***Master's Thesis***

***Japan's Renewable Energy Potoentials***

***Possible Ways to Reduce the Dependency on Fossil Fuels***

*by*

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# *Japan's Renewable Energy Potential*

*Possible Ways to Reduce the Dependency on Fossil Fuels*

***A Master's Thesis submitted in partial Fulfillment of the Requirements for***

***the Award of the degree***

***Master of Science: International Corporation Policy***

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***Ritsumeikan Asia Pacific University***
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***By***

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# *Abstract*

*Fossil fuels are the main fuel of modern times, without which the globalised world, as we know it, might not be the same. However, fossil fuels are of finite nature and some, like oil, are going to completely deplete in the near future while others, like coal, may last a while longer. Germany, Japan as well as most other countries are highly dependent on the import of oil, gas or coal and have to pay the world market price. Unsustainable extraction brought fossil fuels under constraint. Due to further increasing consumption and decreasing extraction of fossil fuels the prices are likely going to increase drastically in the next decades. Countries who want to (partly) mitigate this issue should start investing in renewable energies and re-arrange their energy generation sector to a more sustainable system. As such, a functional mix of renewable and conventional power plants can reduce the need for fossil fuels in the electricity generation sector, thus reduce the carbon dioxide emission while securing supplies and stability. This solution, should it be taken, can lead to more independence from world market prices and international politics around fossil fuels.*

*The main aim of this study is to investigate Japan's potential for renewable energies and how they could influence the country's energy generation sector. Qualitative and quantitative research designs were adopted to provide reasonable arguments to support the hypothesis that a fair share of Japan's total (electric) energy demand could met by capitalising on renewable energy sources, while some of the old thermal power plants get phased out. The issue has grown in importance in light of recent events, wherein after the Fukushima incident all nuclear reactors were shut down and replaced with fossil fuels. As a direct result, the energy prices for consumers grew rapidly over the last few years. However, very little is known about future developments in the energy sector, policies and lastly the support of the population for those plans will show where Japan is heading.*


*Keywords: Fossil fuels, renewable energies, sustainability, policies, Germany, Japan*

# *Certification*

*I, HUEHN Philipp Konstantin, hereby declare that this Master's Thesis is my own work which contains ideas and information from published as well as unpublished works of different scholars who are recognized through the references listed in the thesis. The main arguments and ideas that are not cited are ideas and agreements written by author of this thesis.*

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*Date, Place* *Author*

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# *List of Abbreviations and Symbols*

| | |
|---|---|
| *3E's* | *Energy Security, Efficiency and Environment* |
| *3E's+S* | *Energy Security, Efficiency and Environment + Security* |
| *ABWR* | *Advanced Boiling Water Reactor* |
| *AEE* | *Agentur für Erneuerbare Energien* |
| *APWR* | *Advanced Pressurized Water Reactor* |
| *BEP* | *Basic Energy Plan* |
| *BMWi* | *Bundesministerium für Wirtschaft und Energie* |
| *BWR* | *Boiling Water Reactor* |
| *CCGT* | *Combined Cycle Gas Turbine* |
| *EEG* | *Erneuerbare-Energien-Gesetz* |
| *EnBW* | *Energie Baden-Württemberg* |
| *EnEV* | *Energieeinsparverordnung* |
| *ENSI* | *Eidgenössisches Nuklearsicherheitsinspektorat* |
| *EPA* | *United States Environmental Protection Agency* |
| *FEPC* | *Federation of Electric Power Companies in Japan* |
| *FIT* | *Feed-In Tariff* |
| *GDP* | *Gross domestic product* |
| *GHG* | *Greenhouse gases* |
| *IPCC* | *Intergovernmental Panel on Climate Change* |
| *ISEP* | *Institute for Sustainable Policies* |
| *kWh* | *Kilo Watt hour* |
| *kWh/m2a* | *Kilowatt hours per meter square per year* |
| *LNG* | *Liquefied natural gas* |
| *Mtoe* | *Megatoe (Tonne of oil equivalent)* |
| *NRA* | *Nuclear Regulation Authority* |
| *OECD* | *The Organisation for Economic Co-operation and Development* |
| *OPAC* | *Online Public Access Catalogue* |
| *PV* | *Photovoltaic* |
| *PWR* | *Pressurized Water Reactor* |
| *RES* | *Renewable Energy Sources* |
| *RTE* | *Réseau de Transport d'Electricité* |

| | |
|---|---|
| *RWE* | *Rheinisch-Westfälisches Elektrizitätswerk AG (until 1990)* |
| *StrEG* | *Stromeinspeisungsgesetz* |
| *Toe* | *Tonne of oil equivalent* |
| *TPES* | *Total Primary Energy Supply* |
| *TWh* | *Terra Watt hour* |
| *UN* | *United Nations* |
| *WNA* | *World Nuclear Association* |

# 1. Introduction and Research Statement

## 1.1. Introduction

### 1.1.1. Current developments

*From the 2nd half of the 18th century, the up come of the steam engine changed the world for all future generations. The Steam Age started a new era. Beginning in the heart of the British Empire, England, new technologies and inventions reached mainland Europe within a few years (Ashton, 1997). Soon after the first contacts, German states, France and other countries imitated machinery from the United Kingdom and began their own industrialisation process. Key factor for a successful industrialisation was access to coal and iron ore (Church, 1986; Ashton, 1997) – within a short period of time coal became the most crucial necessity of the Steam Age. Blast furnaces burned coal in order to melt iron ore, trains needed coals to run, and the rapidly growing population of the cities used coals for heating their rooms or cooking their food.*

*Coal and the other fossil fuels, mineral oil and natural gas, have been the driving force of the (modern) industrialisation process around the globe. They were the cornerstone of the advancement of many science fields, without mineral oil for instance, the transportation sector would not be what it is today. Modern society, as most of us experience nowadays would be not the same without fossil fuels. However, just like all natural resources, fossil fuels are finite. It takes millions of years for coal or mineral oil to arise: perfect conditions, such as high temperatures and pressure levels are necessary for them to build up. Due to ruthless exploitation of the deposits, fossil fuels are now under severe constraint, which are predicted to run out in the near future (Maggio and Cacciola, 2012). Coal is believed to last for a few more centuries, however, mineral oil deposits are going to run dry much sooner.*

*The fast pace of economic and industrial development however, has never been sustainable, extracting fossil fuels, the surrounding environment was destroyed, and by burning fossil fuels, huge amounts of carbon dioxide emissions were released in the world's atmosphere. Since the beginning of the industrialisation, an annual increase of the carbon dioxide concentration in the atmosphere has been measurable and more important, noticeable.*

*Carbon dioxide is a greenhouse gas and, next to other greenhouse gases, such as methane or carbon monoxide, it is directly linked to the phenomena described as global warming and climate change. Nevertheless, the $CO_2$ – emission continues to grow steadily, while, as a direct result, the effects of the climate change get stronger as well (IPCC, 200).*

*Many countries can feel the growing impact of climate change on their environment already. Devastating natural disasters, such as long spells of draught, like in California (EPA, 2016), or several catastrophic storms, are some of the consequences of climate change. Yet it is not easy to cut down carbon dioxide emissions. The main reason for that vicious circle is, like already stated above, that modern society is highly dependent on fossil fuels. Without mineral oil, transportation would come to a sudden halt, and international trade would be limited if not paralyzed. Directly linked to the dependence on fossil fuels is the dependence on fossil fuels imports for many countries. Japan and Germany are highly dependent on imports. Shrinking deposits will lead not only to increasing prices, but also to potential subjections. Fossil fuel exporting countries, by dictating prices, can destabilise importing countries and gain worldwide influence. For instance, the Russian Federation in 2015 pressured Eastern European countries to pay for already imported gas by closing gas pipelines. Especially in winter, gas shortages can lead to serious conflicts within affected countries. For these reasons, a lack of steady supply of fossil fuels is a very uncomfortable position that no industrial economy would like to be in.*

*The oil crises in the 1970's showed developed countries their dependence on Middle Eastern oil imports. Sudden shortages resulted in a deep recession and major changes in the energy policy of affected countries. Mineral oil based power plants were phased out and often replaced by nuclear power plants. Alternative energy generation research received generous grants and emergency warehouses were built. Unfortunately, when they finally sustained the crisis, and oil prices dropped, the world continued its old ways and most alternative energy generation projects got abandoned. As of now the world market prices for mineral oil are on a 7-years low (2016-2017), but prices are not going to stay low since the demand continues growing and the oil peak is predicted for the near future. Thus, the capability to generate electricity with national resources is crucial to maintain independence, power and economic stability. Moreover, if a country is able to generate energy by itself, it can re-invest the finance that was previously spent on primary energy resources in its own structures and local economies. It is vital for all nations to analyse their own potential of energy generation since it will not be possible to maintain the energy sector in the current fashion.*

*Renewable energies can be used to replace conventional power plants and trigger a paradigm shift, away from large, centralised power units towards a vast variety of decentralised power plants. This means a more demand driven generation where the energy is locally produced and consumed.*

*Combined with the necessary grid expansion to enable small units to feed in the national grid and wider application of power electronics, which are necessary to be able to control the dynamic shifts in the grid, the decentralised approach can significantly reduce transportation losses and electric grid upgrade cost. Renewable energies can replace some of the country's thermal power plants and reduce carbon dioxide emissions. For major electricity consumer, such as large factories, thermal power plants are not easily replaceable – a good combination between conventional and renewable power plants is therefore advisable. However, there is no unique universal solution for the entire world, as each country has its own potential that needs to be analysed for efficient and sustainable utilisation.*

### *1.1.2. Germany and Japan*

*Germany and Japan get compared quite often against each other. Both nations have almost the same land size and became industrialised during the first stage of the Industrialisation era. The German states and later on the young, unified German Reich had good prerequisites for the industrialisation process. Rich coal deposits in the Ruhr Valley, Silesia and the Saarland, combined with access to iron ore made a rapid development possible. The process took place a few years later in Japan, compared to European states or the U.S. After centuries of self-imposed isolation, the Meiji Restoration began in the year 1866 with the resurrection of the emperor who decided to modernise the country on the model of Western nations (Sumikawa, 1999). The country began to send diplomats, who studied the industrial development process and modern sciences of European countries before they returned to Japan (Beasley, 1972). After carefully monitoring the possibilities, Japan started to evolve into a modern nation, in which all available resources were utilised to catch up with the Western countries. Factories got erected, railways were built and the entire country searched for natural resources. When coal deposits were found in Kyushu and Hokkaido, the exploitation began swiftly after their discovery.*

*The Case of Hashima*

*(端島; Hashima) or Battleship Island (軍艦島; Gunkanshima) on the shores of Nagasaki Peninsula was declared a world heritage site by the UNESCO world heritage committee in July 2015. It is one of a few industrial heritage sites in Japan, which is not only seen as a symbol of Japans accelerated industrialisation during the Meiji Period after centuries of isolation, but also as a place where people were forced to work under inhumane conditions during the second World War.*

*Its sole purpose was to support undersea coal mining. When the first traces of coal were found on the surface of the islands in 1810, the time was not right yet, and it took about 60 years until the first attempts of coal mining. The first shaft was eventually excavated in 1887 – when the industrialisation slowly reached Japan and Hashima started to grow. Mitsubishi bought the entire land plot, including the coal mine soon afterwards, in 1890. The conglomerate was in dire need of coal to fuel its growing heavy industry complexes around Japan, and Hashima proved to be the most convenient place. Because of the Japanese industry's increasing hunger for coal, the small island had to grow in order to accommodate coal miners and their families, infrastructure as well as additional space for machinery.*

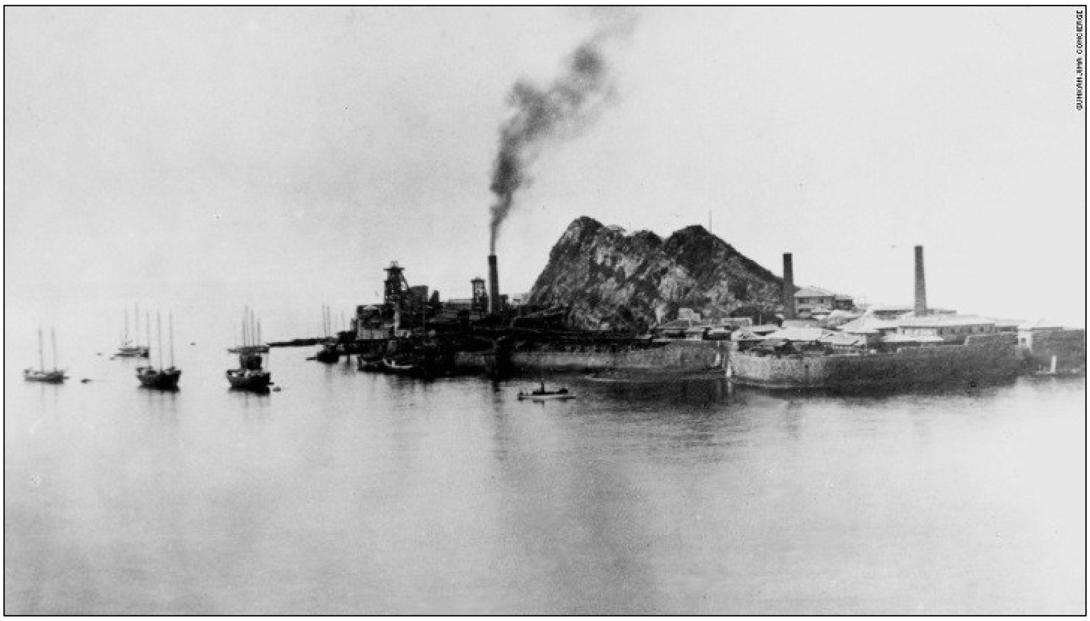


*Fig.1: Gunkanjima in the 1880's*
*(Source: Magnay, Diana (2013) Dark History: A visit to Japan's Creepiest Island, CNN)*

*The first reclamation was carried out in the year 1897 and until the year of the island's shutdown Gunkanjima underwent six aggradations which almost doubled its land area. Even Japan's first reinforced concrete building (at 7 stories) was not built in Tokyo, but in Hashima. Those innovations were necessary because more and more people came to the island. At one point the peninsula had a population of 5,259 people, who all lived, jammed together in small apartments.*

*Except a few shopkeepers, entertainment or infrastructure related jobs all workers were employed by Mitsubishi heavy industries, who worked in the undersea mines. On another note, the people of Hashima earned good money, and technical innovations such as television or electric rice cookers reached the battleship earlier than the rest of Japan.*

*The highest annual output was reached in 1941, totalling 411,100 tons. However, after the Second World War and Japan's fast economic recovery decreasing output numbers and the shrinking importance of coal for Japanese consumers, Mitsubishi decided to shut down the mine in January 1974. All workers were all of a sudden redundant and left the island in great haste – the last boat left already on April 20th in the same year.*

*Fig.2: Gunkanjima in 1973 – one year before its shutdown (Source: Gunkanjima Concierge)*

*What is left today is a grey concrete island, shaped by industrialisation, uninhabited ever since the last human being left the place. With the approval as a World Heritage Site in 2015, the island is being visited by many tourists (Unesco, 2015). (All Information about Hashima comes from the book: Hashima: The Ghost Island by Burke-Gaffney).*

*Both nations however, required more resources than what they could extract from their own territory. Their expansions to save resources for themselves led eventually, apart from other political reasons, to the Second World War. Even after the defeat, territory and resource losses, Japan and Germany managed to recover quickly and became the 2nd and 3rd largest economies (in terms of GDP) in the world, right after the United States of America. Currently they are ranked 3rd and 4th, behind the People's Republic of China and the United States of America (IMF, 2009).*

*Nowadays, even though Japan and Germany are high-technology and goods exporting countries, both are still dependent on primary energy sources imports. Especially Japan, without any large fossil fuel deposits left, has to import most of its energy.*

*After the oil crisis, at the Washington Conference (held in February 1974), all attending countries (including Japan and West Germany) agreed on three energy security goals: diversification of oil suppliers, diversification of energy sources and energy conservation measures (Ikenberry, 1986). Japan began to invest heavily in atomic energy and liquefied gas (LNG) to meet electricity demands. Germany, however, decided to increase the number of suppliers and utilise the country's coal deposits.*

*First projects and research groups for renewable energies received financial support as well, but as the prices for oil dropped and mineral oil was widely available again, energy/resource conversation plans were shelved by most countries. The Kyoto Conference in 1997 was able to revive those attempts, not necessarily aiming to save resources in the first place, but on top of the agenda was the development of a mutual method to reduce global emissions of carbon (UN, 1998).*

*Germany developed guidelines for better insulation of buildings, energy conversation regulations and a subsidy system to promote renewable energies for the public, in order to meet the requirements of the agreement. The broad success Germany had in recent years, serves as a case study for many countries who want to analyse the positive and negative side effects of the shift to renewable energies and the German energy transition process. Japan, on one hand, invested in renewable energies, but saw nuclear energy as the main countermeasure for its* $CO_2$ *– emissions on the other, and planned to increase the share of nuclear energy on the total electricity generation up to at least 40% by 2017 (World Nuclear Association; 2012). This policy came to a sudden halt after the Tohoku earthquake hit Japan in 2011. The nuclear power plant Fukushima Daiichi was severely damaged. The resulting meltdown released radioactive particles and made the surrounding area uninhabitable for an indefinite period of time. As a direct result the Japanese government decided to shut all nuclear generators down and started to develop alternative policies. However, the growing fossil fuel imports reduced Japan's independency and increased energy prices nationwide. Carbon dioxide emissions started to grow and the goals of the Kyoto Protocol could not get fulfilled.*

*Considering the steady expansion of human life, electricity consumption is highly likely to continue increasing rather that shrinking. Even more efficient devices can only help to control the demand, along with the transition to electricity based transportation, the need for electricity will most likely stay high.*

## *1.2. Research Problem*

*As a result of the Fukushima disaster, Japan's plans to continue enforcing its nuclear energy sector were first halted and then withdrawn. After the shutdown of all operating nuclear power plants, domestic energy generation relies heavily on fossil fuel driven power stations. Due to the need to import all vital fossil fuels, energy prices and, greenhouse gas emissions grew rapidly since the complete nuclear reactor shutdown. For this reason Japan has to restructure its energy generation sector in order to meet demands, and more importantly, gain independence from fossil fuel imports as well as reduce greenhouse gas emissions, in the near future. Different approaches, like higher efficiency of power plants, a higher share of renewable energies or a demand reduction could be possible solutions. This study draws from various sources and determines the most effective method to analyse Japan's renewable energy potentials.*

## *1.3. Methodology*

*The Japanese government has to decide where the energy generation sector of the country is heading in the future. Since the majority of Japan's energy requirements are being imported, the longing for more independence is strong. Electricity generated by nuclear power plants was expected to be the answer for a long time and became a national strategic priority after the 1970s oil crisis.* $CO_2$ *emissions were under control, even the compliance of the Kyoto protocol targets seemed to be possible, and at the same time, electricity supply was secured. Nuclear energy was thought to cover around 50% of Japan's electricity demand in the future. However, after the Fukushima incident the government decided to cease expansion plans.*

*Now, Japan is trying to restructure its electricity generation. Nuclear energy is not popular among the Japanese population, but it ensures steady electricity generation without the need for fossil fuel imports. Renewable energies could be an alternative as well – reducing the overall dependence on foreign primary energy supplies. Germany, which began to restructure its electricity sector around the beginning of this millennium, could serve as a useful case study for the Japanese government. The goal of this study is to find out which renewable resources are available in Japan and can be utilised for energy generation purposes. Supported by the example of Germany, this report attempts to show that Japan has the potentials to build up its own (self-sustainable) renewable energy generation without compromising on supply security and grid stability.*

