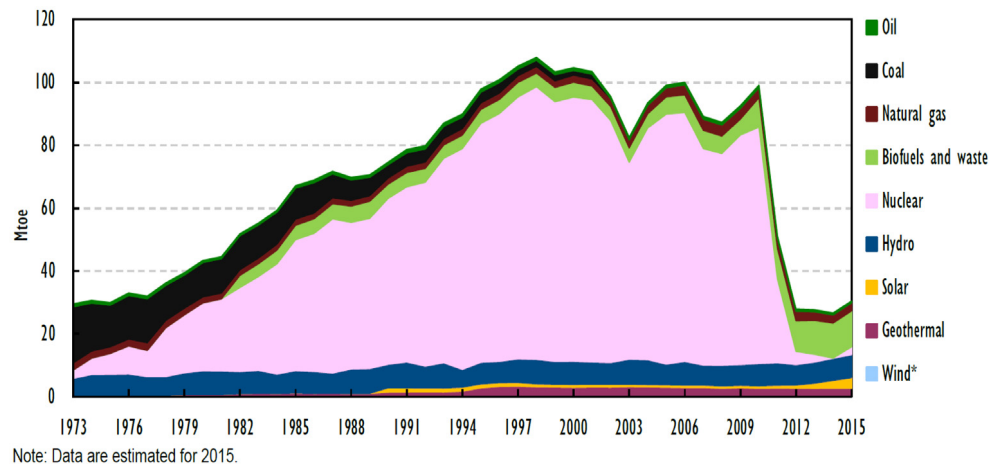
The economic development for the country according to the designated strategic plan was mostly based on the energy efficiency improvement and development of various renewable energy resources. Japan based on this designated plan decided to increase the share of renewable resources to over 9% in the total energy supply sources. As a result of these policies the energy efficiency as well as the investment on renewable energy resources increased considerably and oil import dependency decreased from 77.4% in 1973 to 43.7% in 2010 in Japan (Agency for Natural Resources and Energy, 0000).

### 3. Objectives of renewable energy dispersal in Japan

Renewable energies, as low-carbon domestic resources, can increase the energy security by diversifying the energy mix and can be considered both a practical challenge and a strategic opportunity in Japan's energy policy objectives that reduce the energy import dependency as well as the CO<sub>2</sub> emissions of the country. Japan by having a varied renewable energy resources, including



(a)



(b)

Fig. 2. (a) TPES and energy production of Japan between the years 1973 to 2015, (b) Energy production by source, 1973–2015 (IEA, 0000).

solar energy, wind energy, geothermal energy, hydropower as well as biomass energy can minimize the nuclear energy consumption which is one of the government's stated objectives for the future energy plan (IEA, 0000). Fig. 4 shows the share of renewable energies that are accounted for 24.9 Mtoe or 5.7% of the total TPES of Japan in 2015. Biofuel and waste energy by the share of 2.6% of TPES or 11.4 Mtoe or hydropower by 1.7% of TPES or 7.3 Mtoe are considered as the main sources of producing electricity in Japan and grew about 11.3% in 2015 compared to 2005. In addition, solar energy by the share of 3.4 Mtoe or 0.8% of TPES and wind power by the share of 0.5 Mtoe or 0.1% of TPES have been increased 15.9% and 11.7% from 2005 to 2015 respectively. Moreover, geothermal energy by the share of 2.4 Mtoe or 0.5% of TPES has experienced 2.3% decrease rate from 2005 to 2015.

During the oil crisis in 1979, Japan in accordance with the “Act on the Promotion of the Development and Introduction of Alternative Energy” and through alternative-energy policies, started to lower its dependence on oil. However, the country has a plan to promote the environmental friendly industries and diversify its energy sources as well as increasing the share of renewable energies in its energy mix to about 10% by 2020.

### 3.1. Energy security and diversification

Proper access to different energy resources with affordable and reasonable prices is not only important in preserving the economic prosperity but also in national security as well. Energy security has particularly been considered as an important challenge for many countries like Japan, that are deprived are many natural resources like fossil fuels and rely mostly on imports to meet their consumption needs (Erdal et al., 2015). Renewable energy markets have been growing considerably in Japan and Japan has promoted its renewable energy potentials not only to diversify energy sources and alleviate the unfavorable fossil fuel overconsumption impacts, but also to improve its energy security in a national level. Furthermore, two oil crisis in the 1970s and the Fukushima nuclear disaster in 2011 has gathered a lot of attention globally in renewable energies as an alternative source of energy to nuclear power and oil (Chen et al., 2014).

Small hydropower and geothermal energy by the power of around 10 Mega Watt (MW) or even smaller based on the renewable energy development strategies in Japan are more on the focus. Therefore, as a result of this strategy, most of the current small hydropower plants (about 95%) and geothermal energy capacity (about 95%) in Japan were constructed and attained