*Another supporting advantage for this thesis is the fact that renewable energies can generate electricity independently from primary fuel imports. In the long run the ability to generate energy with national resources proves to be far more attractive than continuing with the status quo.*

*Japan has some unique features that make it significantly more complex than other countries. Its two electric grid systems, 60 Hz power frequency in the south western grid and 50 Hz in the north east, divide the country and, unlike Germany which is connected to the European grid, Japan has no connection to other continental grids. Ten spatially restricted firms control the grid and electricity generation in the country. Up until 2016 it was not possible for households to choose their electricity provider, they had to purchase the energy from the company that was operating in the household's area. The recent reform process is going to change the Japanese power sector. However, even now it is uncertain in which direction the country is exactly heading – continuing with former plans by focusing on nuclear energy or starting a new era of energy generation?*

*The purpose of this study is to examine the renewable energy potential of Japan, and how this potential can be utilised by the energy generation sector to optimise the country's energy mix (in terms of self-sustainability and import independence). Energy mix means a wide variation of power plants using renewable energy sources as well as conventionally fuelled power station (conventional fuels are fossil fuels and nuclear energy).*

*An optimised mix ensures more independence from fluctuating energy prices and imports, reduction of carbon dioxide emissions, more sustainable energy generation, and supply security as well as grid stability at the same time.*

### *1.3.1. Research Methodology*

*A descriptive research methodology was used for this study. A literature review was conducted in order to obtain required data for the analysis of the energy generation sector and policies in Germany and Japan, as well as the gathering of data about electricity generation systems and international statistics to support the report's arguments. The majority of the secondary data was reviewed through the university library using a vast range of information sources such as the university's OPAC system, academic and commercial journals, data bases, and internet search engines.*

*Since the comparison of two complex energy generation sectors cannot be seen as a case study and relies heavily on long-term developments and policies, the researcher chose a descriptive research approach and tried to analyse the developments as detailed as possible. The literature survey is designed for listing the potential of renewable energy sources in Japan.*

*The various energy resources are being compared by the available potential they can utilise in the country. By comparing the country's political and technical framework with those of Germany, the research tried to point out major differences between both countries and identify strengths of the German system which Japan could use to improve its own energy generation sector.*

## *1.4. Hypothesis*

*Japan can utilise more of its own renewable energy potential, resulting in the reduction of $CO_2$ – emissions, dependency on fossil fuel imports and replace some of its fossil fuel driven or nuclear power stations with new forms of energy generation systems.*

### *1.4.1. Research Questions*

*The energy generation sector in Japan is going to face major changes in the near future. Former plans of the government to focus Japan's energy generation on nuclear energy have been altered after the Fukushima incident. Conventional power plants, operated with fossil fuels, compensate the lost capacities. This practice however, increased Japan's $CO_2$ – emissions remarkably. Supply security is the most important point for the government. Nevertheless, the question of sustainable and independent energy generation is just as crucial for future developments.*

1. *How will Japan's energy generations sector (possibly) look like in the future?*
2. *Is it advisable to shift to renewable energies or should the government continue with its old plan of nuclear energy as the main energy source?*

### *1.4.2. Sub Questions*

1. *What did Germany do to develop its renewable energy sector?*
2. *Where does Japan's main potential lie (in terms of renewable energies)?*
3. *Why is Japan not enforcing the usage of renewable energies and, what are the main problems?*
4. *How will the energy generation sector develop?*

## *1.5. Research Objective*

1. *Analyse the world's energy generation sector*
2. *Compare Germany and Japan's energy generation sector*
3. *Japan's potential in renewable energies*
4. *Political and technical framework*
5. *Future development of the sector in Japan*

## *1.6. Literature Review*

*All natural resources on earth are limited. In the early development stages of mankind, forests were cut down to harvest timber for construction or fuel purposes. With the Industrialisation mankind began to exploit natural resources, especially fossil fuels, on a much faster pace than they can regenerate. However, natural resources are the main source for all terrestrial life. Human consumption of those resources is limited by the total capacity of the natural environment and should not exceed it.*

*One of the first authors to discuss the unsustainable development of mankind and future outcomes was Thomas Robert Malthus (1766-1834) who stated in his essay "An essay on the principle of population as it affects the future improvement of society" in 1798 that the unequal nature of food supply to population growth would lead to a situation in which food consumption will exceed the actual food supply, resulting in large scale famines. His work does not discuss the issue of shrinking fossil fuels deposits, but his key argument, that a growing population in combination with growing consumption will exceed available resources is definitely valid for all natural resources. His thesis eventually inspired modern authors to think about sustainability and the environmental constraint.*

*Kenneth Ewart Boulding (1910-1993) for instance argued in his essay "The Economics of the coming Spaceship Earth" the earth as a spaceship, in which man has to find his place, after exploiting all the planet's natural resources, in an environment without unlimited reservoirs of anything, either for extraction of pollution. Therefore man has to live in a cyclical ecological system which is capable of continuous reproduction of required materials (Boulding, 1966). Another well renowned group that mentions the consequences of unsustainable development is the Club of Rome. In their book "Limit to Growth" they simulated the interactions between the earth's and manmade systems, resulting in three possible scenarios.*

*Two of them lead to "overshoot and collapse" in the 21<sup>st</sup> century, only the third scenario results in a stabilised world (Club of Rome, 1972). This book has been constantly updated and revised to stay up to date with current developments. Since planet earth is an extremely complex system, the simulation cannot take all factors into consideration. A little uncertainty is left due to the lack of knowledge and data. Nevertheless, the majority of the scenarios are not positive and can be seen as a warning. In the same vein, Herman E. Daly brought his work "Towards a Steady State Economy, 1973" to the conclusion that for a sustainable development, society, population, capital and technology have to be effectively combined to ensure a level of material life for all people.*

*To meet that goal, the consumption of renewable resources should not exceed the speed of their regeneration, while the consumption of non-renewable resources has to be monitored and should not exceed the speed of technology development of renewable resources which could replace them. The amount of emissions and pollution should not exceed the absorption capacity of the environment (Daly, 2007, 1990).*

*Despite awareness and acknowledgement in the 1970s, nothing of significance happened until the Kyoto Protocol in 1997. The first international agreement in which many countries, with the exception of the US and China, tried to develop a way to effectively reduce their* $CO_2$ *– emissions in order to counter the effects of global warming. The Kyoto Protocol was not mainly about sustainability, but with the reduction of carbon dioxide and other GHGs new ideas and sustainable systems received more attention than before.*

*Carbon dioxide, in chemical components specified as* $CO_2$*, is one of the major GHGs emitted by burning fossil fuels in combusting engines or thermal power plants. The global electricity supply sector accounts for the release to the atmosphere of over 7700 million tonnes of carbon dioxide annually (2100 Mt C/yr), making up 37.5% of total* $CO_2$ *emissions (Sims, 2003). Under current practice, the rate of annual carbon emissions associated with electricity generation, including from combined heat and power cogeneration, is projected to surpass the 4000 Mt C level in 2020 (IEA, 1998). Since it is easier to monitor and control GHG emissions from a limited number of centralised, large power stations than countless small emitters, the energy generation sector is likely to become a prime target in the future where GHG emission controls are implemented and GHG mitigation is valued (Sims, 2003).*

*Sims listed some suggestions for the mitigation of carbon dioxide emissions as well. The first is a more efficient conversion of fossil fuels, that means thanks to technological progress, the current world average power station efficiency of 30% has the potential to increase to more than 60% in the long term. Second is how cogenerations power plants could replace separate plants for power and heat generation thus significantly raise the utilisation effectiveness of the used fuel.*

*This idea should work well provided certain preconditions are satisfied. Countries with cold climates, for instance, can effectively use the released heat of the burning process for heating houses other facilities. Hot countries however, have no use for the heat surplus. Switching to low-carbon fossil fuels and suppressing emissions is another way the author mentions. In order to increase efficiency and reduce emissions, coal power plants should be replaced by gas. By using combined cycle gas turbine technology the carbon emissions per generated kWh electricity could be reduced. While many countries have coal deposits, not many have access to natural gas.*

*This geopolitical problem is partly the reason why coal power plants are widely used while natural gas power stations are still seldom (Sims, 2003).*

*The decarbonisation of fuels and flue gases, combined with carbon dioxide sequestration could be another way to reduce emissions. Hereby is the fossil fuel used to creating hydrogen-rich secondary fuels which are used to generate energy in fuel cells. Decarbonisation of flue gasses after the combustion process can become an effective GHG abatement option. In this scenario, the carbon dioxide gets stored over geological time frames, in depleted gas fields or mines for example. However, his idea is just a theoretical approach and bears high risk factors such as uncontrolled carbon dioxide outbursts.*

*Another way to reduce emissions is to increase the number of nuclear power stations, this could replace base load fossil fuel power plants around the globe. A significant advantage is that if the technology is available and tested, the new power plant replaces the fossil fuel driven one without any problems. Energy can get produced constantly without emitting carbon dioxide. However, reactor safety, radioactive waste transport, waste disposal and proliferation are problems that have not been solved completely. Additionally to the problem of the long half-life period of Uranium and other radioactive elements comes the supply question. Even though the fuel rods of a nuclear reactor can get recycled, new material has to get used as well. Not many countries have Uranium ore deposits, which leads to another dependency situation (Sims, 2003).*

*Increasing the use of renewable sources of energy is possible. Technological progress makes the use of new power plant types possible. With declining costs for those technologies, renewable energies could meet a greater share of the rapidly growing world energy demand in the long term. Renewable energy flows vary from location to location and make the techno-economic performance of renewable energy conversion highly specific (Sims, 2003). Some renewable systems are still in the development stage and need further research and investments to be able to function as power plants in the future. Other types are already in use and contribute to the total share of energy generation. However, they have advantages and disadvantages, just as any form of energy generation does. Yet they can be seen as the first step towards a sustainable energy generation sector.*

*Following the author's suggestions is an assumption of carbon mitigation cost. If the investment cost required for a reduction of one tonne of carbon emissions is negative, the project can be assumed to be an economic option regardless of any emission reductions. The assumptions are based on the carbon offset value.*

*A wide range of win/win opportunities can reduce emissions with either cost savings or even at zero cost. For instance, where gas infrastructures are in place already, a CCGT system is more reasonable than coal. Hence no negative cost* *reduction options exist for natural gas to replace coal. With the need for infrastructure, carbon trading could support the construction plans effectively.*

*With regards to renewable energy solutions, hydro, wind and biomass power plants could potentially reduce carbon dioxide emissions by replacing fossil fuel fired plants. In some specific cases, investment in the technologies can generate power at lower cost. Assorted wind and biomass projects might be able to replace even natural gas CCGT plants. However, for the majority of those sites, all renewable energy projects are still more costly than CCGT technology. Nuclear energy, in terms of $/t C, is theoretically a zero cost mitigation option. In order to be more cost efficient than CCGT technology, the carbon offset value has to increase (Sims, 2003).*

*In Europe, the German power system is not only the largest in terms of size, but also in terms of installed renewable energy capacity. Worldwide the country has the third largest amount of renewable energies (excluding hydro) installed (BMU, 2011). In 2014, the main share of electricity was generated by burning hard coal and lignite (44%). Renewable energies contributed already more than one quarter while nuclear energy supplied 16% to the grid (Bayer, 2015). Furthermore, the country's main share of electricity is still generated by four major power suppliers: E.ON, RWE, EnBW and Vattenfall. With more renewable coming on the grid, the ownership profile of generation has been shifting. The big four own most conventional power plants, but only a small share (around 5%) of the installed renewable energies (Bayer, 2015).*

*The "Energiewende" is Germany's national energy transformation strategy to decarbonise the economy. And after Fukushima all nuclear power plants are scheduled to stop operations until 2022 (Schreurs, 2012). With the "Energiewende", Germany wants to achieve a significant reduction of greenhouse gas emissions of the power generation sector, which is responsible for roughly 45% of GHG emissions from energy (UNFCCC, 2013). In order to reach these self-imposed goals, improving the overall energy efficiency, and increasing the share of electricity generated by renewable energies is crucial. To maintain grid stability, thoughtful use of cross-border interconnections and careful consideration of bordering EU-members is just as important as the above stated points (Bayer, 2015). Otherwise the energy transformation could prove problematic.*

*Fig.3 on the next page shows the share of energy sources in Germany in the years 2001 and 2011. The share of nuclear energy and hard coal decreased significantly within a decade while the share of renewable energies increased three-fold.*

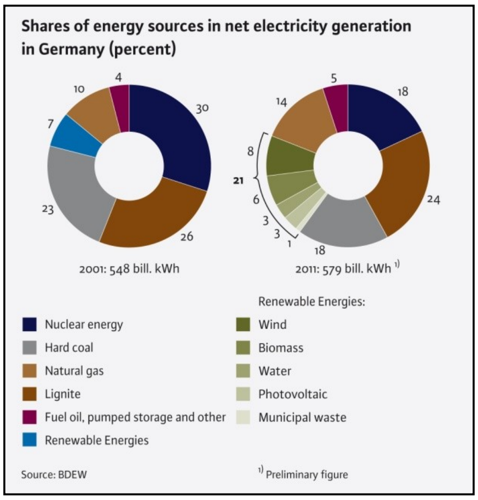



*Fig.3: Germany's net electricity generation in 2001 and 2011*
*(Source: BDEW)*

*In 2013 Japan had an electric energy production of 998 TWh (EIA, 2015). The main share of the energy demand was generated by burning fossil fuels. This meant Japan has been the world's largest importer of liquefied natural gas, second-largest for coal, and third-largest net importer for crude oil and oil by products (EIA, 2015). The US Energy Information Administration states that before Fukushima, around 20% of Japan's total energy demand was generated by nuclear energy. The World Nuclear Association on the contrary, states that Japan generated more than 30% of its electricity demand from nuclear sources – and planned to increase the share to more than 40%. Fig.4 illustrates that 27% of Japan's electricity was generated by nuclear energy in 2010. In 2013 this share had shrunken to 1% of the total generation. While the total generation output decreased, the share of fossil fuels increased and contributed to 87% of Japan's electricity generation in 2013.*

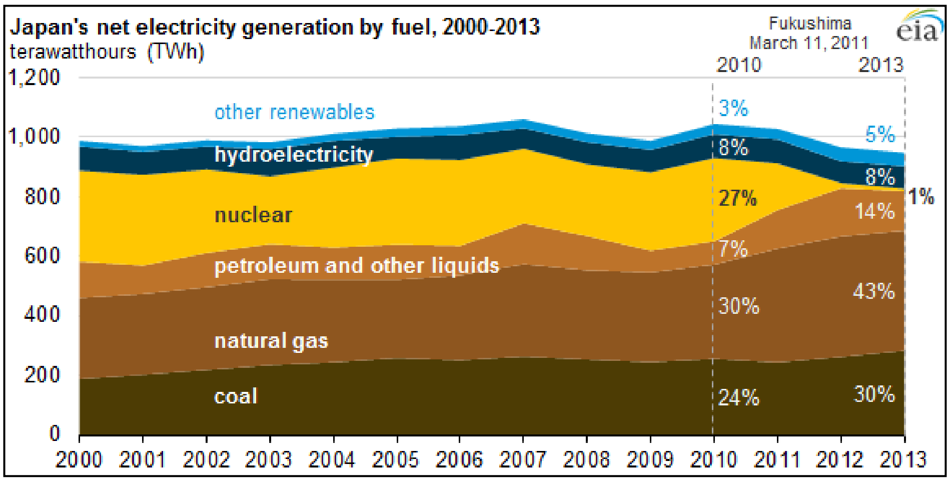



*Fig.4: Japan's energy generation by fuel between 2000 and 2013*
*(Source: EIA (2015) Japan plans to restart some nuclear power plants in 2015)*

## *1.7. State of Research and Aim*

*Recently, various authors have compared Japan and its energy generation sector to the German counterpart. As the German energy transition is being carefully monitored in Germany and due to its indisputable success (in terms of renewable energy growth), Japan and many other countries has tried to learn from Germany's energy policies (Cherp et al., 2017). German policies and their impact on the energy generation sector have been discussed by many authors before (Hake et al., 2015; Huenteler et al., 2012; Lovins, 2014; Nature News,2013). Out of these authors (Huenteler et al. 2012, Lovins 2014) focus on Germany and Japan, they pointed out that Japan has not managed to increase its renewable energy significantly because the government sticks to old policies, which did not pay enough attention to renewable energies (Lovins, 2014).*

*Additional authors who conducted study about these two countries exclusively are (Feldhoff, 2014); and (Hermwille, 2016). Furthermore, on the Japanese side, the Japanese Renewable Energy Institute has also analysed the German "Energiewende" thoroughly in their report: 10 Q&A on the German Energiewende – a contribution to the Japanese energy debate in early 2017. The knowledge gained could help in shaping Japanese energy policies (Pescia and Ichiyanagi, 2017). Chowdhury et al. (2014) come up with an in-depth analysis of the solar sector and its growth due to policy changes and why Japan's solar sector decreased in the early 2000's while Germany's solar capacities grew rapidly during this period.*

*Cherp et al.,2017 have written an in-depth analysis on past decisions of both countries, the role of major players in the energy generation sector (namely coal, nuclear, renewables) are well pointed out as well. The Japanese Renewable Energy Institute has a more policy based approach analysing the German energy transition, following an explanation about Japan's situation.*

*Earlier reports, like Banks et al. (2014) focus on the energy generation sector and mention that due to the sudden phase out (in Germany) and shut down (in Japan) of nuclear energy in both countries, the carbon dioxide emissions are about to rise as nuclear energy is mainly replaced by fossil fuels (short term).*

*The focus of previously mentioned papers is either narrowed down on one energy source or policies only. So far, there has been no work that tried to list all prominent renewable energy sources like wind, hydro, solar and biomass, and their not so well know sub categories like tidal or wave power, and their potentials. This paper thus is attempting to provide an analysis of all potentially significant energy sources and tries to explain the major policy tools of the German "Energiewende" for possibly later implementation in Japan. (Wakiyama et al. 2014) states that exogenous shocks like the Fukushima disaster may reduce* *electricity consumption for a short time, but they cannot introduce a low-carbon (low-consumption) transition.*

*Concluding that government reforms need to keep the post-shock window open and possibly expand it even further. The German policies are certainly not perfect, but throughout these changes it became possible to build up a renewable energy sector in an industrialised country with comparatively high population density. Key decision element is the increase of resource independent energy (electricity) generation which could come with a reduction of greenhouse gas emissions. However, in this case, the main target is not to reduce GHG emissions as much as possible, it is energy independence.*

# *2. Energy Generation, Consumption and Policy*

## *2.1. Energy Supply and Consumption*

### *2.1.1. World Wide*

*Among the first electricity power stations in the world were plants, which generated electricity with the kinetic energy of flowing waters. Water, just like other energy sources, is perceived as a primary energy source, which is also able to be converted into secondary energy. The other main source of electricity was generators which were driven by steam engines. Burning coals, was the main source of these engines, another primary energy carrier. The advantage of the latter technology was that provided a steady supply of coals, it was feasible to generate electricity wherever it was needed. Water power plants required rivers or streams and could only be constructed under applicable situations.*

*Fossil fuel primary energy carriers became the main asset for the quick electrification of the industrialising countries, their relatively cheap prices and transportability laid the cornerstone of their success. Now, more than two centuries after the first countries began to industrialise, the importance of fossil fuels has hardly changed – furthermore, with an ever increasing world population and an advancing globalisation process, the demand for primary energy carries continues to grow. Around the world the electricity generation sector is converting fossil fuel based primary energy sources to electricity. However, other industries, households and the transportation sector consume fossil fuels, in other energy forms other than electricity, as well. Other primary energy sources used to have a marginal existence, growing energy prices and possibly future supply shortages however, have led to an increase of alternative energy sources within the last two decades. Recent developments however, caused cheap mineral oil prices. If the prices for fossil fuels are low, other projects, such as modernisation efforts or renewable energy projects seem economically unattractive and more likely be postponed. This short term development can lead to an investment backlog as long as the prices for conventional energy carriers are low.*

## *2.1.2. Energy Supply*

*Primary energy is energy that has not been converted into other forms of energy, for example electricity or movement, yet. All primary energy dependent sectors such as industry, transport and energy generation convert those primary energies to secondary energies, which can be either heat, electricity or fuels for transportation.*

*The following figure shows the world's total primary energy supply (TPES), which is a term used to indicate the sum of production and imports subtracting export and storage changes (OECD, 2013). Fig.5 indicates that this supply increased more than twice from 6,101 Mtoe in 1971 to 13,699 Mtoe in 2014.*

*Fossil fuels are the main source of primary energies, with a share of 86.7% in 1971 and 81.1% in 2014. They remained to be the dominant source of energy throughout the 20$^{th}$ century, even now all alternative sources, in large scale, only contribute to only a fifth of total demand. Although fossil fuels did not lose much of their importance within the last five decades, the composition did change to some extent. Mineral oil lost its predominance, and in 2014, it was only a few percent higher than coal or natural gas.*

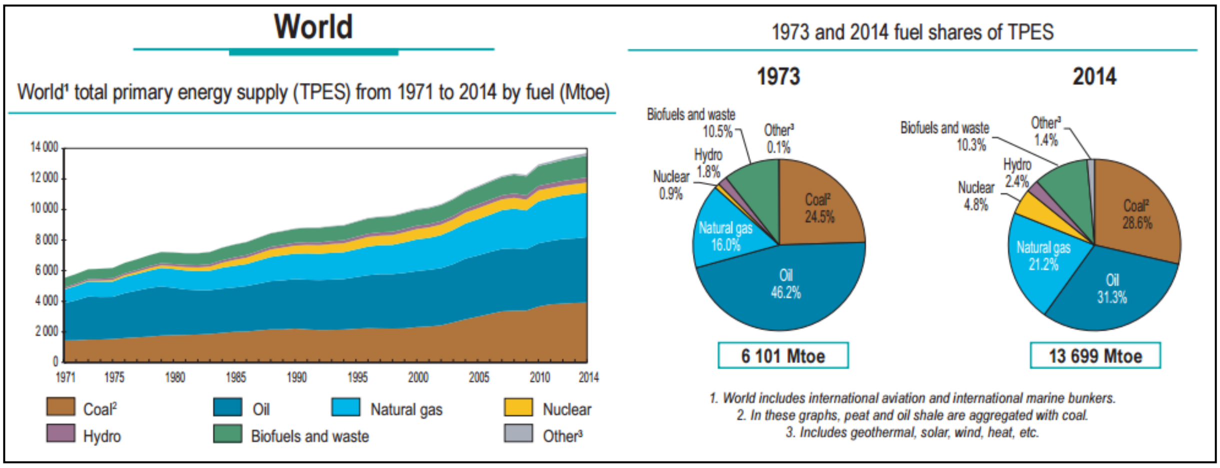



*Fig.5: Primary Energy Supply Worldwide between 1973 and 2014*
*(Source: IEA Key World Energy Statistics 2016; Page 6.)*

*According to Fig.6, the International organisation helping governments tackle the economic, social and governance challenges of a globalised economy (OECD) was the world's main primary energy supplier in 1973. In 2014, the same member countries contributed only 38.4% of the total share. Especially China, which made up around 22.4% in 2014, as well as other countries in Asia, increased their share in order to meet their own growing energy demand.*

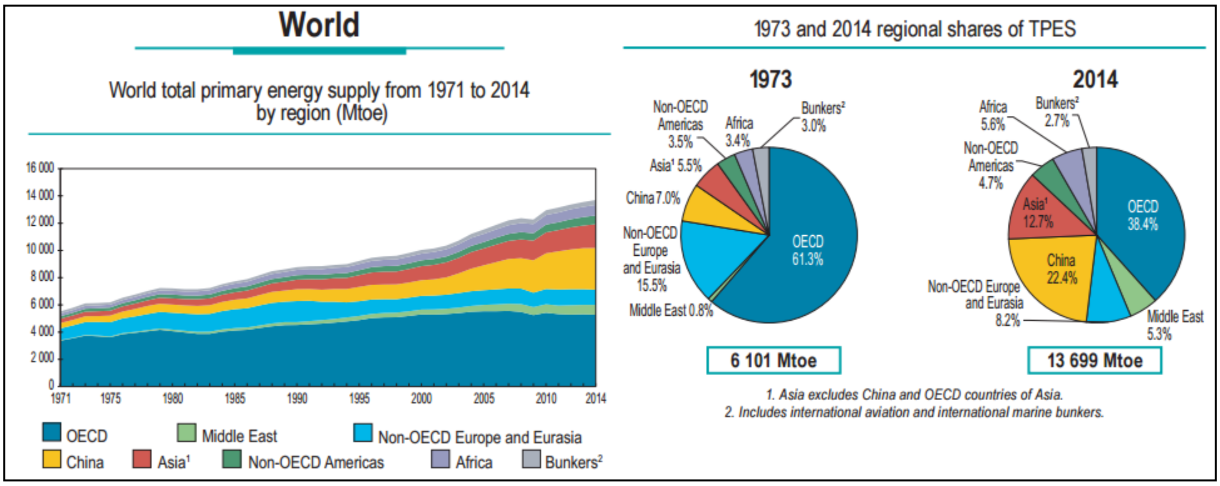



*Fig.6: Primary Energy Supply by Region between 1973 and 2014*
*(Source: IEA Key World Energy Statistics 2016; Page 8.)*

### *2.1.3. Energy Consumption*

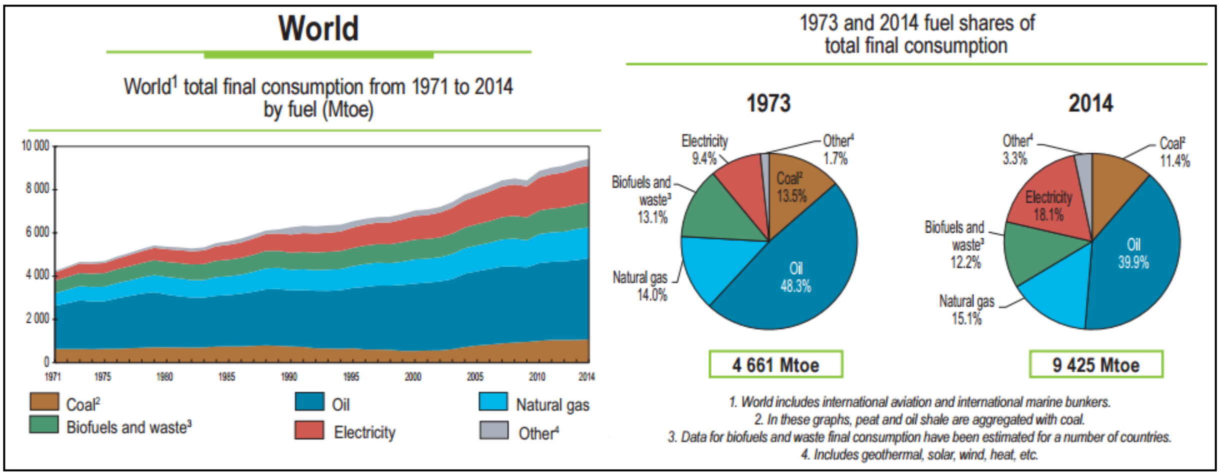



*Fig.7: Energy Consumption Worldwide between 1973 and 2014*
*(Source: IEA Key World Energy Statistics 2016; Page 28.)*

*With the second phase of industrialisation beginning in countries around the world, the world wide population started to grow rapidly. The advancing globalisation boosted the energy demand even more up. As illustrated in Fig.7, in 1973 the overall consumption was around 4500 Mtoe. In 2014 the basic demand increased to 9425 Mtoe, more than twice as high as it was in 1973. The fuel shares show that the demand for electricity went up from 9.4% in 1973 to 18.1% in 2014. Other fuels lost or gained small percentages, however, the figure for mineral oil decreased from 48.3% to 39.9%. Its importance for the transportation sector is still unmatched as there is no readily available technology that can replace most conventional combustion engines on the streets or the oceans of the world yet.*

### *2.1.4. Electricity Generation*

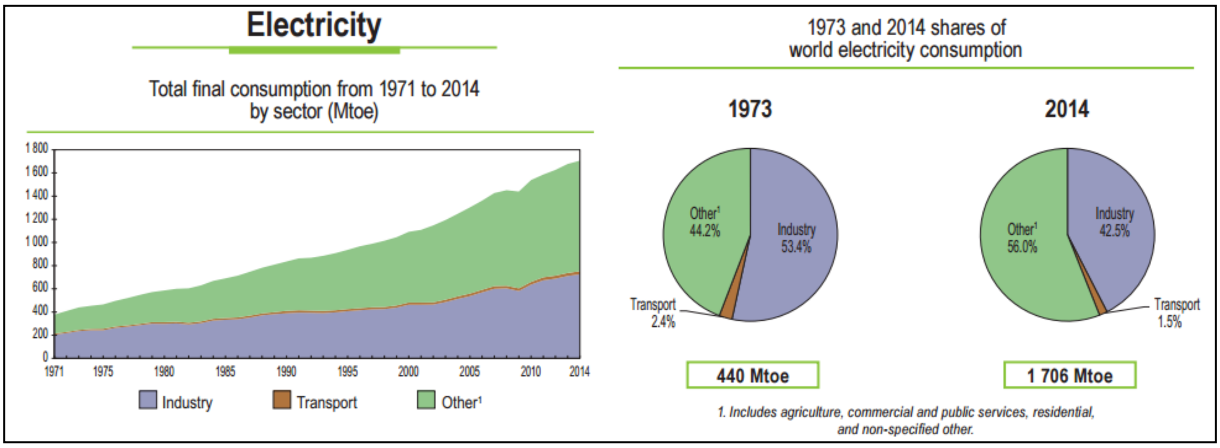



*Fig.8: Electricity Consumption between 1973 and 2014*
*(Source: IEA Key World Energy Statistics 2016; Page 35.)*

*As previously stated, electricity demand grew sharply due to advancing industrialisation and globalisation. Fig.8 shows that in 1973 total consumption amounted to 440 Mtoe, which then steadily increased to 1705 Mtoe in 2014. This shows that the demand went up four fold in the last decades. Largest consumer in the 70's was the industry sector, in 2014 however, this position belonged to the "other" category. The term "Other" comprises private households, agriculture, commercial and public services as well as non-specific other consumers. This combination does not allow a detailed insight in the consumer behaviour, thus it is not clear which sector's electricity demand grew the most. The composition of the electricity generation by fuel has partly changed within the years.*

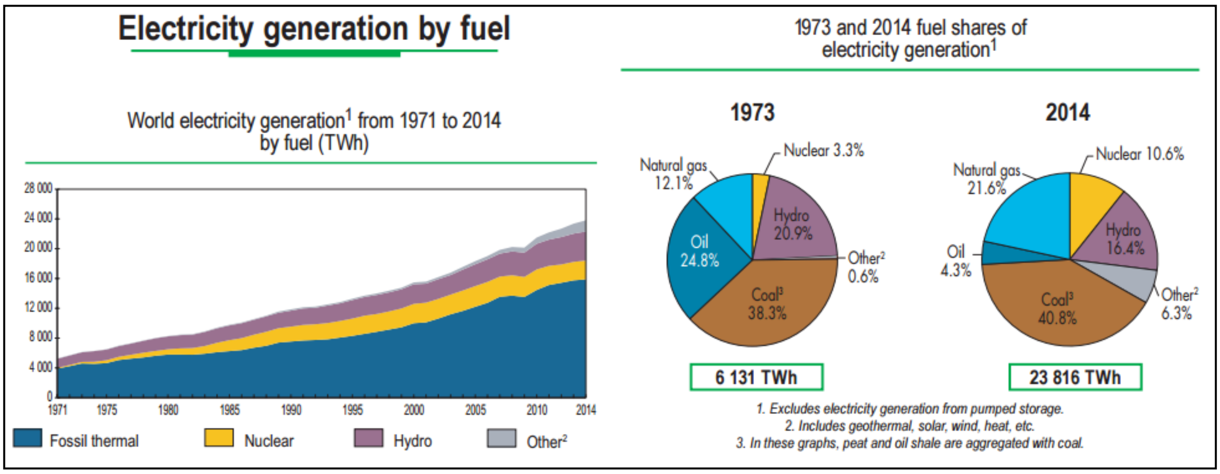



*Fig.9: Electricity Generation by Fuel between 1973 and 2014*
*(Source: IEA Key Energy Statistics 2016; Page 24.)*

*Fig.9 depicts that the total generation increased from 6.131 TWh to 23.322 TWh.*

*However, even though mineral oil in 1973 was an important source for electricity generation (24.8%), the following oil crisis in the 70's reduced this share to only 4.3% in the year 2014. This supply gap was filled by natural gas, and nuclear power, which was also promoted in developed countries. The red section "Other", including all common renewable energy sources, has been slowly growing since the beginning of the 21st century, before that its share was marginal. Hydro power is listed separately and decreased from 20.9% to 16.4%.*

## 2.2. Demand and Supply

### 2.2.1. Japan

*In 2016, the Eastern Asian country, Japan is now the country with the 4th highest GDP in the world. Being already completely developed means that the energy demand in each of the four sectors: residential, industry, transport and commercial is high.*

*As illustrated in Fig.10, the total primary energy supply in 2013 was 453 Mtoe. Since 2003 demand has decreased by 1.1% annually. The most noticeable change in the chart is nuclear energy, which increased from 2003 to 2008 by 2% (total of 14%) but then completely vanished in 2013. This is a direct result of the Fukushima incident in 2011, which led to the complete shut-down of all nuclear reactors in Japan. At the time this report was written, one station, the nuclear power plant Sendai I+II（川内原子力発電所）in the Kagoshima prefecture, with two reactors restarted and put back into operation.*

*In 2013 only 4.7% of the total energy supply were supplied by renewable energies, the rest was fossil fuel based.*

**Total primary energy supply, 2013***

| | | |
|---|---|---|
| **453 Mtoe** | | |
| -1.1% annual growth since 2003 | | |
| Share of renewables | 4.7% | |
| IEA average | 9.1% | |
| Compared to IEA countries | | IEA avrg |
| Share of coal in TPES | 8th highest | 20% |
| Share of oil in TPES | 4th highest | 35% |
| Share of gas in TPES | 12th highest | 26% |
| Share of nuclear in TPES | 16th highest | 10% |
| Share of biofuels in TPES | 28th highest | 5% |
| Share of hydro in TPES | 15th highest | 2% |
| Share of other in TPES | 19th highest | 2% |

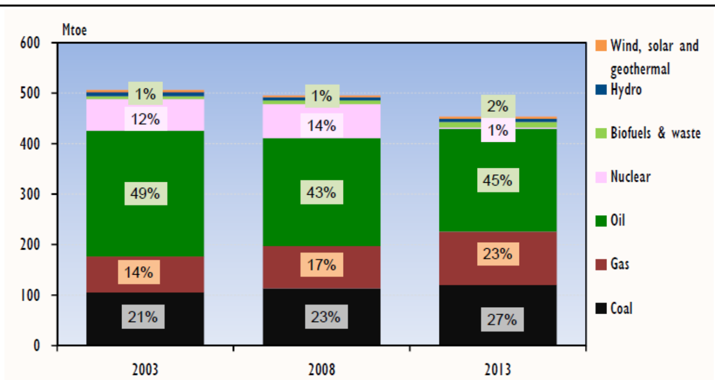



*Fig.10: Japan: Total Primary Energy Supply in 2013*
*(Source: IEA Japan Overview One pager August 2014)*

*Fig.11 shows that like total energy supply, final consumption has also been decreasing since 2002, by one percent annually t. The industry sector was still the main consumer, at nearly 40%. The transport and commercial sectors required 24% and 22% respectively while the residential sector demand accounted for only 15% of the total consumption.*

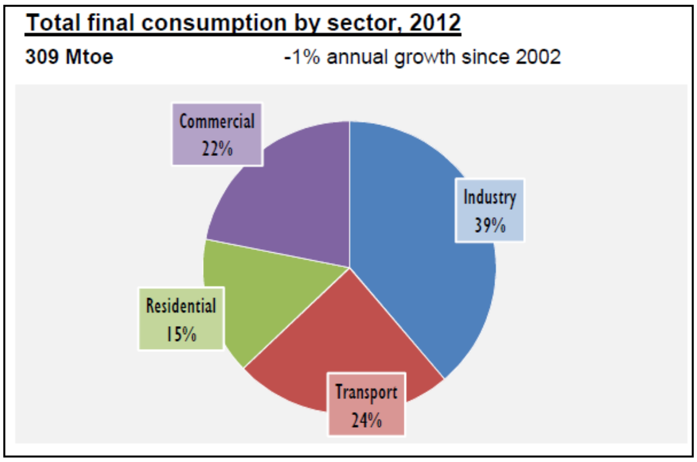



*Fig.11: Japan: Total final Consumption in 2012*
*(Source: IEA Japan Overview One pager August 2014)*

*On the other hand is the electricity demand slowly growing as seen in Fig.12, but not significant, at merely 0.1% annually. In 2013, the main energy source for electricity generation was natural gas, at 39%. Coal accounted to 32 percent of the total demand and mineral oil contributed 15%. Fossil fuels made up to 86% of the electricity generation. The figure for nuclear energy was only 1%, before the incident, however, nuclear energy made up approximately 26.90% of the total electricity generation (IEA, 2009). After the shut-down of all nuclear reactors conventional power plants fuelled by fossil energies were used, in order to meet the demand. Renewable energies, including wind, geothermal, solar, hydro and biomass combined, make up around 13% of the total generation.*

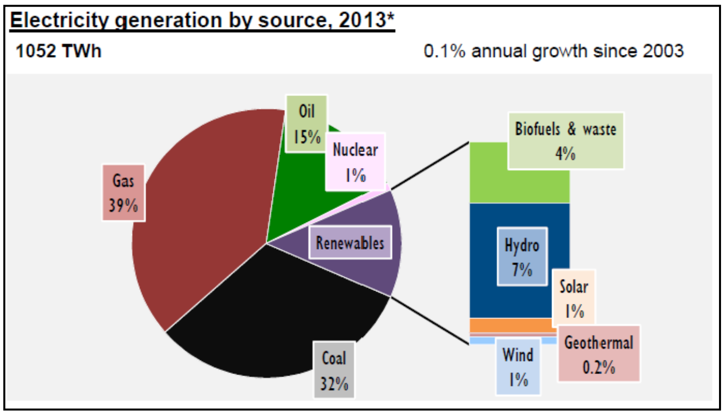



*Fig.12: Japan: Electricity Generation by Source in 2013*
*(Source: IEA Japan Overview One pager August 2014)*

*According to Tab.1 which is based on IEA data, Japan's energy self-sufficiency is only around 6%, the lowest among IEA members, whose average is 73%. This means that 94% of Japan's energy supplies are being imported. The country with 127 million citizens and highly developed industries is therefore highly dependent on fossil fuel imports. Especially raw products such as crude oil, mineral gas and coal are close to being 100% imported. The production of oil products is split between imports and domestic production with main trading partners being Middle Eastern and Oceanic countries.*