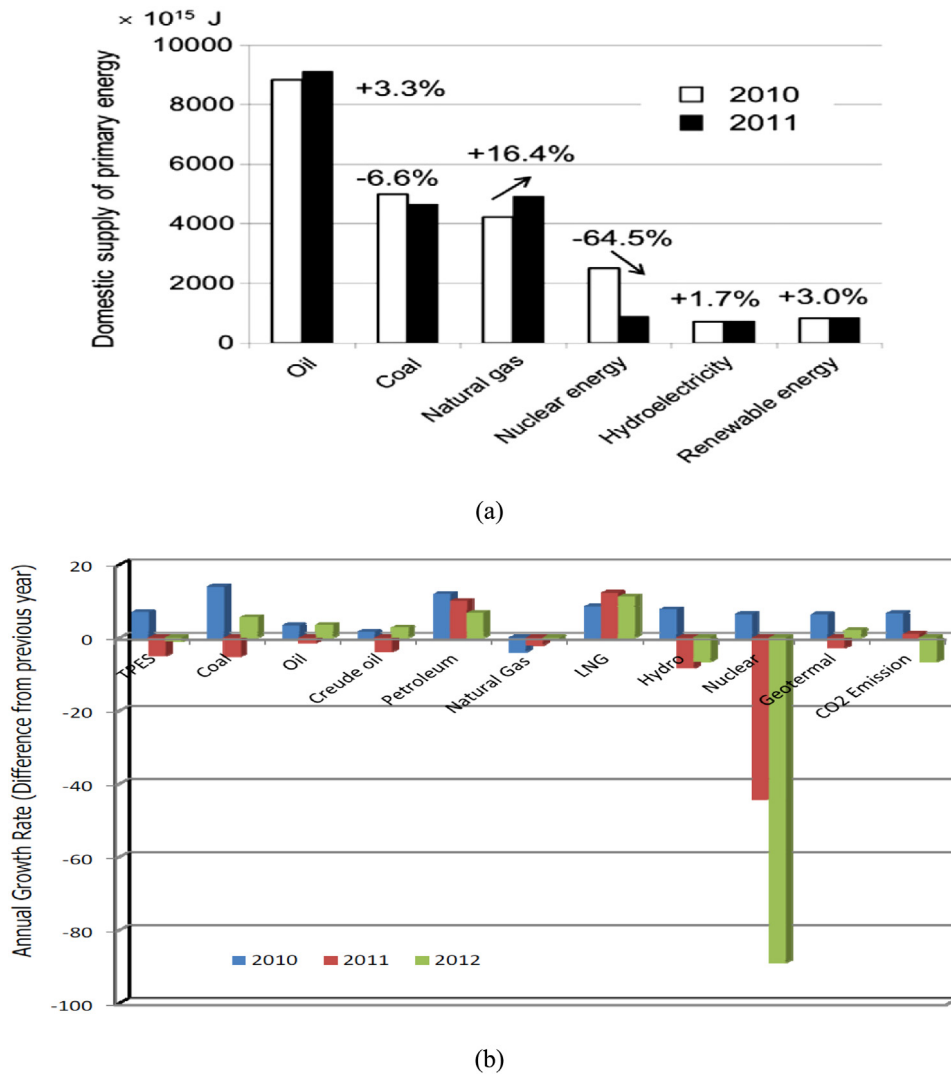


Fig. 3. (a) The primary energy distribution of Japan in 2010 and 2011 (Amagai et al., 2014), (b) Annual growth rate of TPES of Japan (Erdal et al., 2015).

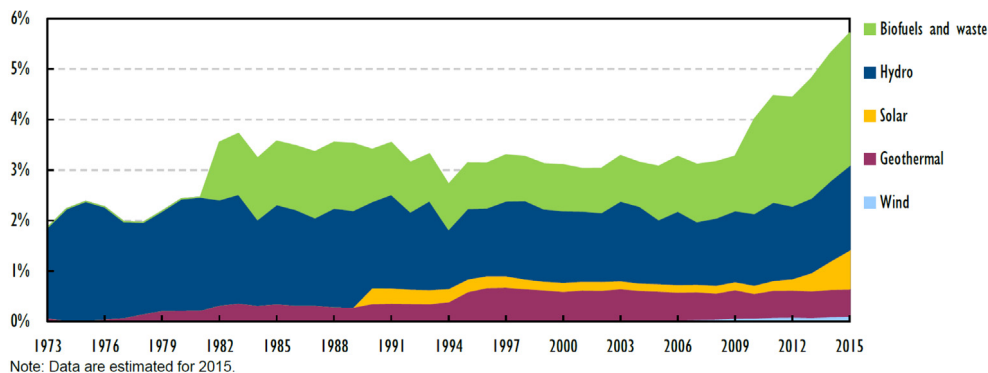


Fig. 4. Renewable energy as a percentage of TPES, 1973–2015 (IEA, 0000).

before 1990 and 1996 respectively (Ummayy, 0000). Japan has a plan that by using various strategies increase its current 39.2 GW of renewable energy capacity to 85.83 GW by the year of 2020, in which the share of hydropower by the amount of 21 GW of the total has a considerable amount of the total. The target components as well as the current components of various renewable energy sources in Japan are shown Fig. 5. Moreover in

the next decade Photovoltaic (PV) capacity and wind capacity as a result of this renewable expansion goal will be increased almost six fold and up to the 28 GW for the PV capacity and double the amount of current capacity and up to the 5 GW for the wind energy respectively (Sawin et al., 0000). If the goal is successfully achieved, the share of Solar PV would be one-third of the whole renewable energy capacity by 2020.

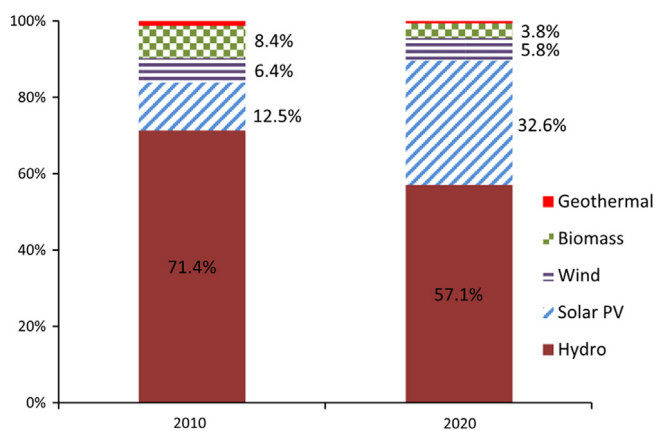


Fig. 5. Various renewable sources in Japan (Current situation and target components) (Sawin et al., 0000).

### 3.2. Energy efficiency

After 1973 oil crisis and 2011 nuclear disaster, the energy security of Japan is more susceptible today than it was before and therefore using mixed sources of energy has been considered as the primary Japanese energy policies. Therefore, the only suitable way to reduce the energy vulnerability in Japan is by improving the energy efficiency managed by Japanese government. There have been a lot of efforts to enhance the energy efficiency, which is the main strategy of Japan that is deprived of different domestic energies. The crisis also resulted in launching major government programs to promote renewable energies like solar energy, wind energy and hydropower energy (Jochem and Gruber, 2007; Moe, 2012).

Eikeland and Sæverud's (Moe, 2012) reported that energy efficiency is the most favorable way for the countries which are deprived of different natural resources and these countries should be the main candidates for energy efficiency enhancements as one of the energy security strategies. In addition, the seriousness of each countries energy problems can depict by the determination of a country on renewable energy policies. As energy efficiency and renewable energy consumption are on the top priority of environmental fields in the terms of tackling with climate change, resource conservation and also providing the proper energy access and creating new economic opportunities to the billions of people, the awareness of their influential role in energy and economic has been risen worldwide (REN21, 2015). In general, as the decline of economic growth as a result of reducing the consumption of energy is not acceptable. Therefore, it is essential for every economy to improve their energy efficiency without impairing or changing the economic performance (Honma and Hu, 2014).