*The electricity consumption per capita is lower than the IEA average and because of Japan's geographical conditions as an island complex the electricity is generated in Japan only (no imports or exports). Carbon dioxide emissions increased by 15% compared to 1990 – mainly because of the shutdown of all nuclear reactors, which were replaced by fossil fuels. Compared to the IEA, the Japanese emissions per capita is still lower than the average among member countries.*

*Tab.1: Fossil Fuel Production and Import: Japan*

| | | | |
|---|---|---|---|
| Country size | 377 | 000 $km^2$ | 8th among IEA countries |
| Population | 127.6 | million | 11.4% of IEA population |
| GDP | 3 994 | billion USD PPP | |
| GDP per capita | 31 311 | USD | IEA average: USD 33389 |
| TPES/capita | 3.5 | toe/capita | IEA average: 4.51 |
| **Fossil fuel production and import dependency** | | | **Main imports in 2013** |
| Crude oil production | 0.2 | Mt | |
| Crude oil net imports | 170.2 | Mt | Saudi Arabia 33%, Emirates 24%, Qatar 8% |
| Production of oil products | 171.4 | Mt | |
| Oil products net imports | 180.1 | Mt | Korea 16%, US 13%, Qatar 11% |
| Gas production | 3.3 | bcm | |
| Gas net imports | 119.9 | bcm | Australia, 21% Qatar 18%, Malaysia 17% |
| Coal production | 0.0 | Mt | |
| Coal net imports | 195.6 | Mt | Australia 67%, Indonesia 17%, Russia 7% |
| Energy self sufficiency | 6% | | IEA average: 73%<br>IEA median: 46% |
| Electricity consumption per capita | 8 304 | kWh/capita | IEA average: 9301 |
| Electricity net imports | 0 | GWh | |
| $CO_2$ emissions (fuel combustion) | 1 223 | $MtCO_2$ | +15% compared to 1990 |
| $CO_2$ emissions per capita | 9.6 | $tCO_2$ | IEA average: 10.3 |

*(Source: IEA Japan Overview One pager August 2014)*

### *2.2.2. Germany*

*The Central European country Germany is in 2016 the country with the 5th highest GDP worldwide. Because it was among the first countries that started to industrialise, the country has already gone far passed that point. For this reason, energy demand of the four main sectors: industry, commercial, residential and transportation are all high.*

*Fig.13 indicates that the total primary energy supply in 2013 was 312.4 Mtoe. Since 2003 the demand has been declining by 0.8% annually. Main energy sources are still fossil fuels, a constant growth of the renewable share is noticeable, however (at 11.9% in 2013). The share of nuclear energy has been slowly decreasing as the slow phase-out until 2022 has been decided – generally perceived as a direct respond to the Fukushima incident.*

**Total primary energy supply, 2013***

| | | |
|---|---|---|
| **312.4 Mtoe** | | |
| -0.8% annual growth since 2003 | | |
| Share of renewables | 11.9% | |
| IEA average | 9.0% | |
| Compared to IEA countries | | IEA avrg |
| Share of coal in TPES | 8th highest | 20% |
| Share of oil in TPES | 18th highest | 35% |
| Share of gas in TPES | 13th highest | 26% |
| Share of nuclear in TPES | 14th highest | 10% |
| Share of biofuels in TPES | 9th highest | 5% |
| Share of hydro in TPES | 19th highest | 2% |
| Other in TPES | 9th highest | 2% |

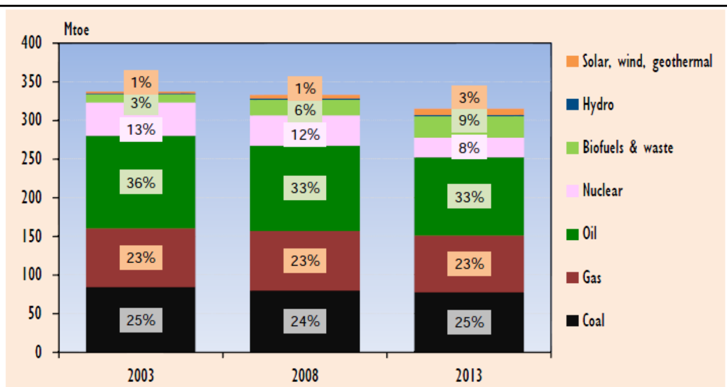



*Fig.13: Germany: Total Primary Energy Supply in 2013*
*(Source: IEA Germany Overview One pager June 2014)*

*As shown in Fig.14, total energy consumption has been deceasing by 0.6% annually. The industrial sector consumed the most energy, slightly over a third of the total consumption, while the transport and residential sectors accounted for around one quarter of the total energy consumption. At 15%, the commercial sector was the smallest consumer.*

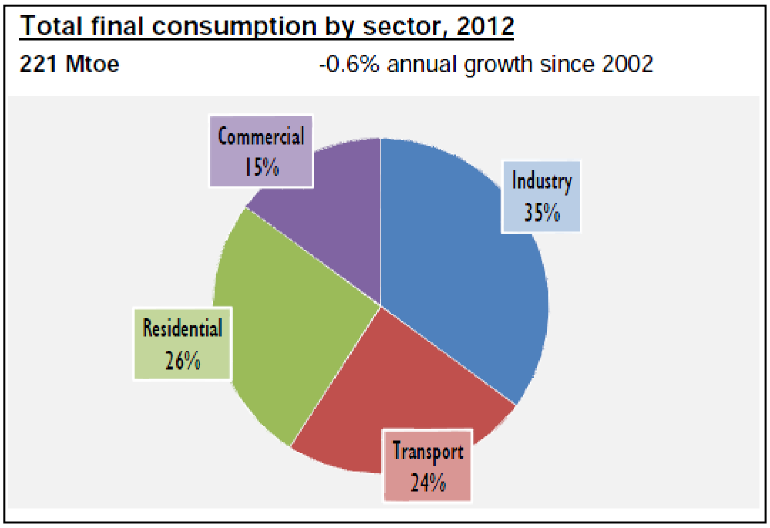



Fig.14: Germany: Total final Consumption in 2012
(Source: IEA Germany Overview One pager June 2014)

*In Fig.15 it is clear that electricity generation increased slightly, at an annual rate of 0.4%. The main energy source in 2013 was 47% coal (hard coal and lignite) as Germany has its own coal deposits, thus the nation is not totally dependent on imports like Japan is. The second largest contributor was a renewable energy mix with 24%. Nuclear energy generated a share of 15% of the total electricity generation. Natural gas and especially mineral oil are not of significance for the electricity sector in Germany.*

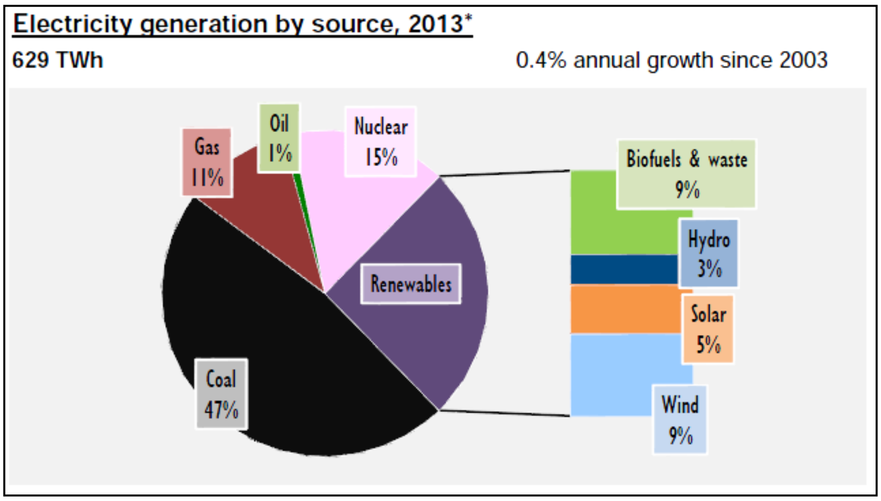



Fig.15: Electricity Generation by Source in 2013
(Source: IEA Germany Overview One pager June 2014)

*Following Tab.2, provided by the IEA, Germany's self-sufficiency level is at 38%, around six times higher than Japan's, but only half of the agency's average. Just like Japan, the main share of the fossil fuels is being imported.*

*The 82 million citizens and the industry require fossil fuels for transportation, production or living. While small quantities of all fossil fuels are being extracted, the majority is being imported. For Germany, Russia stands out as the main trading partner for energy.*

*Electricity consumption was rated at 7.384 kWh per capita, which is lower than the IEA average. Furthermore, Germany is able to generate a surplus of electricity and export it to other European countries (up to 3.765 GWh in 2013). Carbon dioxide emissions also went down by 20% compared to the level recorded in 1990.*

*Tab.2: Fossil Fuel Production and Import: Germany*

| | | | |
|---|---|---|---|
| Country size | 349 | 000 $km^2$ | 9th among IEA countries |
| Population | 81.9 | million | 7.3% of IEA population |
| GDP | 2 851 | billion USD PPP | |
| GDP per capita | 34 808 | USD | IEA average: USD 33389 |
| TPES/capita | 3.8 | toe/capita | IEA average: 4.51 |
| **Fossil fuel production and import dependency** | | | Main imports in 2013 |
| Crude oil production | 2.6 | Mt | |
| Crude oil net imports | 90.1 | Mt | Russia 35%, Norway 12%, UK 10% |
| Production of oil products | 99.7 | Mt | |
| Oil products net imports | 87.3 | Mt | Netherlands 50%, Belgium 16%, Russia 12% |
| Gas production | 12.7 | bcm | |
| Gas net imports | 70.2 | bcm | Russia 42%, Netherlands 30%, Norway 21% |
| Coal production | 12.1 | Mt | |
| Coal net imports | 47.6 | Mt | Russia 23%, US 21%, Colombia 16% |
| Energy self sufficiency | 38% | | IEA average: 73%<br>IEA median: 46% |
| Electricity consumption per capita | 7 384 | kWh/capita | IEA average: 9301 |
| Electricity net imports | -3 765 | GWh | |
| $CO_2$ emissions (fuel combustion) | 755 | $MtCO_2$ | -20% compared to 1990 |
| $CO_2$ emissions per capita | 9.2 | $tCO_2$ | IEA average: 10.3 |

*(Source: IEA Germany Overview One pager June 2014)*

## 2.3. Energy Generation Sector

*"Hen Henry Adams, the one-of-a-kind American historian tried to contrast the medieval period with the modern time, the emblems he chose for those two eras were the Virgin and the Dynamo. He said that the earlier times expressed its aspirations in building cathedrals consecrated to a spiritual ideal: in our time we exalt the generation of electricity – another invisible but powerful essence. The votaries of the electric cathedral certainly agree with this assessment. A textbook for power-plant operators says of the generating station, "It is like a shrine of source of unfailing light which must be given ceaseless attendance once it is brought into being". " (Hayes, 2005)*

*With electricity it was for the first time possible to generate energy and transport it from the power plant directly to the consumer. Before that breakthrough, all energy had to be brought in form of primary energy carriers, such as wood and charcoal in the earlier times over coal with the beginning and during the height of the Industrialisation, to mineral oil for heating until recent days, to the consumer. The division of generation and consumption makes it difficult to verify which energy sources are used to generate electricity. A broad energy mix with various types of power plants is usually used to ensure supply security and to reduce dependency on a single energy carrier. However, main energy source is still, in most countries around the globe, fossil fuel.*

*A modern life without electricity is simply inconceivable, as machines in factories or households all require power in order to function. Supply security and grid stability make it challenging for grid operators to introduce new renewable technologies as some renewable systems are dependent upon certain weather conditions, hence causing sudden changes in the available power units in the grid. Conventional power plants, especially the large coal units, and nuclear reactors need time to start up. Sudden changes in the grid are difficult to control for the large units because they also need time to gear down their power output. On the other hand, there are some other renewable energy sources, which are able to feed in the base load and replace conventional power units, thus also able to reduce carbon dioxide emissions effectively.*

*It is important to note that the optimal energy generation sector is different for each country or region. Geographical preconditions need to be taken into consideration in order to find the most suitable power plant type for each individual area. North Africa for instance has high solar radiation. Hence photovoltaic systems can be used efficiently in that area all year round. Northern Europe however, has low solar radiation and long hours of darkness in the winter, which means that a solar system is only useable with limitations.*

*Japan's landmass reaches from the 45th latitude in the north (Hokkaido) to the 20th latitude in the south (Okinotorishima). As a result of its widespread geographical situation the country has six different climate zones. Tropical climate on the islands in the south and cold, dry climate in the north offer different possibilities to the energy generation sector.*

*One of Japan's peculiar features is the bisected power grid. Fig.16 illustrates the differences. The north east, including Tokyo area, uses 50 Hz mains frequency while the south west uses a mains frequency of 60 Hz. Only a few frequency converter facilities (purple) enable both grids to exchange power with each other (FECP).*

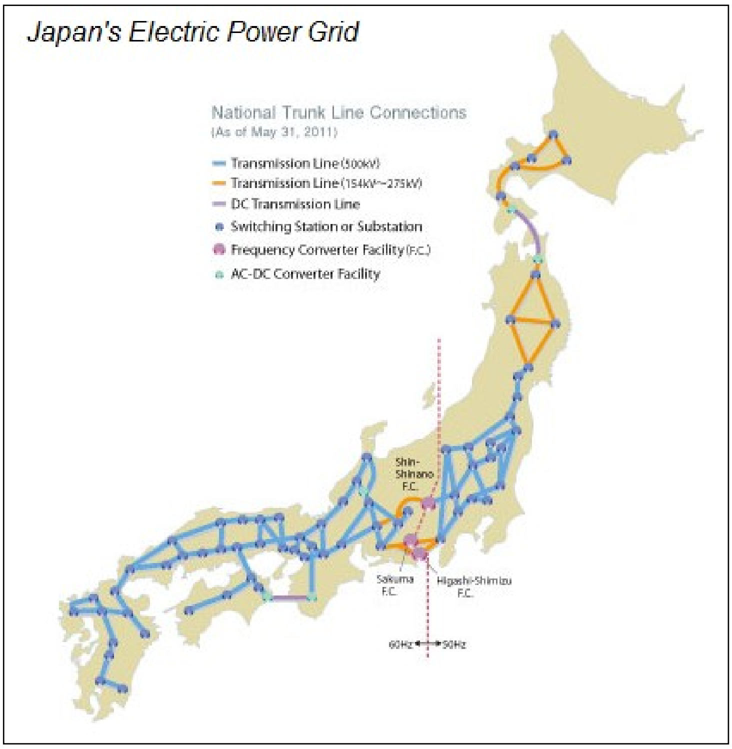



*Fig.16: Japan's Electric Power Grid*
*(Source: FEPC Grid Structure Japan)*

*This chapter does not only introduce the major conventional and renewable energy types but also their potential in Japan. While the dependence on fossil fuel imports has been discussed in the previous chapter already, an analysis of the Japanese energy generation sector will be able to explain the structures of this sector.*

### *2.3.1. Power Plant Types*

*Fossil fuel burning power plants are referred to as conventional power plants. Some sources claim that nuclear reactors are conventional power plants as well. However, as this type of power plant is seen as a separate technology, nuclear reactors are not labelled as conventional power plants in this report. Renewable energies are the newcomers and do not have a specific name yet, thus are referred to as renewable energies.*

*The categorisation is by energy source, divided on the main generic name, the segmentation is as follows: Fossil Fuels, Nuclear Energy and Renewable Energies.*

### *2.3.2. Fossil Fuels*

*The prevailing power plant type, which is driven by fossil fuels, is a thermal power plant. A thermal power station converts heat energy (in form of steam) to electric power. Water is heated until it turns into steam, this steam is then sent up to the steam turbine which drives an electrical generator. The required water can be heated in several ways, using biomass, fossil fuels, nuclear fuel rods, or – given a high enough temperature and pressure level of the steam – geothermal sources can generate electricity. On average, the efficiency of a conventional thermal power station, considered useable electric energy produce, as a percentage of the heating value of the fuel consumed, typically varies between 30-45% (Krauter, 2014).*

*The rest of the energy input is considered as waste heat and must leave the plant to the environment. That explains why thermal power plants have either large cooling towers, or can be found next to water banks. However, more efficient power plants utilize the potential of the heat in form of district heating, also known as co-generation.*

*Japan's energy generation sector generates the majority of its electricity by using thermal power plants. After 2011 around 88% have been supplied by fossil fuels. Main energy carrier for the energy sector is currently LNG (43.2%), followed by coal (30.3%) and oil (14.9%) (METI, 2014). Fig.17, provided by the FECP shows the different energy sources for the electricity generation of Japan.*

*In FY2012, Japan's power sector accounted for 478Mt-CO2/yr, or 37% of national total GHG emissions (excluding LULUCF). CO2 emissions from power generation have increased by about 65% since FY1990 (290Mt-CO2/yr), mainly because of increased electricity demand (880TWh in FY2012 compared to 748TWh in FY1990) and the increased use of fossil fuel-fired power plants following the Fukushima nuclear disaster (0.53kg-CO2/kWh in FY2012 compared to 0.39kg-CO2/kWh in FY1990). The increase in electricity use was observed mainly in the residential and commercial sectors, which together are responsible for more than 60% of power sector emissions (Kuramochi, 2015).*

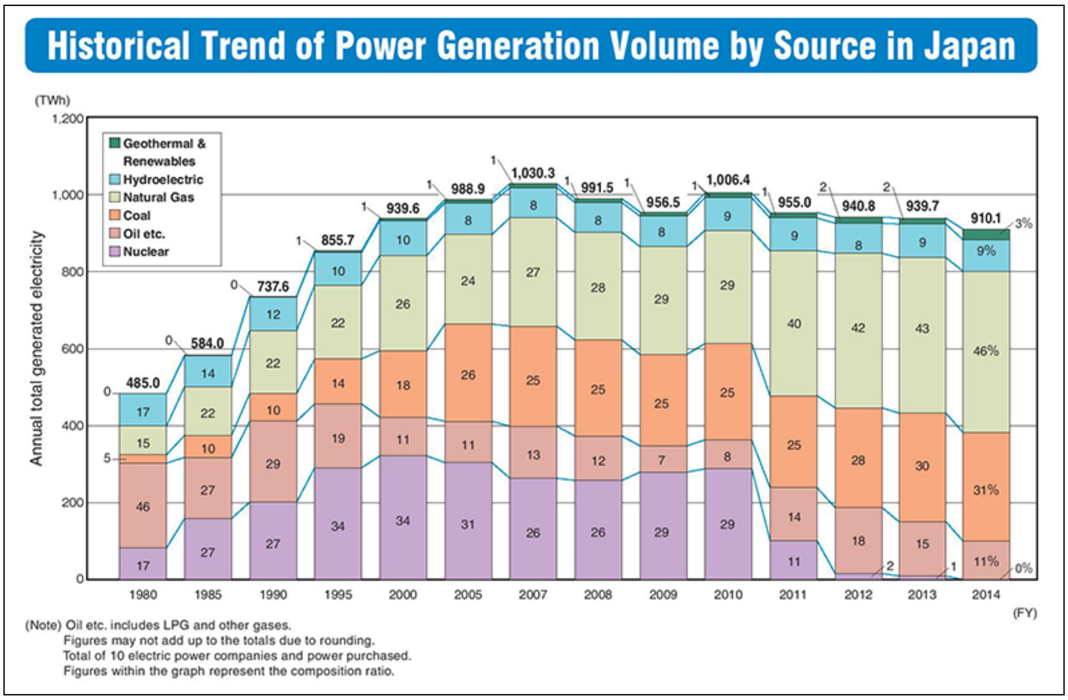



*Fig.17: Power Generation Volume by Source*
*(Source: FEPC Electricity History Japan)*

*Mineral- and Crude Oil*

*Oil has been vital for Japan's industrialisation in all sectors. Even used for electricity generation after the Second World War, the oil shocks in the 1970's showed that a diversification of the energy sources was necessary. As depicted in the figure of the FEPC, in 1980, 46% of the country's electricity was generated by mineral oil, which had been steadily decreasing until 2010. In 2011 strategic reserves were reactivated to compensate for the stoppage of nuclear reactors, oil contributed 18% of the national energy generation in 2012 going down to 11% in 2014.*

*Mineral oil stays important for the Japanese industry. However, in terms of energy generation, oil is not as important as it used to be. Strategic reserves* *(power plants) are available and can be reactivated in order to meet demand peaks or to compensate breakdowns of other power stations.*

*Natural Gas*

*The importance of natural gas or LNG for the Japanese energy market has been steadily increasing since the 1980s. Although this portion on the total energy generation in 1980 was only at 15%, LNG became more important within the next decades, especially in 2011 the dominant role of LNG became visible as the energy source generated 40% of the total electricity demand. In 2014 its share rose again to reach 46%.*

*LNG plays a vital role for Japan's energy sector, the liquefaction process requires between 10 and 25% of the energy content of the gas. Due to high cost of offshore pipelines and long transportation ways, it is economically feasible to use liquefied natural gas though. Gas fuelled power plants have the advantage of relatively small sizes, as well as short turn on and off times, thus they are able to serve peak demands and they can compensate load differences.*

*Coal*

*Hard coal or lignite played a vital role during the first stages of Japan's industrialisation process. However, for energy generation this primary energy carrier was not widely used. In the 1980's only 5% of the energy demand was supplied by coal. As substitute for mineral oil the share of coal grew and stabilised at 25% in the early 21st century. After 2011 the portion increased slightly and became almost one third of the total electricity generation in 2014. Coal power stations are usually large units that are close to coal fields, since Japan does not have any considerable coal deposits, or harbours from where they can receive the huge quantities of material they need to run.*

*Coal power plants are used for the base load as the large units are not able to respond quickly to changes, heating up and cooling down processes take hours, thus are avoided as much as possible.*

### 2.3.3. Nuclear Energy

*Nuclear energy has been commercially used in Japan since 1966. As a direct respond to the oil shocks in the 70's (oil, imported from the Middle East, fuelled around 66% of the electricity in 1966) , nuclear energy became a national strategic priority in 1973 (Suzuki, 2014). The modern technology should help to reduce Japan's already noticeable high dependency on fossil fuel imports, while also providing enough electricity to support the country's economic growth (WNA, 2016).*

*Japan's reactors are light water reactors, in this type "light" water (ordinary water) is used to moderate and cool the reactor core (Lamarsh, 1981). The eastern grid has mainly boiling water reactors (BWR) in operation, while the western grid relies on pressurized water reactors (PRW) to generate electricity.*

*The main difference between both reactor types is that in a BWR the reactor core heats up the water around the fuels rods until it turns into steam, that steam then drives a steam turbine. APWR reactor heats water which does not boil as the pressure level is so high that is stays fluid. A heat exchanger transfers the heat to a low pressure water system, and the emerging steam drives the connected turbine (ENSI, 2011). Advanced systems were developed by Japanese companies to increase the operational safety. Worldwide there are only four advanced boiling water reactors (ABWR) in use and all of them are in Japan. The advanced pressurized water reactor (APWR) is not commercially used. All used nuclear reactors use thermal systems to generate electricity and can be classified as thermal power plants. Their ability to generate substantial amounts of electricity but relatively slow responding times makes nuclear power stations to base load power plants.*

*In early 2011, 56 reactors with an installed capacity of 47.5 GWe (net) generated 30% of Japan's demanded electricity. In order to meet emissions mitigation goals nuclear energy was planned to generated 41% of Japan's electricity by 2017 and around 50% by 2030 (WNA, 2016). However, these plans came to a sudden halt, due to the Great East Japan Earthquake and the subsequent nuclear incident in the power station Fukushima Daiichi (*福島第一原子力発電所*). The installed capacity broke down to 44.6 GWe (net) as the reactors in Fukushima are severely damaged and became non-functional. All other reactors were also shut down and inspected. Currently 43 are operational and potentially able to be restarted, 24 among which are in the process of restart approvals. The two reactors of the nuclear power plant Sendai in Kagoshima (*川内原子力発電所*), restarted in August and October 2015, are at the moment the only nuclear reactors in Japan which generate electricity – all the other reactors are still under maintenance (WNA, 2016).*

*Fig.18 shows the current situation of the nuclear energy sector in Japan. After the incident, all six reactors of Fukushima 1 are being abolished. Additionally some other reactors in Japan are not going to be restarted in the future as well (grey). Three reactors are currently under construction (green), 41 are suspended (red) and two are under operation (blue).*

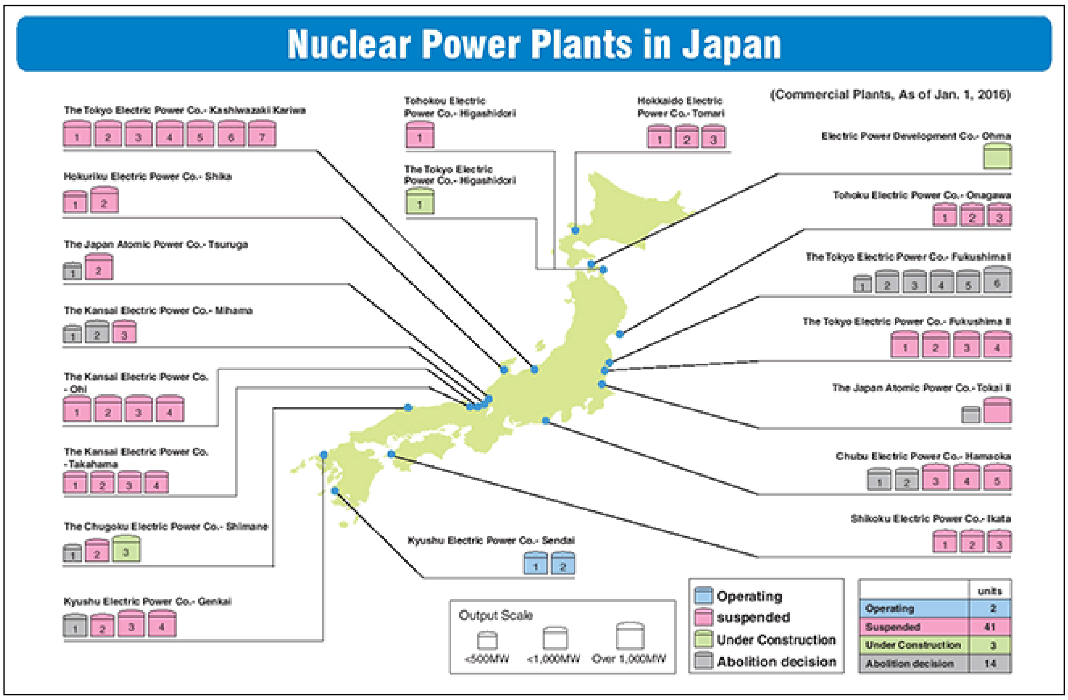



Fig.18: Nuclear Power Plants in Japan
(Source: FEPC Nuclear Power Generation Japan)

### 2.3.4. Renewable Energies

*Solar*

*Solar energy is radiant light and heat from the sun which are utilised by various technologies (IEA, 2011). Solar heating, photovoltaic and solar thermal panels are used to generate electricity or heat, either in large-scale complexes or on the rooftop of private houses, the range of applicable solutions for solar technology is large. Flexible and not dependent on the electric grid it is possible to supply single consumers or island grids.*

*Crucial for energy production, however, are optimal weather conditions and the strength of the solar irradiation in the area. That means without sun the photovoltaic panels cannot generate electricity, solar thermal panels cannot heat up water. On the other hand, provided sunlight, the panels are able to generate electricity. Solar panels' performance, however, varies with changing weather conditions. Countries with a fairly large share of PV technology in their energy mix are highly vulnerable to fluctuations in the national electricity grid. Other power plant types need to be able to cushion sudden changes to keep the grid stable and to ensure supply security.*

*Sudden surpluses of electricity cannot necessarily be used at the time they are generated – weather-dependent renewable energy sources require other power plant types or energy storage systems to ensure constant electricity supply.*

*Japan's Potential*

*According to the IEA, Japan was the second largest market for solar growth in 2013 and 2014. During that time, 6.9 GW and 9.2 GW of nominal capacity were added to the already existing capacities, cumulating up to a total of 23.3 GW. With that notably amount of installed capacities, the country became the number three in terms of electricity generation in the world, behind China (28.2 GW) and Germany (38.2 GW). The currently installed capacity is estimated to be sufficient to supply up to 2.5% of the country's annual electricity demand (IEA 2015).*

*Fig.19, the global horizontal irradiation map of Japan shows the sun's average annual sum of irradiation between the years 2007 to 2012. Especially the southern parts of Japan show promising measured data. The Ryukyu Islands* (琉球諸島), *Kyushu*(九州), *Shikoku* (四国)*and southern parts of the Japan's main island Honshu* (本州) *have high sun irradiation, between 1450 kWh/m² and 1600 kWh/m² annually (by comparison, Germany's average annual sun irradiation is around 1000 kWh/m²). While Honshu's* (本州) *southern coast line is densely populated, other areas have vast unpopulated areas.*

*Falling prices in production (from over 980 Yen/Wp in 1993 to 380 Yen/Wp in 2011, IEA) and financial incentives by the Japanese government made photovoltaic systems attractive for households. Especially in urban areas, energy balance can be improved by placing solar panels on the currently not used rooftops.*

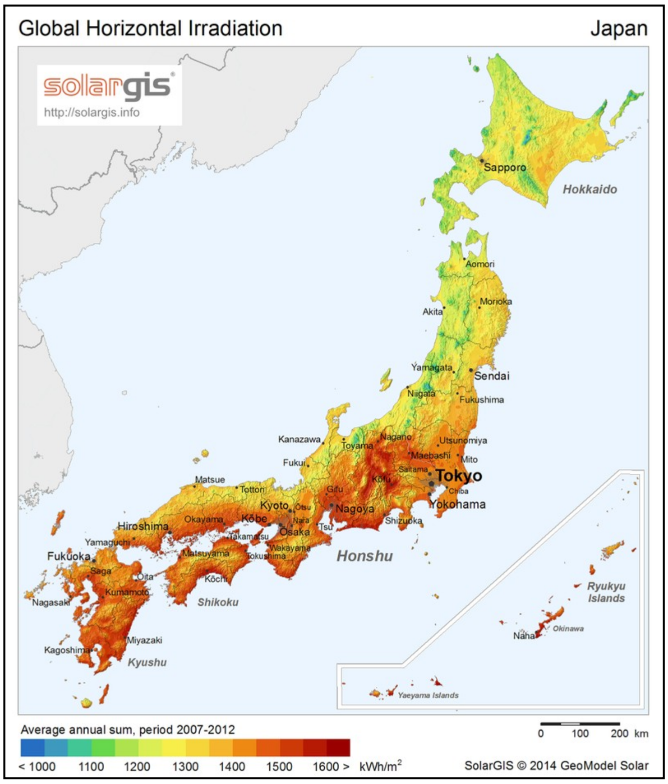



*Fig.19: Horizontal Radiation Japan (Source: Solar GIS Global Horizontal Irradiation Map: Japan)*

*Wind*

*The use of wind power by human can be traced back to the first century AD. First for grinding crops, pumping water or sailing over the oceans. Electricity generation is relatively new in the field of wind power, the first windmill used to generate electricity was built in 1887 in Scotland by Professor James Blyth (Price, 2005)*

*However, it took almost another century until the real potential of wind power was acknowledged. From small wind mills on top of buildings to large on- and offshore wind farms that are capable of generating hundreds of megawatts – even gigawatts in some cases – thus feed in vital electricity in the national grids.*

*Electricity is generated by the wind passing through the turbine blades. Mechanical energy is transformed into electric energy which can be fed in the power grid. It is a clean energy with little land use and high (potential) energy yield (Fthenakis, 2009). Although it is possible to generate a lot electricity per single power station (Offshore SIEMENS D-7 Platform 6-7 MW rated capacity) wind power is just as dependent on weather conditions as solar energy. One of the advantages of wind power is that it is easier to predict and it is possible to plan with wind energy to a certain degree. Large installed capacities, however, can cause sudden power peaks in the grid.*

*Japan's Potential*

*Fig.20 states that wind Power has only limited potential onshore (about 280 GW); Hokkaido and Tohoku have reasonable wind speeds while the southern part does not provide enough speed to run wind power stations. The offshore potential on the other hand is high (around 1800 GW). All sea areas around the main islands show high wind speeds which could be utilised. Especially the northern areas around Hokkaido and in front of the Izu peninsula, where wind speeds around 8.5 m/s or even higher have been recorded (Kojima, 2012). Some high yield zones are close to the mainland and can supply electricity without long transmission lines. While Hokkaido and Tohoku, except a few cities, are not densely populated, especially the area around the Izu peninsula could generate electricity for highly populated areas in and around Tokyo or Nagoya.*

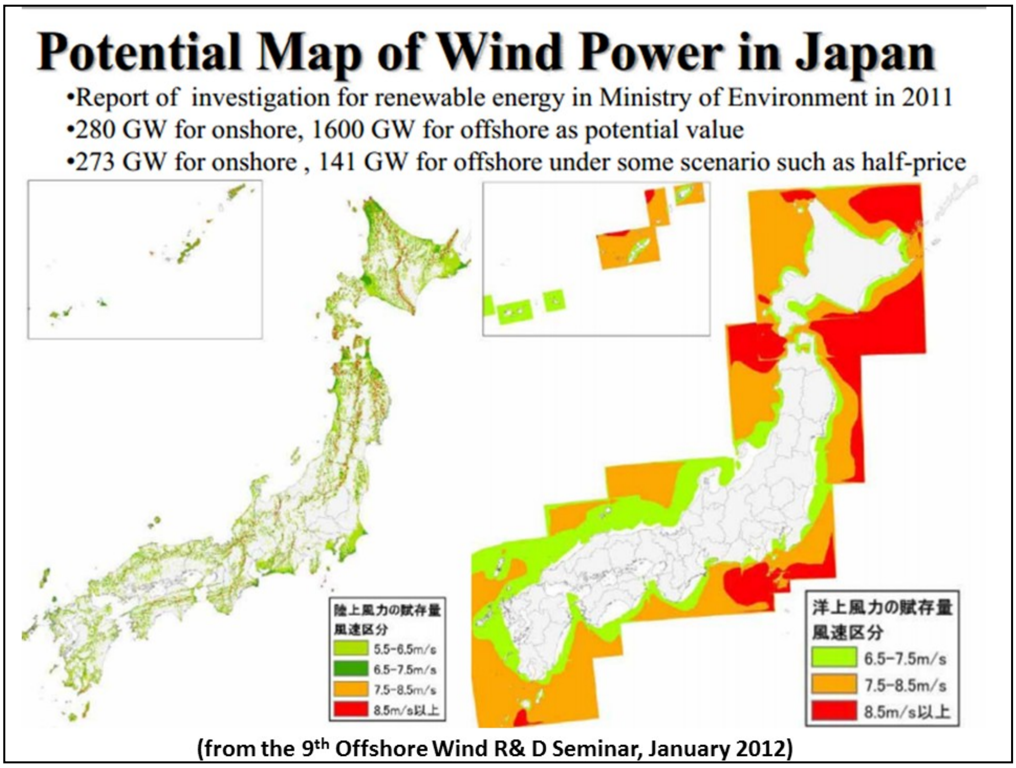



*Fig.20: Potential Wind Power Map Japan*
*(Source: United Press International (2013) Japan plans biggest ocean wind farm)*

*Biomass*

*Biomass can be defined as any organic matter that can be renewed over time. In other words, biomass is stored energy. Through photosynthesis, sunlight, carbon dioxide and water it can be turned into oxygen and simple sugars which are stored. Even though they emit carbon dioxide when burned they are considered to be carbon neutral. The main reason for biomass to be considered as carbon neutral is that fossil fuels are hydrocarbon deposits derived from organic matter from a previous geological time. They are fossilized biomass, and the containing carbon was removed from the atmosphere, stored underground (Ashton, 2015).*

*New biomass, when burned, only emits the $CO_2$ it removed from the atmosphere while fossil fuels release the stored carbon dioxide which means a surplus on greenhouse gas particles in the atmosphere.*

*Biomass is versatile, almost anything can be used. Energy crops, food waste or human/animal residues have a higher energy density and prove to be more efficient than simple greenery. It can be utilised in form of gas (biogas plant) for heating, generating electricity or cooking, biofuel for transportation, chemical substitutes for fossil fuel based chemicals or in form of wood for heating. Its generation can be decentralised and operate completely independent from the* *electric grid – the gas can also be used for generating electricity or stored in the national gas grid or special containers and used when needed. The transportability and decentralised functionality makes it possible for biomass to be utilised almost anywhere in the world.*

*Japan's Potential*

*The potential for biomass utilisation in Japan is enormous. Fig.21, Biomass Usage and Potential in Japan indicates that some areas are being utilised already while other require infrastructure until they can be utilised. According to the MAFF, forestry residue and agricultural residue are unused at the moment.*

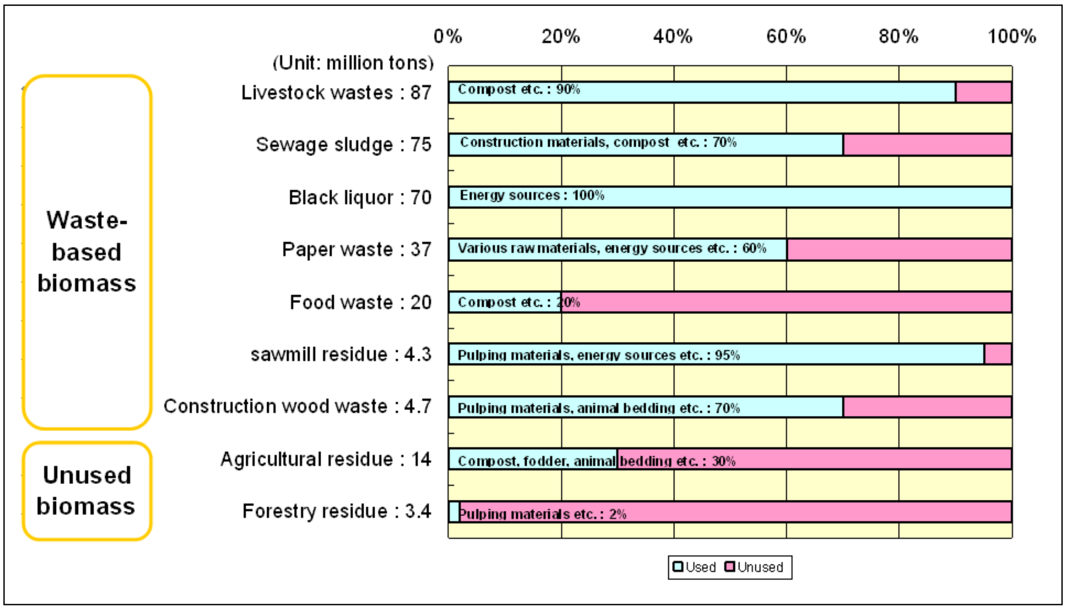



*Fig.21: Biomass Usage and Potential Japan*
*(Source: MAFF, basic plan for the promotion of biomass utilisation (2009))*