After the March 11th earthquake disaster in 2011, Japan did a major effort in improving the energy efficiency and by changing the country's direction of future energy policy is expected to have an aspiring renewable energy policy. The energy efficiency in Japan is still a main Japanese strategy in a way that Japan still has the well-established energy efficient country image throughout the world (Moe, 2012). Although the energy import dependency would be stay constant in the year 2030, import bills due to the short-term energy efficiency developments compared with the current level will reduce 25%–30%. Moreover, as a result of energy efficiency improvement in the long-term coupled with renewable energies policy establishment, the import bills will fall by almost 70%. In comparison with predicted GDP growth, the fossil fuels import bills by 2050 are considerably separated from the real GDP

and their amount of GDP reduces from 2.6% in 2013 to 0.5–0.6% in 2050. Therefore, regardless of the accessibility of nuclear energy, this situation which is highly considerable for both the energy security enhancement goals as well as the decarbonization goals intensifies the energy efficiency development and the importance of renewable energies consumption (Oshiro et al., 2016). In addition, it is important to consider that improving energy efficiency by boosting renewables can reduce greenhouse gases (GHGs) and increases the share of renewable energy without new investment (Harmsen et al., 2011). Reducing carbon emissions globally which have extended to a dangerous and unbearable levels requires the energy sector transformation toward the increasing of energy efficiency and renewable energy consumption (Garrett-Peltier, 0000). Renewable energy systems are considered to be environmentally superior to conventional ones from the viewpoints of CO<sub>2</sub> reduction and the practical utilization of resources. Due to Kyoto Protocol Japan has increased its renewable energy intensity in order to improve energy efficiency (Chien and Hu, 2007).

### 3.3. CO<sub>2</sub> reduction

The amount of CO<sub>2</sub> emissions in Japan by 16% increase from the 1990 has amounted to 1.23 billion metric tons of CO<sub>2</sub> equivalent in 2013, that transportation sector by having a considerable portion of this amount accounts for 18% of CO<sub>2</sub> emissions (IPCC, 0000; GIO, 2015). Based on the United State Energy Information Administration, Japan in 2014 due to having a large fossil fuel based energy systems was the 8th largest CO<sub>2</sub> emitter in the world that in recent years these energy systems have resulted in serious problems such as high Green House Gas (GHG) emissions (U.S. Energy Information Administration, 2014). The amount of CO<sub>2</sub> emissions for different energy consuming sectors between the years 1973 to 2014 is shown in Fig. 6. The CO<sub>2</sub> emission due to the fuel combustion in Japan is estimated 1189 million tons (Mt) in 2014, which had a 14.2% more than in 1990 that coal and oil by having 39.1% and 38.2% of the total emission are considered as the largest CO<sub>2</sub> emitters. It is worth mentioning that GHG emissions in 2007 by having a steady increase reached to 1221 Mt and after faced a 12.5% decline during 2008–09.

As shown in Fig. 5, increasing the use of fossil fuels in power generation after the 2011 disaster and nuclear shutdown subsequently, CO<sub>2</sub> emissions increased by 11.8% from 2010 to 2014 which power generation accounting for 48.6% of the total in 2014 (by 46% growing from 1990 to 2014) was the largest CO<sub>2</sub> emitter sector. In addition industry and transportation each by 19.2% and 17.5% of the emission were the second and third most emitter sectors and the remaining 14.7% was due to the households, Services and other energy industries including refining and agriculture (IEA, 0000).

The goal of Strategic Energy Plan of Japan is to reduce 30% of the domestic energy-related CO<sub>2</sub> emissions by 2030 compared to the 1990 level (Ozkan et al., 2016). Various technologies like fuel shifting from coal to Liquefied Natural Gas (LNG) combined cycle as a less polluter and more affordable fossil fuel than oil, boosting renewable technologies like wind and PV, rechargeable battery and electricity saving, shifting from conventional fossil fuel driven engine vehicles to electric vehicles in order to limit CO<sub>2</sub> output from transportation and Carbon storage and carbon capture at point sources such as large fossil fuel power plants in order to reduce CO<sub>2</sub> in the energy industry and etc. have been established and developed in recent years to decrease CO<sub>2</sub> emissions from each sector (Komiyama and Fujii, 2015; Lipponen et al., 2011; Markusson et al., 2011). Nuclear power generation as a zero-emission power source that does not emit CO<sub>2</sub> during plant operation has been used for a long time as a primary source

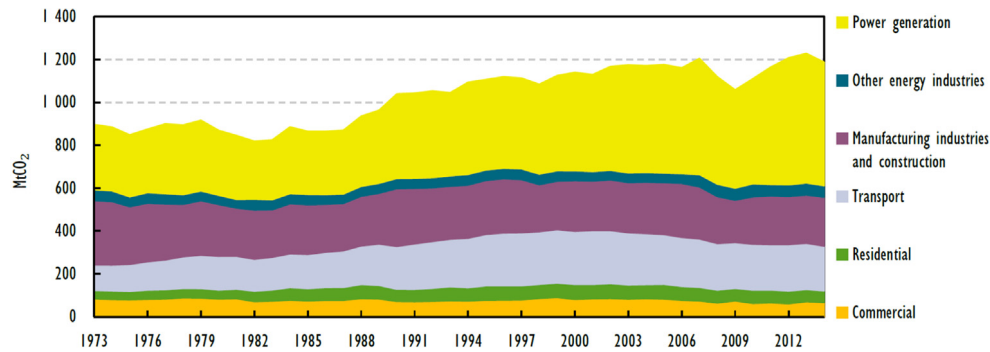


Fig. 6. CO<sub>2</sub> emissions by sector, 1973–2014 (IEA, 0000).

of power generation to reduce CO<sub>2</sub> emissions to prevent global warming (Ozkan et al., 2016). However, after Fukushima incident The Strategic Energy Plan revised in July 2011. The government decided to foster renewable energies significantly. Moreover, it has been revealed based on the environmental concerns that increasing the share of other alternative resources such as solar energy and also promoting renewable energies in power generating sectors should be supported by a major energy policy reviews that would contribute to Japan's energy supply system (Vivoda, 2012).

#### 4. Overview to renewable resources in Japan

##### 4.1. Biofuels and waste

Based on the Kyoto Protocol biofuel program using by-products and unutilized agricultural products is being promoted by Japanese government, in order to not have a negative impact on domestic food accessibility. In addition biofuel program promotes rural development and is a favorable way to tackle with climate change and energy security (Koizumi, 2013a). However as share of renewable energy sources of TPES has increased from 4.0% in 2010 to about 5.7% in 2015, which this amount of growth accounted for 24.9 Mtoe, biofuels and waste by the amount of 11.4 Mtoe or 2.6% of TPES play an integral rule in renewable energy development strategy. In addition, biofuels and waste by 37.5% growth have the highest share of energy production in 2015 among other renewables. It is worth mentioning that about 70.4% of biofuels and waste supply (about 7.8 Mtoe) are consumed for heat and electricity generation and only the slight amount of it is used in the industrial sector (2.7%) and a really small amount in households (Fig. 4) (IEA, 0000; Kang et al., 2015).

Matsumoto et al. (2009) reviewed the future potential of biofuel and also biofuel initiatives in Japan. Koizumi (2013b) reviewed improvements and outlooks toward the Japanese biofuel program and stated that biofuel programs in order to solve the environmental and energy security problems and also to improve the rural development is getting the considerable attention by the Japanese government. Moreover, it was also concluded that the Japanese biofuel program and the economic analysis of domestic biofuel markets and programs needs to be performed. Since the price of biofuels is high currently, the Japanese government has done some actions like tax reduction for biofuel manufacturing facilities and establishing subsidies to boost biofuel production and utilization and also reduce greenhouse gas emissions (Marquardt, 2015). In addition, increasing the efficiency of biofuel by using more advanced equipment which is the most necessary factor in extending biofuel production and doing further researches by domestic research institutes, private companies and universities are actions to boost the production of biofuel and reducing the GHG emission (Koizumi, 2013a). For instance,

The Japanese government under the Kyoto Protocol started its biofuel programs and committed to reduce its 1990 greenhouse gas emissions by 6% between the years 2008 to 2012. In order to promote the bioethanol utilization and production, the tax policy was established in 2008. At the first stage of biofuel expenses reduction policy, for the first three years, the biofuel manufacturing facilities fixed-assets tax reduced by 50%. The second stage, the tax reduction for the portion of bioethanol in bioethanol-blended gasoline was established. Moreover, promoting the biodiesel fuel production containing the vegetable oil mixed with diesel used by official cars, public buses and municipal garbage trucks is getting a great amount of attention among the Japanese municipal government and non-governmental organizations.

##### 4.2. Hydropower

Japan is deprived of many natural resources and for supplying its oil, natural gas and coal supply relies highly on the imports. Therefore as the most of its fossil fuel energy is imported from politically unstable countries like middle eastern countries and also in order to cope with the problems of global warming, power generation systems using renewable energy sources like hydropower are attracting much attention in Japan (Komiya and Fujii, 2013). After the 2011 disaster in Japan, the Japanese society has realized the importance of alternative sources of energy in the situation of energy shortage crisis. Therefore, small scale energy generated renewable energies in dispersed locations are getting an increasing attention (IMF, 2015; Maeda and Kamada, 2009c; IEA, 0000). To make the distribution of renewable energy technologies through the country much easier, the feed-in-tariff scheme for renewables was introduced by the Japanese government in July 2012 (Komiya and Fujii, 2013; Ueda et al., 0000; Esteban and Portugal-Pereira, 2014). Hydropower energy by having more than 100 years of historical background and as a domestically produced renewable energy, was the main electricity generation method in Japan until the 1960s and had a significant role in developing the economic situation and modernizing of the country (Koyama et al., 2014; Mitsumori, 0000). Hydropower by 7.3 Mtoe has a share of 1.7% in the total 5.7% or 24.9 Mtoe growth of renewable energy sources in TPES and 24.1% in domestic energy production from 2010 to 2015 (IEA, 0000). Although rivers in Japan during recent years has utilized for power generation considerably, it has been estimated the Ministry of the Environment that these rivers and canal networks still has the small-and medium-scale hydropower generation potentials reserves up to 14,440 MW (Ueda et al., 0000). Until the 1950s, hydropower energy in Japan due to numerous favorable sites with suitable geographical situation and sufficient water was the most effective electricity energy production source throughout the country. There are a large number of mini or micro hydropower (MHP) facilities which are mostly located in



steep slope lands in mountains and have a potential to produce electric power up to 1 MW (Fujii et al., 2015). Fig. 7 shows the location of various power plants including hydroelectric power plants dispersed through Japan. As it can be perceived from the picture, hydro power plants are in the center of attention and their number is increasing significantly to supply a great portion of renewable energy of Japan in the foreseeable future (IEA, 0000).

However, small hydropower generation due to the various benefits such as this type of power generation (1) can locally be produced and consumed (2) can be contributed to the domestic or local economy, (3) can be considered as a stable source of energy that because of their physical constraint on siting additional capacity are set at constant generation quantities, (4) and they almost have no environmental side effects, and (5) they can create new job opportunities and etc. among other types of renewable energies, has been attracting much attention in Japan. On the other hand, (1) high initial costs, (2) difficulties in adjusting to time-consuming administrative regulations, (3) Not-applicable Feed in Tariff (FIT) for all the facilities, and (4) high maintenance cost, are the various challenges of small hydropower (Mitsumori, 0000; Nakata, 2000).

#### 4.3. Solar

Japan in response to the 1970s oil crisis and 2011 Fukushima disaster has set to develop alternative sources of energy and expand the capacity of its renewable energy from the current amount of 39.2 GW to 85.83 GW by 2020. Thus, until the early 2000s solar energy enhancement was one of the main priorities for the country. The country has a plan to increase its PV capacity by FIT and loss interest rate loans to 28 GW – almost six fold – in the next decade (Sawin et al., 0000; Chiaroni et al., 2014). By achieving to this goal one-third of the total renewable energy capacity will be supplied by solar PV by the year of 2020 (Chen et al., 2014; Moe, 2012).