*Hydro*

*Water power generates electricity through the transformation of kinetic energy of falling- or running water. Hydropower was used by mankind long before the electrification took place, various implementations for irrigation or mechanical gadgets – saw mills, trip hammers or textile mills facilitated monotonous and hard labour. The first commercialised power plant in Cragside, England began its operation in 1878 (AIA, 1987). Electricity can be generated by hydro power in various ways: conventional dams which store (usually) large amounts of water are able to generate large amounts of electricity. Or the run-to-the-river power plants, which use the speed of running water, are often found next to running waters, their sizes range from micro- to medium sized stations, depending on the amount of available water and flowing speed.*

*Recent developments have led to pumped storage plants which are used to store surplus electricity in form of water during periods of overproduction, and release the water to generate electricity during peak demand.*

*Water power can generate electricity steadily, the amount of water may fluctuate through the year, but it is possible to feed into the base load or store energy for peak demands. This adaptive capacity makes water power appealing for a well equilibrated energy mix. However, large dams change the ecosystem of the affected area and are not usually seen as sustainable leading to the conclusion that large scale projects have to be carefully evaluated in order to prove their sustainability.*

*Japan's Potential*

*Hydropower is currently Japan's main renewable energy source, with a share of 9% on the total electricity generation in 2014. In 2013, the total installed capacity was 49 GW (IEA, 2015). Fig.22 shows the potential number of station in various sizes and the resulting power output. As most feasible sites for large scale power plants have been exploited already, the future potential has to be utilised by small-scale or even micro hydro power plants, as Japan still has many sites suitable for that purpose. It can be seen from Fig.22 that largest potential in terms of power output is in the category 10-30 MW while the largest potential in terms of numbers is in the category 1-3 MW. The development potential is considerable, however, those sites are (usually) not easily accessible and comparably expensive.*

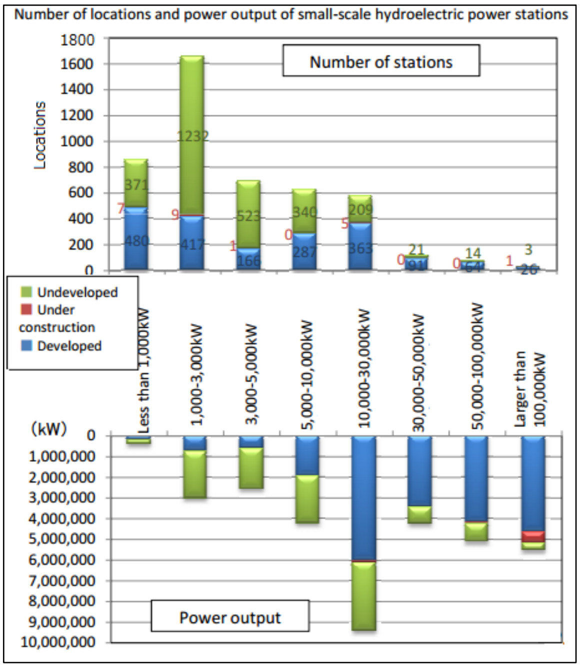



*Fig.22: Locations and Power-Output Hydropower Japan*
*(Source: METI (2012) Japan Renewable Energy)*

*Tidal and Wave*

*Tidal energy is another form of hydro energy using the changing tides to generate electricity. Wave power is simply the transformation of the energy of waves into electricity. Both are modern approaches to make use of the untapped energy potential that is within the oceans. Just like wave power technology, tide energy is still in the first development stages. Tides are more predictable than wind or sun, which gives this technology an advantage compared to its two competitors wind or solar power.*

*Currently commercialised in a few places in the world, the potential for tidal energy is expected to be much higher. Opened in 1966, the Rance Tidal Power Station, France generates around 240 MW peak and 57 MW on average (De Laleu, 2009). The power plant is located in a river delta, separating the sea and the river Rance, during high water the power plant opens its gates to let water flow in the river delta and during low water, the water flows back to the sea. Both ways generate electricity.*

*Wave power has not yet come out of the development stage. The first experimental farm is being tested in Portugal since 2008. So far there are different technologies and approaches being tested, but the most effective has not been determined yet.*

*Japan's Potential*

*As Japan is an island country surrounded by oceans, the potential for both technologies is estimated to be high. Especially the region of southern Japan, around Kyushu, has particularly high tides (around 250 cm). Other areas around the south coast also have relatively high tides with a daily average of 190 cm. Fig.23: Mean Daily Tidal Range Map shows the potential for the technology around the globe. Japan's south is clearly marked with high tides.*

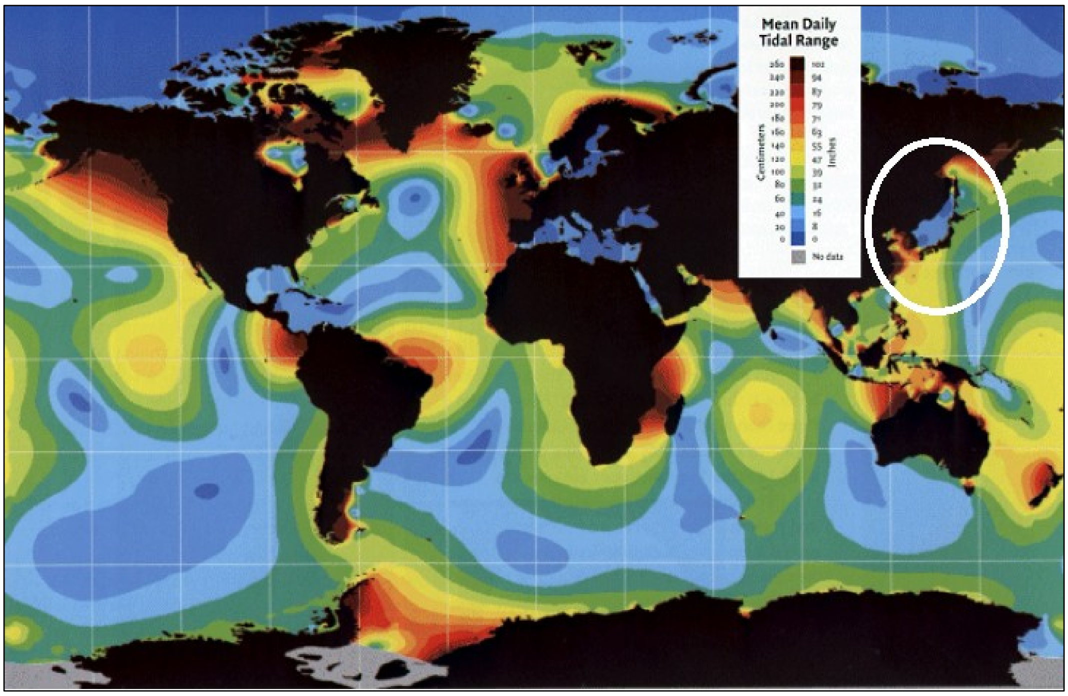



*Fig.23: Mean Daily Tidal Range World Map*
*(Source: EPRI Ocean Tidal and Wave Energy Page 1-6)*

*Compared to other areas in the world, the wave power potential of Japan is high. Its long coast line though makes the utilisation attractive. As seen in Fig.24, the average potential is between 20-30 kW/m on Japan's east coast.*

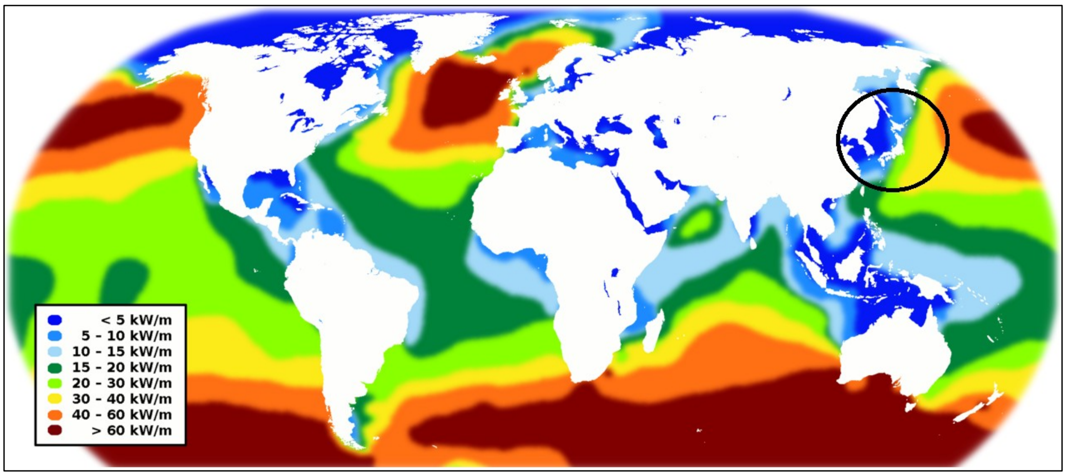



*Fig.24: Wave Energy Resource World Map*
*(Source: Wikipedia World Wave Energy)*

*Both technologies prove to have potential in Japan. Technology wise they are not that advanced as other renewable technologies and the true potential of the oceans may not have been realised yet. For an island country these technologies can be highly attractive, as they do not require any land.*

*Geothermal*

*Geothermal energy, defined as the heat from the earth, is a statute-recognised renewable source. (Kagel, 2007) Originating from the earth's inner structures and radioactive decay, heat is generated and stored in the earth's crust. This energy can be used in direct and indirect ways. Direct usages are heating and cooling of private households or public buildings, greenhouse heating, relaxation and healthcare in spas, even cooking with the hot water or steam is possible. Electricity generation is an indirect use and can only be implemented when temperature and heat levels are high enough to run an attached steam turbine.*

*Japan is located right on top of the Pacific Ring of Fire. The tectonic activities do not only cause constant earthquakes, but also contribute to a high volcanic activity. That is why geothermal energy in Japan is close to the surface, often even visible in form of hot springs, referred to as "Onsen" or steam rising up from crevices. However, according to the IEA (International Energy Agency) geothermal energy with an installed capacity of 353 MW contributed in 2013 only 0.3% to Japan's electricity generation (IEA: Oishi, 2014). The potential, on the other hand, is much higher, estimated 23.5 GW in electricity could be generated by geothermal power plants.*

*This amount is enough to supply around 40 million households and making Japan the country with the third largest geothermal potential in the world (JSF, 2014).*

*Japan's Potential*

*Japan's total geothermal power potential is estimated to be around 23,470 MWe, the third highest in the world, after the United States of America and Indonesia. However, currently only a small percentage of that amount is being utilised (535 Mwe) (Muraoka, 2008). Fig.25 shows all major geothermal power plants that were operated in 2012 by electric power companies. The majority of those plants are located in the northern area (Tohoku) and the southern island (Kyushu). There are just a few large ones, with the power plant Hatchobaru in Oita being the largest one (110 MWe). Compared to large conventional power plants, the power output is rather low, as most of those power plants can generate up to 500 MWe per block. However, the potential of geothermal energy is there and can be taken advantage of.*

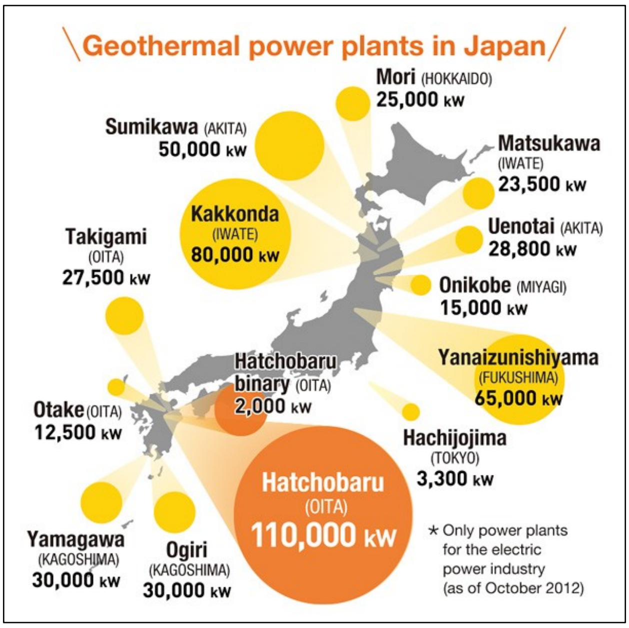



*Fig.25: Geothermal Power Plants in Japan (2012)*
*(Source: Mitsubishi Heavy Industries: Geothermal Power)*

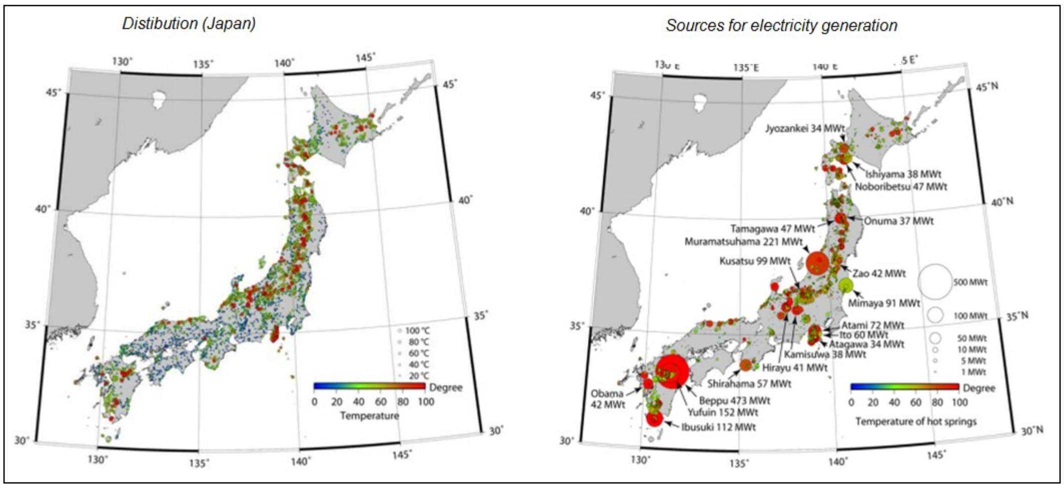



*Fig.26: Geothermal Sources and Potential*
*(Source: Muraoka (2014) Geothermal Energy Asia)*

*The left picture of Fig.26 shows the distribution of 3,686 hot spring sources in Japan. High temperate sources are mainly concentrated in Kyushu and from Chubu up to Hokkaido, the small Izu peninsular shows a dense concentration of high temperature sources as well. Furthermore, the right picture indicates that the major potential for electricity generation is Kyushu (with Beppu area to be the most promising one with a potential output of 473 MWe) and Tohoku. Most sources can only generate small quantities of electricity, which is maybe enough to supply local communities in sparsely populated areas of the north.*

## *2.4. Energy Policy Analysis*

*This section deals with Germany's energy policies that have been deployed in the last decades to support the use of renewable energies or improve energy efficiency, and as a result augmented the country's energy independence. The second part summarises Japan's energy policy in the last decades until today.*

### *2.4.1. Germany*

*Security of supply, economic efficiency as well as environmental and climate friendly energy are the three central themes of Germany's modern energy policy. Supporting structural change in the electricity generation sector in order to mainly rely on decentralised renewables (in the energy generation sector) until the year 2050 (Grigoleit, 2012) and reducing the overall energy demand through efficiency enhancement, are the key points of that policy.*

*For the so called "Energiewende" or "Energy transition" which means the transition process from the usage of non-sustainable fossil energy carriers and nuclear power towards a sustainable energy supply by renewable energies, Germany has made some pioneering and exemplary regulations, boosting the utilisation of renewable energies in the country, to reach its long-term strategic goal (Bechberger, 2012). This method was highly successful and many countries (including Japan) tried to imitate some of the mechanisms Germany adopted. The German role model is a good example for other countries around the world that proves the applicability of renewable energies in the electric power grid.*

*Fig.27 shows the achievements of the energy transition process in the year 2013, milestones and targets until 2050. GHG emissions are expected to go down until by 2050 by 80-95% of the 90s level. The share of renewable energies should make up 80% of the country's energy mix – while energy efficiency is projected to witness a 50% increase.*

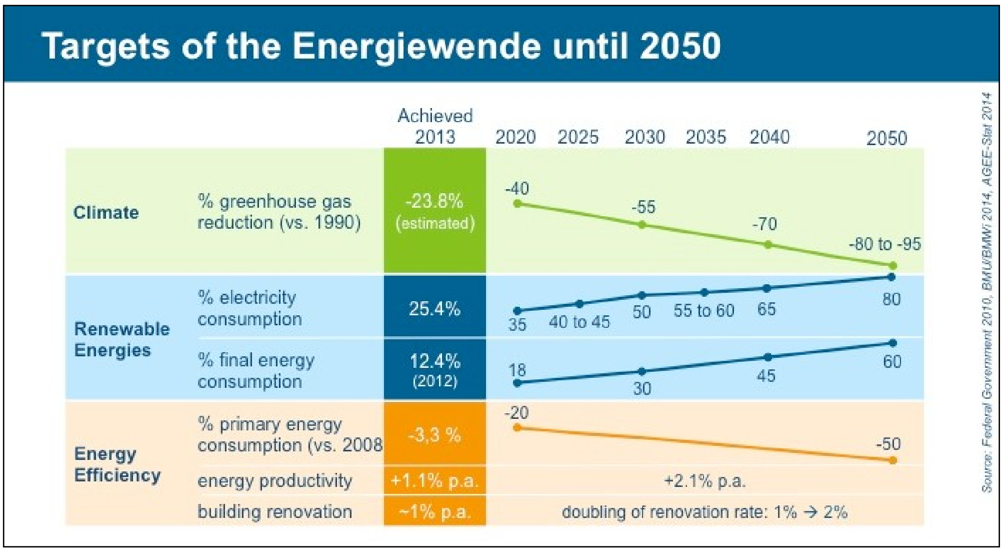



*Fig.27: Targets of the Energiewende until 2050*
*(Source: APO Tokyo (2015): The German Energy transition)*

*In 2015, the share of renewable energies on the gross electricity generation was already around 30.1% in Germany, far ahead the European goal of 20% by 2020. This was another increase of almost 4% compared to 2014 (AEE, 2015). Other industrialised countries reached lower shares, France 17.42% (RTE, 2015), the USA at 12.56%, and the UK the lowest at 11.99% (EIA, 2012). At the same time Japan reached a share of 12.5% (including 8.2% from hydro power) (ISEP, 2014). As the country is still highly dependent on energy imports, such growing self-sufficiency in the electric sector was politically supported. In order to understand Germany's success it is necessary to know that it results from not only suitable background conditions for renewable energies but also due to a comprehensive promotion approach which had been launched at the beginning of the 1990s.*

*In 1991, the first-feed in law of Germany, the Act on Supplying Electricity from Renewable Energies (Stromeinspeisungsgesetz, StrEG) forced grid operators to integrate renewable power stations into the power grid system and even to prefer feeding in electricity generated by renewables (Jacobs, 2015). Fixed remuneration of renewable energy sources had been offered for all electricity which was generated by renewable energy sources (RES), Thus leading to an early market breakthrough in wind energy. Its successor, the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) in April 2000 improved the regulations of the StrEG in many respects and made it possible for other renewables, namely solar photovoltaic and biomass energy, to enter the market (Bechberger, 2004).*

*Key promotion tools made this particular policy highly successful and increased the share of renewable energies in Germany significantly within a short period of time. Subsidies for the operational costs, and promotion programmes supported*