Renewable energies accounted for 5.7% of Japan's TPES in 2015 (or 24.9 Mtoe) that the share of solar power in Japan's TPES from 2005 to 2015 is 15.9%, that a great portion of this produced electricity (about 85%) is used for commercial electricity and the remainder is used by households and heat generation. The renewable energy electricity in 2015 by having the 16.9% of the total electricity generation accounted to 170.7 TWh that solar electricity had the share of 36 TWh or 3.6% of this amount. The share of renewables especially solar energy in the total energy basket of the country has increased from 8.4% in 2005 (or 95.2 TWh). In addition it has been estimated that the generated renewable electricity will grow about 13.5% in 2020 and 23% in 2030 which solar power by 20-fold growth will account for about 7%, corresponding to 74.9 TWh (IEA, 0000). Moreover, there might be some challenges like limited land area which might be a one of the serious barriers for renewable energies promotion in Japan (Os- hiro et al., 2016; OECD, 0000). Besides these challenges there have been many policies to boost solar energy technology in Japan. After the first oil shock, ministry of economy, trade and industry in 1974 by recognizing of the country's energy susceptibility, has set up a 25-year R&D plan called the "Sunshine Project" to develop solar energy technologies. Besides Sunshine project, considerable increasing of solar energy budget by 200% and establishing a new agency of New Energy and Industrial Technology Development Organization (NEDO) in 1980 were the actions for fostering renewables. The "Law Concerning the Promotion of the Development and Introduction of Alternative Energy" in 1980 was established to promote the development of alternative energies and also reduce the Japan's oil dependency (IEA, 2008; Kimura, 0000; Duffield and Woodall, 2011). Furthermore the government and private sectors considerable investment in renewables particularly in solar energy and also tax incentives for homes and

buildings to install solar photovoltaic equipment have caused that the share of renewable energy, particularly solar photovoltaic in Japan increase considerably (METI-Japan, 2012). Fig. 8 shows the renewable electricity generating capacity (excluding large hydro) for the years 2003 to 2014. The solar PV investments due to the FIT system incentives as it is revealed in Fig. 8 has increased considerably in a way that during the four years (from July 2012 to January 2016), the installed renewable energy capacity under the FIT system reached up to the 26.9 GW. In addition, the domestic installation of solar modules between the years 2011 and 2012 increased by 171% (Esteban and Portugal-Pereira, 2014).

#### 4.4. Geothermal

Japan by having many volcanoes as well as approximately 28,000 hot springs in the country has the third ranking geothermal energy potential, and the eighth ranking of geothermal electricity production in the world and is famous for its geothermal energy (Antics and Sanner, 2007; Sugino and Akeno, 2010; Sarkar and Bhattacharyya, 2012). It is worth mentioning that majority of the geothermal power plants in the whole world were built after the 1973 oil crisis and between the years 1970s and 1980s. The fact that geothermal energy does not need to be imported and is basically free and also the urgent growing demand for electricity generation from alternative energy sources led to non-optimal plant designs for geothermal resources. Sarmiento and Steingrimsdottir (0000) and Kanoglu (2002). During the year 2009, the number of the geothermal power plants in building operation were 20 at 17 locations nationwide which most of them are located in the Tohoku and Kyushu districts. In 2006 the total net power output from all the geothermal power plants, reached to the amount of 535.26 MWe. The details about different geothermal power stations in Japan including their locations has been shown in Fig. 9 (Sugino and Akeno, 2010).

Geothermal resources by providing 2.4 Mtoe or 0.5% in the total 24.9 Mtoe or 5.7% of TPES, and 2.6 TWh electricity are considered as the significant energy resources in Japan (IEA, 0000). The Japanese government by using various energy policies like FIT scheme and subsidies as in its 2014 Strategic Energy Plan has been trying to encourage investors to facilitate geothermal power development (IEA, 0000).

#### 4.5. Wind

After oil crises in 1979 and Fukushima nuclear disaster Japan has initiated various efforts to lower its dependence on oil by focusing on alternative energy sources and diversifying the country's energy basket, improving the electricity sector and facilitating the penetration of independent producers. The country has a plan to reduce the global warming, diversify its energy resources, and also promote the environment-related industries that can provide a faster recovery from unexpected accidents by increasing the share of renewable energies up to the 10% of its energy mix by the year of 2020 (Erdal et al., 2015; Sakaguchi and Tabata, 2015). The investment on wind energy as an environmentally friendly and the cheapest form of renewable energy is increasing throughout the world (Yaniktepe et al., 2013). In 2015, wind power had the share of 0.5 Mtoe or 0.1% of total (24.9 Mtoe or 5.7%) of Japan's TPES from renewable energy and the total installed wind capacity in Japan with annual growth of 11.7%, reached 3038 MW (IEA, 0000; Supply, 0000). Fig. 10 shows the number of turbines as well as the total installed wind capacity in Japan. As can be seen, Japan restructured its national energy policy and started to develop wind energy supplies to build a reliable supply of domestic renewable energy and decrease

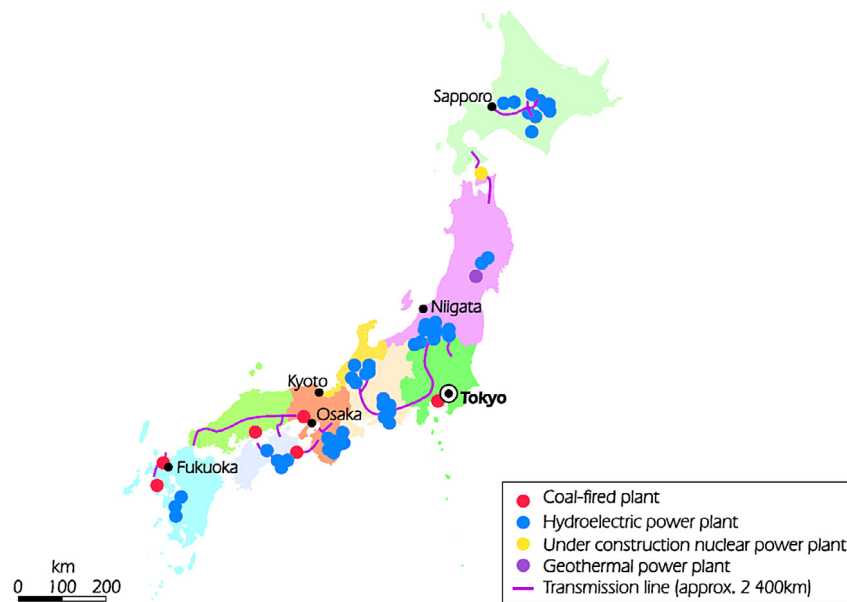


Fig. 7. The location of various Japan's power plants including hydroelectric power plants (IEA, 0000).

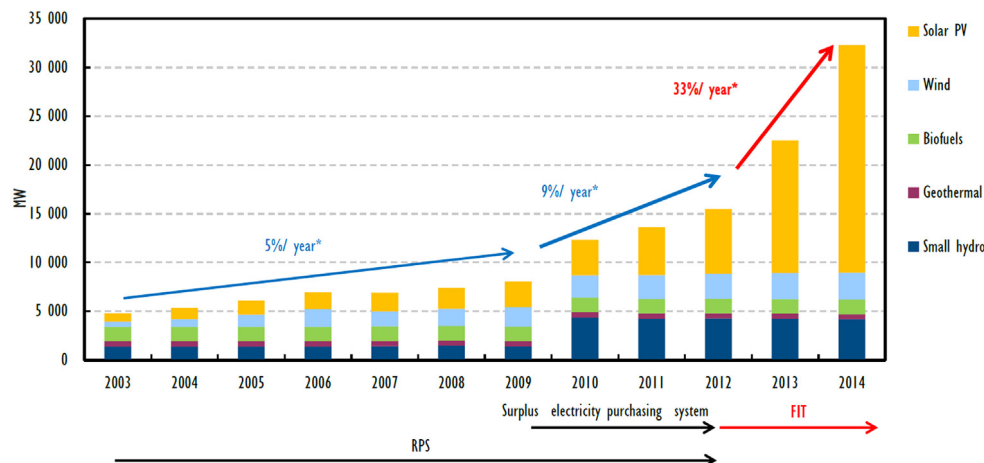


Fig. 8. Renewable electricity generating capacity (excluding large hydro) for the years 2003 to 2014 (IEA, 0000).

the nation's reliance on nuclear power (U.S. Energy Information Administration, 2015).

Wind power, is expected to play a critical role for developing a sustainable energy system and tackling with the energy and climate change concerns in Japan (Komiya and Fujii, 2013). The economic effect of constructing wind power plants is large.

Quantitatively, as the energy provided from one windmill unit to the grid is much more than one rooftop solar panel. Therefore, wind energy in terms of grid lines requires a bigger investment and provides more power per energy unit (Global Wind Energy Council, 0000a). There have been a lot of efforts to support wind energy in Japan. Fig. 11 shows the installed capacity of wind energy in Japan with various policy instruments up to 2012. Renewable Portfolio Standards (RPS), based on "Special Measures Law Concerning the Use of New Energy by Electric Utilities" and capital subsidies were the two main market policies for wind energy in Japan. Capital subsidies started in 1998 and lasted until 2010 that because of that wind power capacity increased considerably to the amount of 2304 MW in 2010 (compared with the amount of 136 MW in 2000). After the year 2010, the NEDO capital subsidies hindered the growth of wind projects in 2010 and the installation of wind energy decreased 20% between the

years 2010 and 2011 (Global Wind Energy Council, 0000b; Association WVE, 0000; Maruyama et al., 2007; Inoue and Miyazaki, 2008; Mizuno, 2014).

In Japan, the incentive program was changed starting in July 2012 from investment subsidies and RPS to the FIT scheme (Pacific, 0000; Yousefi et al., 2017; Mortazavi and Maleki, 2019; Kahouli, 2019). The FIT system established highest price for renewable electricity suppliers.

## 5. Discussion

Having a secure, reliable and affordable energy supply is essential for the economic stability and development in every country. Japan as the fourth largest exporter country in the world imports 96% of its national primary energy needs from other countries and is highly dependent on external energy imports. After two most challenging energy crisis (1970 oil crisis and 2011 Fukushima nuclear disaster), Japan realized the sensitivity of its energy supply conditions and decided to fundamentally reconsider its energy policy and focus more on further diversifying its energy mix, boosting the share of renewable energies, reducing its carbon emissions and also improving its energy efficiency.

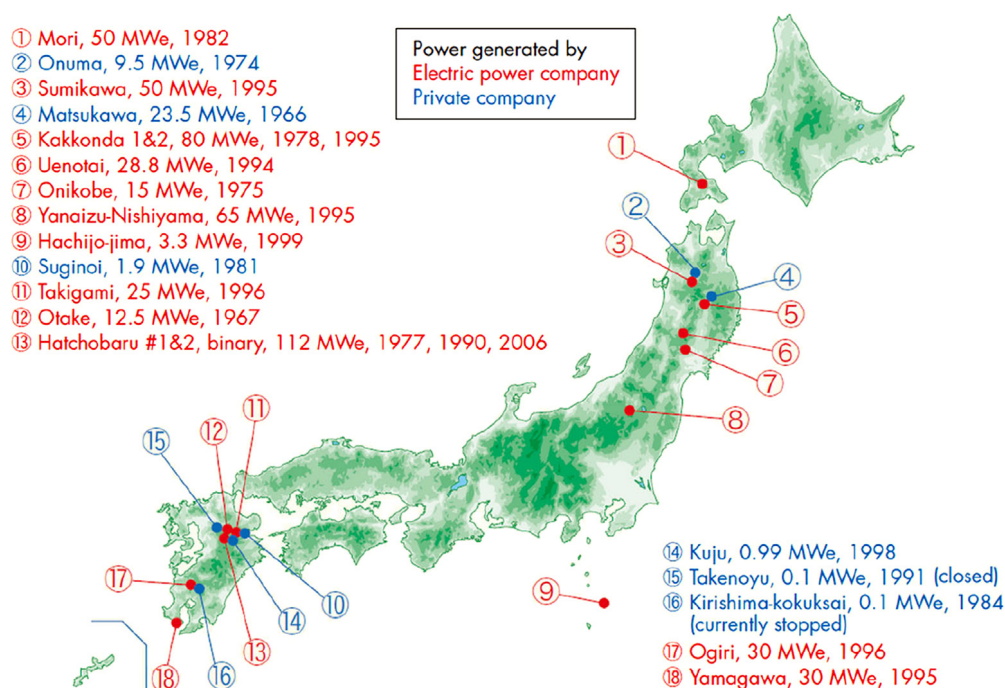


Fig. 9. Geothermal power stations in Japan (Sarkar and Bhattacharyya, 2012).