*RES through investment subsidies (grants or soft loans), fixed feed in tariffs, and tax exemptions (Environmental Tax Reform) made RES financially attractive to private investors. The decision to phase nuclear energy out – the run-time for many reactors was later extended, before changing everything after Fukushima in 2011 again – was indirectly influencing the growth of alternative energy forms (Bechberger, 2004). The EEG is regularly reviewed and updated the latest update was conducted in 2017 with the EEG 2017 which set the goal for renewable energies at: 40–45 % by 2025, 55–60 % by 2035; min. 80 % by 2050; and set up regulations of calls for tender for large plants, with exemption for citizen energy initiatives. Another main feature of the new EEG is the paradigm shift from regulated prices towards a market price based system (large scale on and off shore wind power, photovoltaic and biomass is affected) (BMWi, 2017).*

*Fig.28 shows the growing electricity generation of renewable energies in Germany ever since the first feed in tariffs in 1991, wherein hydro power was the dominant source of renewable energy, to the latest update of the EEG in 2014 where a renewable energy mix is clearly visible.*

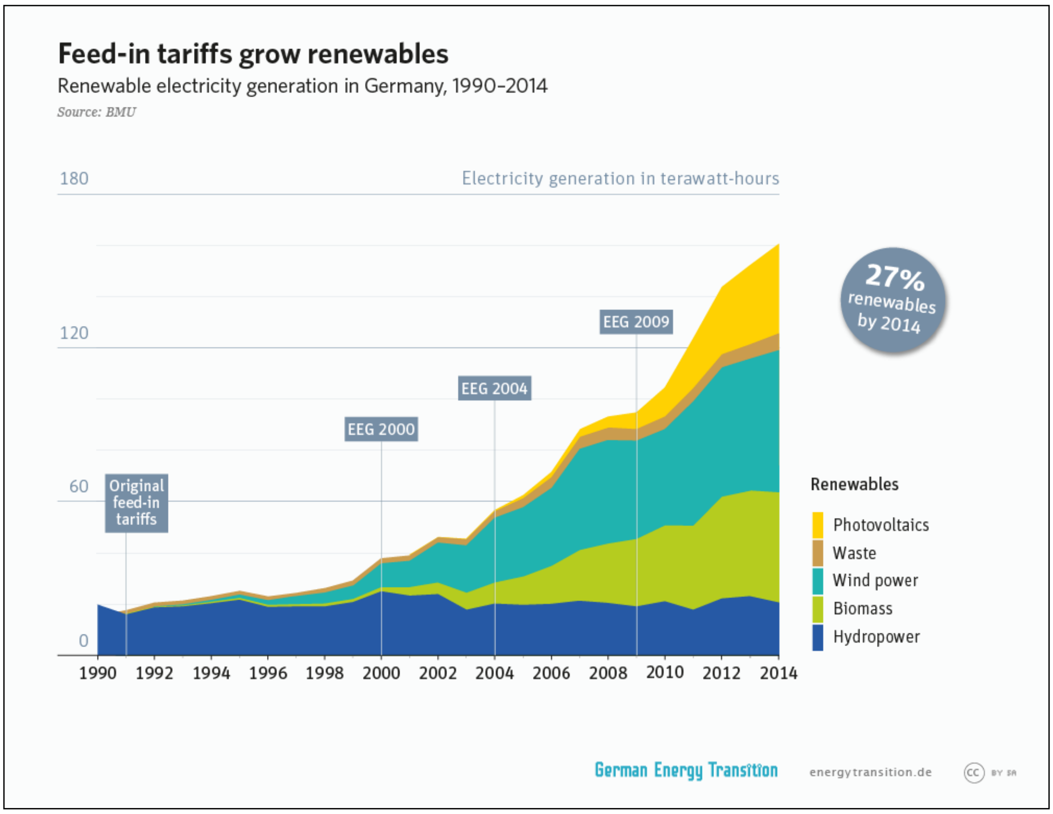



*Fig.28: Development of Power Gen. Sources 1990-2014*
*(Source: Energy Transition (2012) Feed-in tariffs)*

*As household investments in renewable energies grew in popularity, the pace of power station decentralisation also increased. Fig.29 illustrates that in 2012 47%*

*of the installed power output of all renewable energies was owned by citizens, 41% by investors and only 12% by energy suppliers.*

*The detailed breakdown of the citizen owned capacity shows that 52% are individuals whom invested in renewable energies. The decentralisation process is not only a movement away from large central and conventional power stations towards small and (optimally) renewable power plants but also a change of ownership of the energy generation capacities (at least in case of Germany).*

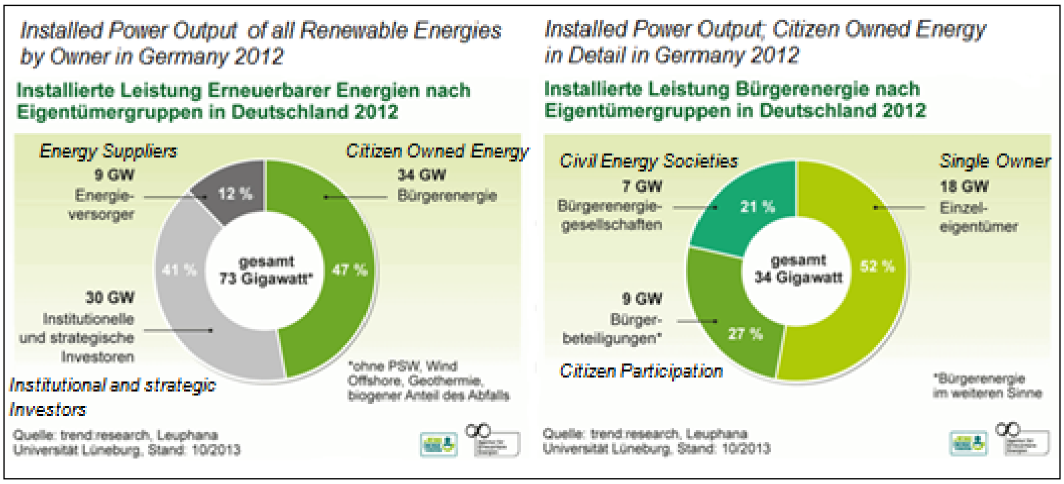



*Fig.29: Installed Power Output and Ownership 2012*
*(Source: Energy Transition (2013) Ownership)*

*However, one consequence of the rapid growth of the renewable energies is the lack of sufficient grid capacities. As the grid is still based on the centralised generation system it becomes complicated to keep the grid stable when overall power fluctuation increases, but expansions require time and considerable investments. The expansion process was even further undermined due to disagreements between prefectures, and also between citizens and politicians. Germany is part of the greater European power grid and can make use of that capacity to keep its grid stable, however.*

*Another way to meet the long-term goals of a high share of renewable energies and greatly reduced GHG emissions is to cut down consumption. Such reduction should prioritise heating, cooling and hot water, which require high amounts of energy when buildings/systems are not well insulated (roughly 40% of the German energy demand is consumed in buildings with heating being the largest consumer). As fossil fuel based heating systems make up the main part in this sector, more energy efficient housing, through new construction or renovation, is essential in order to reduce emissions (Morris, 2012).*

*The Thermal Insulation Ordinance of 1976 was the first regulation subject to public law for energy saving thermal insulation buildings in Germany, but only on technical standards (DIN4108). However, it was amended twice. The Heating*

*Appliances Ordinance ("Verordnung über energiesparende Anforderungen an heizungstechnische Anlagen und Brauchwasseranlagen (Heizungsanlagen-Verordnung - HeizAnlV)") from 1978 to 1998 set standards to the equipment and dimensioning of central heating systems using water as the energy carrier as well as on hot water systems. In 2002 both predecessors merged into the Energy-Conversation Ordinance (Energieeinsparverordnung, EnEV) which combined all aspects for energy efficient housing in private and commercial sectors.*

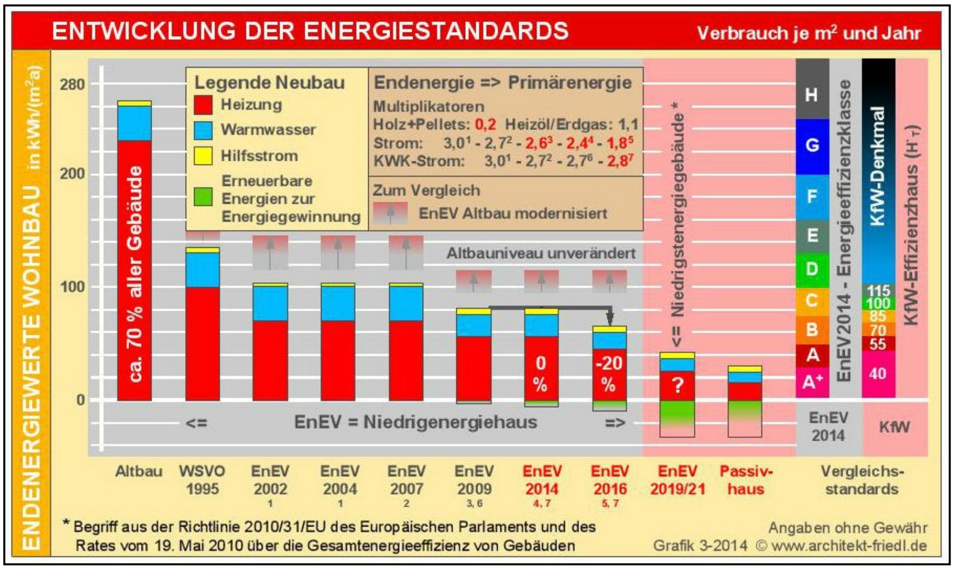



*Fig.30: Energy Standards for Buildings*
*(Source: German Energy Efficiency Ordinance (2014))*

*The potential of retrofits has yet to be taken fully under account for the energy transition. The EnEV does not encourage building owners enough to renovate their buildings towards energy efficiency, furthermore only urgent problems are fixed.*

*As seen in Fig.30, the average energy consumption of 70% of all buildings is around 260 kWh/m²a, newly built houses can only consume around 60 kWh/m² a and have to generate some electricity with renewable energies. This standard will get even lower in the near future until the energy generated by the house exceeds the energy consumed by house. At the moment the renovating rate in Germany is around 1% (all buildings will be renewed within 100 years) attempts to increase the ratio to 2% have not been successful yet. As there is no legal obligation to increase the renovation rate, the progress will continue to stagnate. To improve the overall situation a substantial increase in funding for retrofits is required (Morris, 2012), in combination with the energy transition incentives for building owners could prove the right tool to do so.*

### *2.4.2. Japan*

*Due to the lack of fossil fuel resources and the gained experiences during the oil crisis, Japan's most important goal was to ensure the country's energy security (Huenteler, 2012, Atsumi, 2007). The energy security is linked with national security, (Calder, 2008) described this intense interconnection as "Energy Angst". This link between energy and national security is seen by (Suzuki, 2014) and (Price, 1990) as the main reason for the fast development of nuclear energy in Japan. Up until today, the so called 3E's (three E's) which are namely Energy Security, Efficiency and Environment characterise Japan's energy strategy.*

*They are part of the Basic Energy Plan (BEP) which is a strategic paper that sets the direction of the national energy policy for the following two decades. The first BEP was formulated in 2003 and revised in 2007 and 2010. The 2010 revision ("2010BEP") planned to reduce domestic energy-related CO2 emissions by around 30% below 1990 levels by 2030, mainly by building 14 new nuclear power plants by 2030 (9 plants by 2020) in addition to the 54 plants existing in 2010 (Kuramochi, 2015, Duffield and Woodall, 2011).*

*In summary, Japan's energy strategy before Fukushima focused heavily on nuclear energy as a (nominally) cheap, quasi-indigenous, and low carbon source (Huenteler, 2012). Renewable energies, on the other hand, did not play a vital role in mitigating emissions before Fukushima. Policy support in the form of investment subsidies (since the mid 1990's) and a Renewable Portfolio Standard (2003) did not increase the number of PV systems and wind power stations significantly. Geothermal projects were constructed in between the 70's and 90's but came to a halt since 1999 (Sugino and Akeno, 2010). Even a feed-in tariff (FIT) system was implemented in 2009 to meet Japan's renewable energy goal of 1.35% of electricity production in 2010. However, this FIT was restricted on residential PV systems (Huenteler, 2012). As Huenteler stated, "Taken together, we see that no stringent regulatory framework encouraging significant investment in renewables had been implemented before Fukushima. Maruyama et al. (2007, p. 2763) even come to the rather disappointing conclusion that ''Japan's renewable energy policy [was] impeding renewable energy use rather than contributing to the spread of it''."*

*The accident at the Fukushima Daiichi nuclear power station was not only a catastrophic disaster but also a serious wake up call for Japan's energy policymakers. Due to the loss of the Fukushima power plant and consequent closures of all nuclear reactors in Japan, the government and energy suppliers had to come up with various measures to influence both supply and demand to prevent unplanned blackouts (Hayashi, 2013).*

*Japan updated its FIT to promote the use of renewable energies in 2012 in which it used the German promotion system as example. Newly constructed power stations were guaranteed to receive fixed prices for their generated electricity for the next 20 years. Another new development was that electricity utilities had to sign contracts with renewable energy producers which meet the standards given by the government (METI, 2012). Fig.31 shows the general feed-in scheme in Japan. The government plays a role of a moderator while electricity utilities and energy generators have to get in touch by themselves.*

*At the same time, the Renewable Energy Act also stipulates an exception that the electricity utility operators can refuse wind and solar PV electricity access to the grid by facilities larger than 500 kW for maximum 30 days per year without compensation when supply exceeds demand in order to secure grid stability (METI, 2012).*

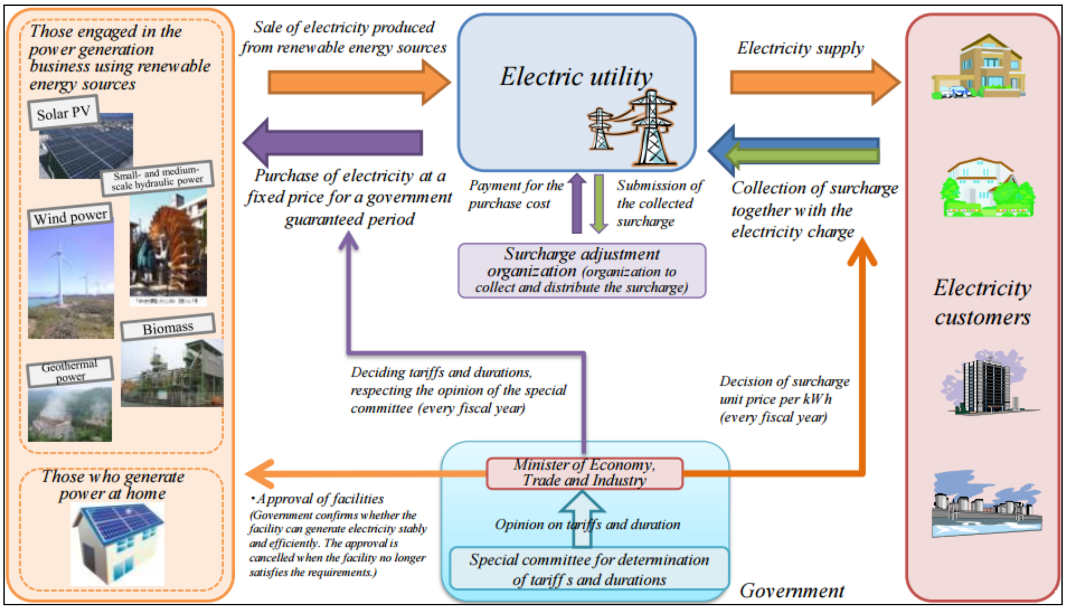



*Fig.31: FIT-Scheme Japan*
*(Sources: METI (2012) Japanese Feed-In Scheme)*

*Tab.3: Tariffs and Duration Renewables 2012*

| Energy source | Solar PV | | Wind power | | Geothermal power | | Small- and medium-scale hydraulic power | | |
|---|---|---|---|---|---|---|---|---|---|
| *Procurement category* | *10 kW or more* | *Less than 10 kW (purchase of excess electricity)* | *20 kW or more* | *Less than 20 kW* | *15MW or more* | *Less than 15MW* | *1MW or more but less than 3MW* | *200 kW or more but less than 1MW* | *Less than 200 kW* |
| *Cost* – *Installation cost* | *325,000 yen/kW* | *466,000 yen/kW* | *300,000 yen/kW* | *1,250,000 yen/kW* | *790,000 yen/kW* | *1,230,000 yen/kW* | *850,000 yen/kW* | *800,000 yen/kW* | *1,000,000 yen/kW* |
| *Cost* – *Operating and maintenance costs (per year)* | *10,000 yen/kW* | *4,700 yen/kW* | *6,000 yen/kW* | – | *33,000 yen/kW* | *48,000 yen/kW* | *9,500 yen/kW* | *69,000 yen/kW* | *75,000 yen/kW* |
| *Pre-tax IRR (Internal Rate of Return)* | *6%* | *3.2%(*1)* | *8%* | *1.8%* | *13%(*2)* | | *7%* | *7%* | |
| Tariff (per kWh) – Tax inclusive (*3) | 42.00 yen | 42 yen(*1) | 23.10 yen | 57.75 yen | 27.30 yen | 42.00 yen | 25.20 yen | 30.45 yen | 35.70 yen |
| Tariff (per kWh) – *Tax exclusive* | *40 yen* | *42 yen* | *22 yen* | *55 yen* | *26 yen* | *40 yen* | *24 yen* | *29 yen* | *34 yen* |
| *Duration* | *20 years* | *10 years* | *20 years* | *20 years* | *15 years* | *15 years* | *20 years* | | |

(Source: METI (2012) Japanese Feed-In Scheme)

Tab.3 shows the feed in tariff and duration of each individual energy source. Small scale power stations receive especially high incentives.

In 2014 a new BEP, the first after Fukushima, was formulated. As a new feature, the 3E's received an "S" for safety as a new pillar of the national energy policy. Most important point in the new BEP is that it does not follow a previous strategy of the former ruling government's (DPJ) to phase out nuclear energy until 2030, but only states that the dependence on nuclear energy will be reduced as much as possible. Furthermore, the paper calls for a swift restart of existing nuclear reactors after approval by the Nuclear Regulation Authority (NRA).

In the new BEP, there is no mention of the future energy mix, only after successful renewable FIT system implementation, nuclear power station safety check and after analysing international climate policy discussions, the path for Japan's future energy generation will be decided (Kuramochi, 2015).

Energy efficiency is another way to reduce carbon emissions. Japan implemented the so called "Top Runners Program" in 1998 after the revision of the Energy Conversation act. This program sets energy efficiency standards for machinery and equipment based on the highest energy efficiency in a given industry (MOE, 1998). Following the latest amendment of the Energy Conversation Act in 2013, the Top Runners Program was applied to other products than machinery and electric appliances for the first time and set new standards for building materials (e.g., windows and insulation). Moreover, a roadmap was developed for new buildings to gradually adapt to the thermal insulation performance standards by 2020 (in FY2011, the rates of compliance for non-residential and residential buildings were 85% and 49%, respectively (Kuramochi, 2015).