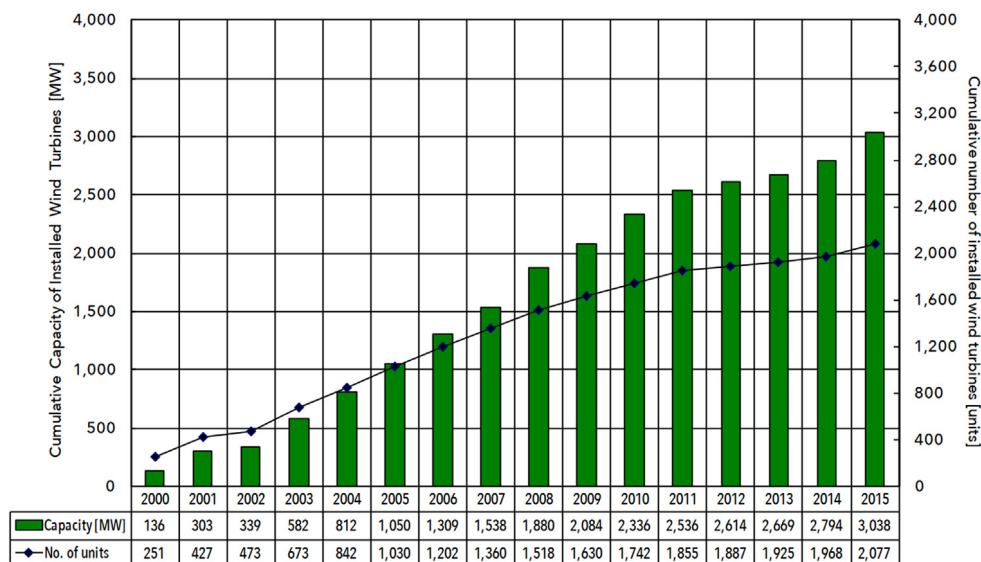


Fig. 10. Total installed wind capacity and number of turbines in Japan (Supply, 0000).

Renewable energies as a domestic source can be considered as a strategic opportunity in Japan's energy policy objectives that not only reduce the dependency of energy import but also by diversifying the energy mix, increase the energy security and as a low-carbon source of energy, reduce CO<sub>2</sub> emissions. There has also been an increased attention over the subject of renewable energies, supply of energy and energy security of Japan in recent years (Maleki, 2019; Zhang et al., 2019c, 2018; Maleki, 2018; Pal et al., 2018).

Technological advancement, suitable policies and feed-in tariff (FIT) systems, tax rebates, efficiency improvement in consequence to R&D efforts are among Japanese government actions to boost renewable energy resources as quickly and cost effectively as possible.

Table 1 shows the renewable energy policies that have been established in Japan. Japan by focusing more on energy supply diversification and importing its energy needs from many countries and not only dependent on a small number of suppliers as well as diversifying fuel types from conventional fossil fuels to renewable and sustainable energies, has started to increase its domestic energy resources and reduce energy imports. In addition, it is worth mentioning that by diversifying the energy supply mix, increasing the energy efficiency and also increasing the potential of renewable energies as domestic alternative and affordable resources, it is possible to improve the energy security of the country and also reduce the amount of greenhouse gas emissions by reducing the share of fossil fuel production. After the 1970 and the 2011 disaster in Japan, the energy policy was redesigned and the country is trying to diversify its energy supply

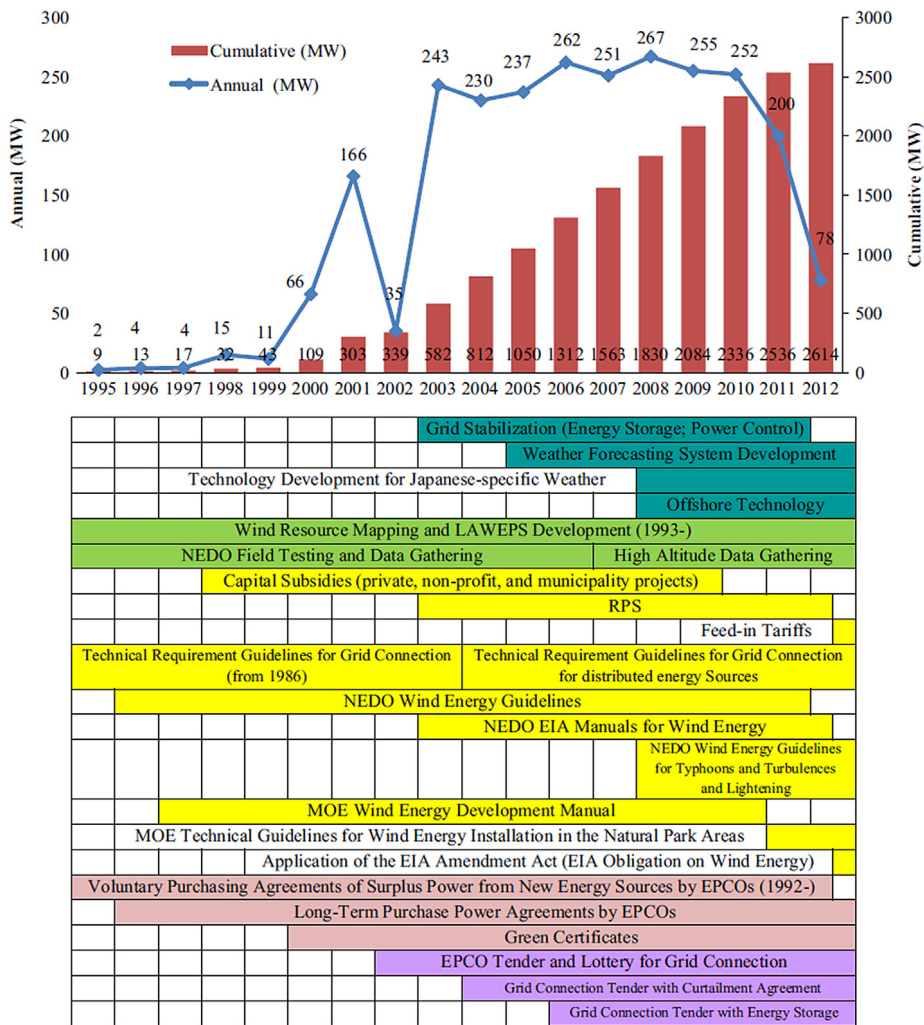


Fig. 11. Annual and cumulative wind energy installation and policy in Japan (1990–2012) (Mizuno, 2014).

resources. Moreover, Japan is maintaining and enhancing energy efficiency, promoting renewable energies as a potential alternative for conventional fossil fuels and reducing CO<sub>2</sub> emissions from the residential sectors toward 2030. However, it should also be mentioned that some barriers such as high cost of renewable energies and the access to the remote areas over the country, climate conditions and sufficient management for maintenance and repair of renewable energy systems have caused some challenges to the improvement of renewable energies in Japan (Mortazavi et al., 2019; Narayan and Doytch, 2017; Aslani et al., 2017; Ellabban and Alassi, 2019; Maji and Sulaiman, 2019; Yu et al., 2019; Ahmadi et al., 2019; Noorollahi et al., 2019).

In addition, the current and future potentials of different renewable energies in Japan were reviewed. Biofuels and waste by the share of 11.4 Mtoe or 2.6% of Total Primary Energy Supply (TPES) and by the share of 37.5% among other renewables have the highest share of energy production in 2015 that are mostly consumed for electricity and heat generation and is expected to grow considerably in following years. Moreover, hydropower energy by the share of 1.7% or 7.3 Mtoe in the total 5.7% or 24.9 Mtoe growth of renewable energy sources in TPES and 24.1% in domestic energy production from 2010 to 2015 and also by having the share of 16.9% of total renewable electricity generation (85.1 TWh or 8.4% of total electricity generation) is going to supply a considerable amount of Japan's electricity in the future. However, Japan by having a mountainous land with

suitable hydropower potential has a great opportunity to boost mini or micro hydropower (MHP) facilities as one of the main sources of the country's energy. However solar power by growing considerably (about 20-fold) and the share of 15.9% of the total amount of 24.9 Mtoe during 2005 to 2015, is going to grow above 7%, corresponding to 74.9 TWh by 2030, which most of this energy will be used for supplying commercial and households electricity and heat generation. Moreover, Japan by having the approximately 28,000 hot springs is famous for it is in the country. Japan's geothermal electricity production is currently rank eighth in the world and has a substantial potential of supplying heat and electricity in Japan and will be considered as one of most reliable domestic energy in the future. In addition, wind power by the share of 0.5 Mtoe or 0.1% of total (24.9 Mtoe or 5.7%) of Japan's TPES from renewable energy and the total installed wind capacity in Japan with 2077 turbines and the annual growth rate of 11.7% in 2015, reached to the amount of 3038 MW that 52.6 MW of this amount includes 27 offshore wind turbines. The net annual wind energy increase was 244 MW that by total energy production of about 5.223 TWh from wind turbines in 2015 supply 0.55% of the national electric demand (953.5 TWh).

6. Conclusion

In this article the security of energy and governmental actions in order to boost energy mix by focusing more on different



**Table 1**

Renewable energy incentive policies in Japan.

Policy title	Year of establish	Description of policy
Basic energy plan	June 2002	<ul style="list-style-type: none"> <li>Contains the Japan's energy policy and its basic principles in relation to:               <ul style="list-style-type: none"> <li>Safety</li> <li>Energy security</li> <li>Economic efficiency improvement</li> <li>Environmental sustainability</li> </ul> </li> </ul>
First basic energy plan	October 2003	<ul style="list-style-type: none"> <li>Nuclear power production promotion</li> <li>Reassuring the constant supply of oil</li> </ul>
New national energy strategy (Second plan)	May 2006	<ul style="list-style-type: none"> <li>Improving the energy security of Japan</li> </ul>
New basic energy plan (Third plan)	June 2010	<ul style="list-style-type: none"> <li>Goals to be achieved by 2030               <ul style="list-style-type: none"> <li>Enhancing the overall energy security of the country</li> <li>Using energy as the driving force to achieve the economic development</li> <li>Assuring the efficiency of energy markets</li> <li>Reconstructing the energy sector</li> <li>Assuring the safety of energy resources</li> <li>Reinforcing policy to deal with global warming</li> </ul> </li> </ul>
Strategic energy plan	April 2014	<ul style="list-style-type: none"> <li>Developed since the disaster at TEPCO's Fukushima nuclear reactor and the Great East Japan Earthquake</li> <li>Restructuring of the FIT system</li> <li>Promotion of disseminated renewable energy resources (solar power, biomass, renewable heat and small/medium hydropower)</li> <li>Diversified development of non-fossil energy sources</li> <li>Instituting Fukushima as a center of the non-fossil energy industry</li> </ul>

renewable energies and also reducing energy intensity, increasing energy efficiency and decreasing energy import dependency and CO<sub>2</sub> emissions in Japan is reviewed. Different renewable energies including biofuels and waste energy, hydropower energy, solar energy, geothermal energy and wind energy are reviewed and their present and future potentials were analyzed thoroughly. It was concluded that renewable energies play an essential role in total primary energy supply in the future energy of Japan and Japan is also trying to boost renewable energies as one of the best sources of energy security in the future and among different renewables, biofuels and waste energy by the share of 2.6%, hydropower by the share of 1.7% and geothermal energy by the share of 0.5% of total primary energy supply are the top three main renewable energy sources in Japan.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### CRediT authorship contribution statement

**Danmei Zhu:** Conceptualization, Methodology. **Seyed Mostafa Mortazavi:** Data curation, Writing - original draft. **Akbar Maleki:** Supervision, Visualization, Investigation. **Alireza Aslani:** Investigation, Writing - review & editing. **Hossein Yousefi:** Validation.

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