# *3. Summary and Conclusion*

## *3.1. Discussion*

*Germany and Japan started under almost the same conditions in their development history, industrialisation and electrification were either based on fossil fuels or – in some cases- hydro power. However, such rapid progress led to an overwhelming demand, to a point that water driven power stations could not generate enough electricity. Other factors as to why renewable source lost ground to fossil fuels at that early stage were mainly because of technical reasons, as far distance transmission was not yet feasible. The demand sides were mainly based in the cities, not necessarily where potential sites for hydro power plants were located. Coal fired power stations were able to generate electricity inside the cities, while the required coal was delivered by the ever expanding train system. In Western European countries (the U.S and Japan included) which began the industrialisation process first, biomass, the main energy carrier was soon replaced by hard coal and lignite. At that time, both countries, the German and Japanese Empire, were able to meet their demand for coal by domestic production.*

*Mineral oil became the preferred energy source for electric energy generation after the 2nd World War. It was widely available and even cheaper than domestically produced coal. Japan, which had exploited most of its coal – which was not of high quality at the first place, began to rely heavily on oil as its main energy source. During this period domestic coal no longer played a vital role for the Japanese energy sector (Kunitomto, 2009). Germany, thanks to a larger coal deposit, maintained its independence over oil driven power plants. The first oil crisis in the 70's led to a sharp increase of the oil price – putting all industrialised countries without sufficient domestic oil production into serious crisis. Alternative technologies received strong research support as all countries tried to reduce their dependence to which they were reminded painfully. Energy conservation and research on renewable energies were supported, while nuclear power plants were constructed to increase the independence from fossil fuels.*

*Although, first nuclear power plants for commercial use had been built in the 60's (Japan 1966, Germany 1962) (Poneman, 1982; Smith and Rose, 1987), the oil crisis further pushed development of nuclear energy. The Nuclear Age brought progress and new means in terms of energy generation. Despite a second oil crisis in 1979, after a recovery phase and the return to normal prices for mineral oil, most projects working on renewable energies or mechanisms to reduce the consumption of fossil fuels were stopped.*

*To reduce the risk of another crisis, most countries diversified their suppliers and tried to use more energy sources. Japan, focused on energy security, began to increase the number of nuclear reactors steadily. East and West Germany invested in nuclear energy as well.*

*The Kyoto Protocol in 1997 brought up the problem of climate change for the first time. $CO_2$-emissions had to be reduced by the industrialised countries that signed the agreement (the U.S. did not sign the agreement).*

*Germany and Japan agreed to mitigate their emissions by 21% and 6% of the 1990 levels. Germany was able to make a lot progress, on one hand because of the collapse of the East German industry after the unification, on the other hand by investing in more efficient technology and energy conservation. The second step was to systematically increase the share of renewable energies and to reduce overall consumption. The so called "Energiewende" (energy transition) successfully took off because strict policies/ regulations and generous incentives boosted the development of renewable energies.*

*Japan proposed a different strategy. To keep energy security high and to reduce emissions, nuclear energy was seen as the most suitable energy source (Atsumi, 2007). While efficiency programs, like Top Runners, improved energy efficiency of electrical appliances significantly, the overall electricity demand kept on increasing. Renewable energies on the other hand, were not seriously supported by the government, which made the 3E's to the main priorities of the Japanese power utilities, and nuclear energy was seen as the most suitable energy source for that policy. However, the accident at the nuclear power plant Fukushima Daiichi should change the conception of nuclear energy in Japan and other countries. As a direct result, Germany announced that all German nuclear power plants will be phased out by 2022. This disaster hit Japan's energy generation sector hard. All reactors were shut down and conventional power plants were reactivated to meet demand. However, this sudden rise of fossil fuel consumption had some adverse side effects.*

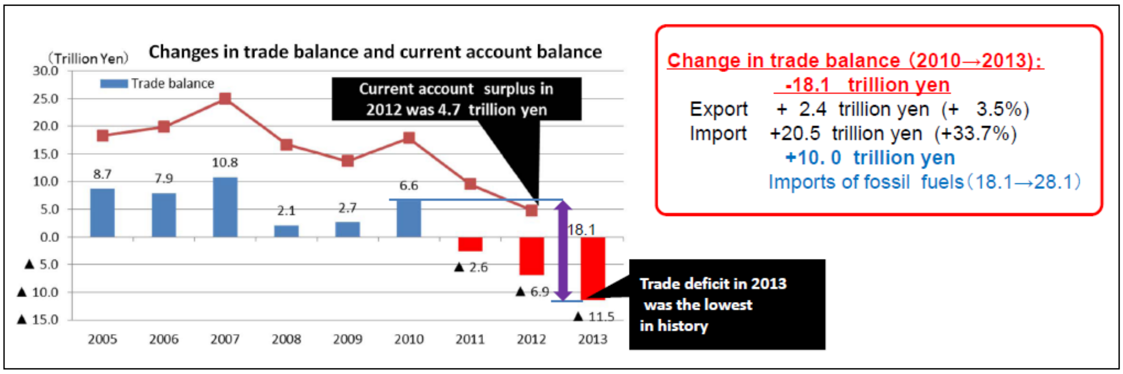



*Fig.32: Trade Balance Japan 2005-2013*
*(Source: METI Japan's Energy Situation and Policy 2014)*

*After Fukushima incident, the additional cost for fossil fuels for increased thermal generation was around 36 billion yen in the fiscal year 2013 (respectively from the fuel costs in 2010) (METI, 2014). As seen in Fig.32, this increase in cost led to a trade deficit, costing over 18.1 trillion yen in the years between 2010 and 2013.*

*As can be seen in Fig.33, the import of fossil fuels also resulted in an inevitable increase of the electricity tariffs, from 20.37 Yen/kWh to 25.51 Yen/kWh (an increase of 25.2%) for the regulated sector and from 13.65 Yen/kWh to 18.86 Yen/kWh (an increase of 38.2%) for the liberalised sector from the tariff level in FY 2011 (METI, 2014). Higher energy prices mean higher production cost, which as a consequence lower the competetiveness of Japanese products on the market.*

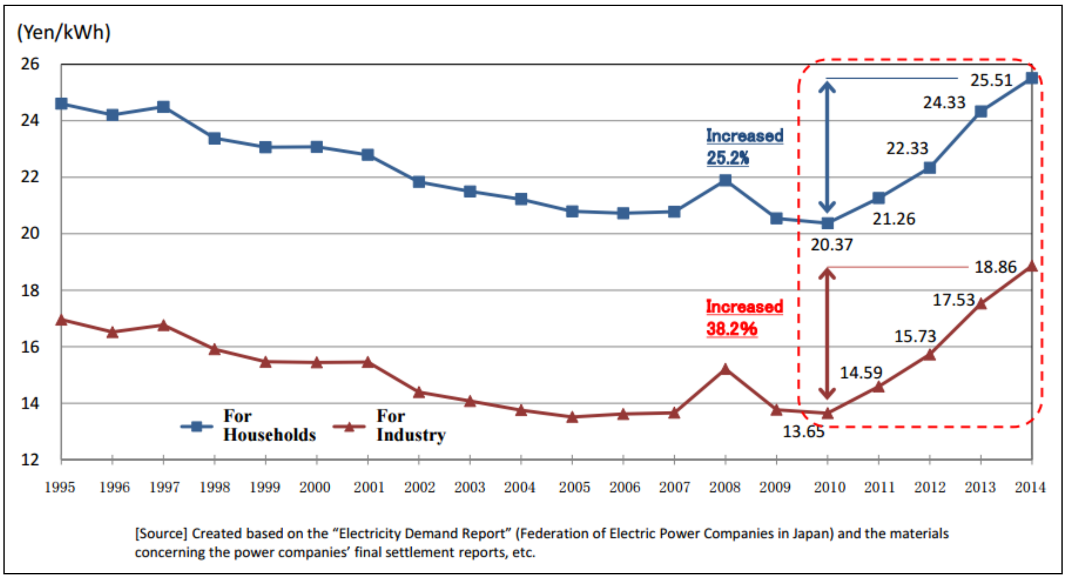



*Fig.33: Electricity Price Japan*
*(Source: IEA (2015) Japan's Electricity Market Reform and beyond)*

*An increase in fossil fuel combustion also led to an increase in carbon dioxide emissions. Tab.4 shows that emissions caused by electricity from 2010 to 2012 went up by 112 million tons of $CO_2$ while the amount emitted by other sources decreased by 29 million tons.*

*Tab.4: Emissions by Energy use (Japan)*

CO2 emissions originated by energy use

| Year | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| Total | 1,138 | 1,075 | 1,123 | 1,175 | 1,207 |
| Electricity | 395 | 353 | 374 | 439 (+65) | 486 (+112) |
| Others | 743 | 722 | 749 | 734 (-15) | 720 (-29) |

(Unit; Million t-CO2)

*(Source: METI Japan's Energy Situation and Policy 2014)*

*Fig.34 shows that energy dependence is just as high as it used to be during the first oil crisis. A scenario that Japan tried to avoid at all cost. The explanation is simple, it was not possible to construct hydro power plants or other renewable energy plants in such a short period – fossil fuels were the only energy source that could meet Japan's energy demand quickly.*

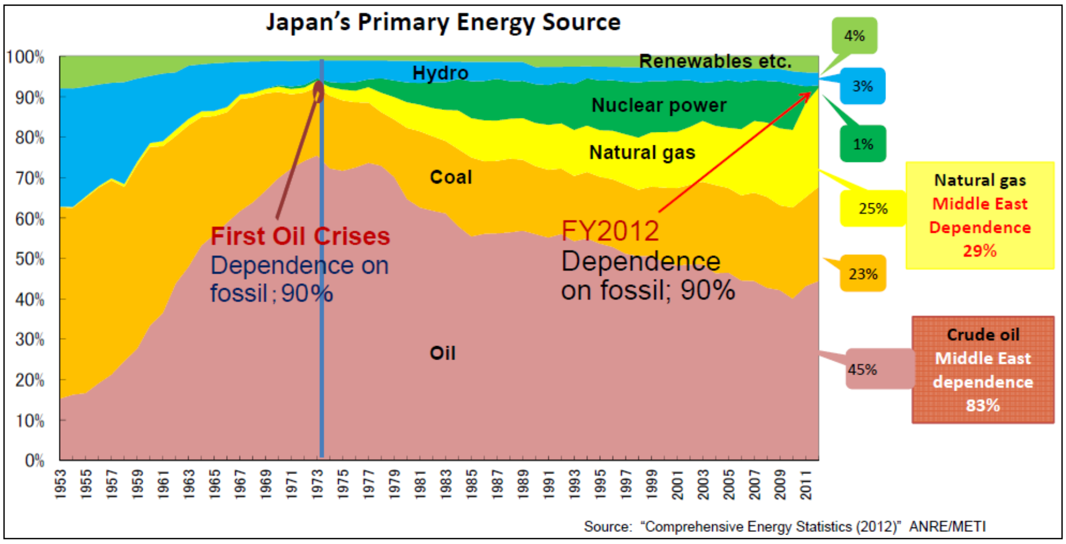



*Fig.34: Japan's Primary Energy Source*
*(Source: METI Japan's Energy Situation and Policy 2014)*

*Because of such situation Japan had to start to come up with alternatives to nuclear energy. Based on the German model, the FIT from 2012 subsidised renewable energy sources for 20 years. Furthermore, Japan can draw on many potential renewable energy sources. Hydro power has been utilised for a long time already, large scale projects however are not available anymore, while many small scale projects are still around and could be developed.*

*Pump storage systems could help store the surplus energy of other renewable sources. Geothermal energy, which had seen utilisation in the 70's to the 90's still has a lot untapped potential that can be used in many ways and thus help to meet Japan's goal of increased self-sustainability and reduce carbon emissions at the same time. Both energy sources are able to feed in the base load and can replace permanently conventional power plants.*

*Solar power has high potential in the southern part of Japan, much higher than in Germany (Pescia and Ichiyani, 2017). Inside cities, rooftops can be used for energy generation – systems are fast installed while being relatively affordable. In contrast, Japan's wind power potentials lie in the northern parts and offshore. As both sources are highly weather dependent, they have to maintain stability for the power grid.*

*Biomass is the all-rounder given the available energy sources. Not only can it be used for electricity or heat generation, but also for refining chemical derivates that are close to their counterpart fossil fuel based products. Different types of biomass can be harvested / collected all around the country and turned into fuels, gas, chemicals, heat or electricity. Especially food waste in the city could prove a valuable resource in the future.*

*Another area in which Japan is thought of having high potentials is tidal or wave power. There are just a few power plants of those types existing in the world, and especially wave power is still in the experimental stage. It is not clear how much energy could be generated. However, it is an attractive opportunity to generate electricity without using scarce land. Even though this unrealised potential should not be neglected and further research needs to be conducted, it can be concluded that Japan's current options are the above mentioned renewable sources.*

*To increase the share of renewables it is important to introduce binding policies. Grid operators in Japan have to sign contracts with renewable energy generators and buy the generated electricity for the following 20 years. However, there has yet to be a counterpart to the German StrGE in Japan, which means that even though power utilities have to sign contracts, they can set individual regulations before they connect renewable power systems to the grid – a process that can take time. This approach is not necessarily boosting investments. With the electric power market liberalisation reform in 2016, it is possible for households to decide from which power utility they purchase their electricity from. This is a first time experience for Japanese households. With that, competition among the electricity generators and retailers is possible. That could lead to lower energy prices, but households could also decide to purchase electricity from renewable energy generators and pay a higher price but support the renewable development. As the liberalisation started in April 2016, it is too early prove that point with sufficient data.*

*Even though this idea seems a little bit unrealistic from an economic point of view, small electricity utilities in Germany work successfully with that scheme. It is too early to determine if the same mechanism could work in Japan, as the liberalisation process has just only started.*

*This recent development could also become interesting for some prefectures as they can generate surplus electricity and sell it to prefectures with high demand. In Fig.35 are all prefectures and their ratio of renewable energy listed. Especially rural prefectures such as Oita or Akita can generate high amounts of renewable energy and "export" it to other, more urban, prefectures. The revenue is used on a local basis and could be considered as locally gained value, an advantage compared to fossil fuel import because money stays in Japan and can be reinvested in rural prefectures.*

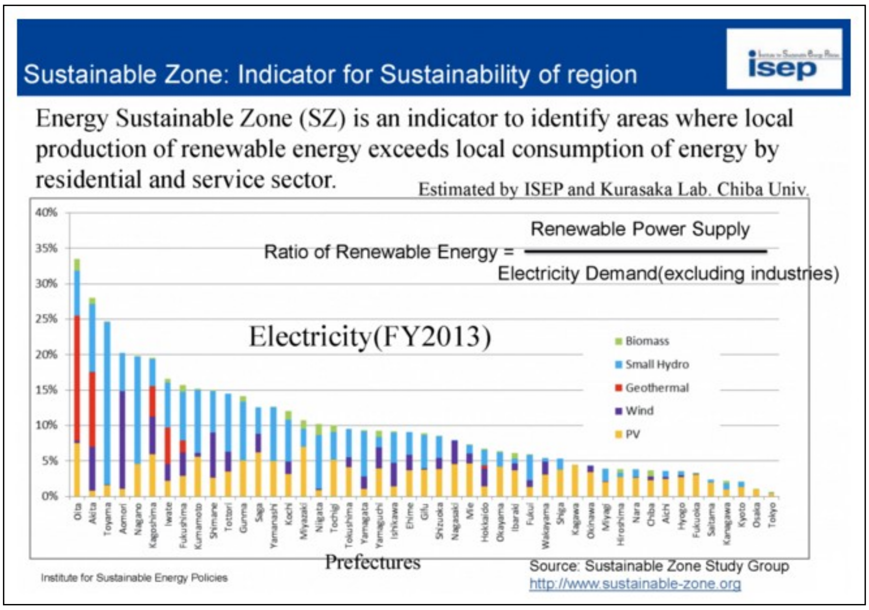



*Fig.35: Electricity Generation Surplus Prefectures*
*(Source: ISEP Library)*

*Another way to increase energy independence is to reduce energy consumption. With the Top Runners Program Japan has a highly successful guideline for electric appliances. Recently the construction sector also received some guidelines concerning the insulation of buildings. Compared to the German EnEV, this guideline is based on voluntary action and not on mandatory regulations for newly constructed buildings. Compared to Germany, the energy consumption per household might be lower. However, insulation efficiency enhancement could help to reduce the overall energy demand for heating and cooling in households further. Energy transition takes time. It is not possible to change an entire energy generation sector within a few years.*

*Germany needed many years to build up the renewable energy capacities it has right now, and it will take decades to reach the ambitious self-set goal of 80% electricity generation by renewable energies in 2050. Japan, on the other hand, planned with nuclear power stations, and typically power stations have a standard life time of 40 years.*

*The burst of the economic bubble in the 90's might has been a side factor why Japan did not necessarily take renewable energies and emission reduction that serious before Fukushima. It was cheaper for the government to continue with the nuclear energy strategy to increase self-sufficiency and reduce carbon emissions. Only after the disaster the government and power utilities had to rethink their approach. However, even with the current pro renewable measures the progress is being under shadowed by inefficient guidelines. Those guidelines and policies are usually voluntarily and not mandatory – a big difference to the German counterpart which relies on mandatory mechanisms to boost development. Previously stated side effects of the increased imported fossil fuels continue to hurt the Japanese economy. As the energy prices are currently low, it is economically more attractive to buy fossil fuels than to invest into renewable energies. However, the prices will most likely not stay at this level, and with fossil fuels getting scarcer, an oil price hike is a risk that should never be overlooked. The time to start the next energy transition phase, away from fossil fuels (at the first step at least for electricity generation) and in the long run eventually from nuclear energy as well towards renewable energies, should not be delayed too long by the Japanese government.*

*On the medium-term, nuclear energy will play a vital role for the Japanese power generation sector. As the life time of a regular power plant is about 40 years, the potential of many reactors has not been fully utilised yet. Most important requirement for a restart is the successful implementation of new security regulations. However, for some of the older power stations it might not be economically feasible to upgrade to the latest safety requirements.*

*It is almost certain that under the leadership of the current Prime Minister of Japan, Shinzo Abe, more than only the two reactors in Sendai, Kagoshima are going to get reactivated. Each reactivated reactor will reduce the dependence on fossil fuels – an important supportive argument as soon as the energy prices start to rise again. As not all stations will be reactivated, a generation capacity gap has to be filled. Renewable energies and energy conservation measure could fill that gap. What is crucial is to note that the government needs to come up with policies that really support renewables – with the current FIT, they are attractive to investors, but a uniform framework with the ten power utilities would be just as important as high feed in remunerations to boost the development of renewable energies. Individual contracts with the local grid operator take time and special requirements can make projects more expensive. A grid connection law, like the German StrGE, would be a nice addition to the FIT and help the progress.*

## *3.2. Conclusion*

*With the available renewable energy sources and their potentials, Japan can set up a stable electricity generation system and increase the share of renewables step by step. While hydro and geothermal power systems generate electricity for base load demands, wind and solar power can generate electricity for peak demand or storage systems. Biomass can be used flexibly to generate electricity or other important chemical components.*

*By increasing the number of renewable energies, the number of fossil fuel driven power plants could get reduced, emissions mitigated and energy independence increased. The role of nuclear power in Japan has not been decided yet, however, it is clear that it will continue to play a role in the Japanese energy sector for an indefinite period of time.*

*Renewable energies can support Japan's energy independence ambitions even better than the way nuclear energy could. As Japan has no uranium ore deposits within its national borders, it is dependent on supplies from outside. Technology for renewable energies, on the other hand, is already available to Japanese companies and can be utilised (raw materials might need to get imported).*

*Other potentials lie in efficiency enhancement, which could be an even stricter Top Runners Program on the demand side or power station modernisation on the supply side. More efficient power plants with heat power cogeneration or just waste incineration plants generating electricity on the supplier side. Increased efficiency reduces the required amount of primary energy carriers for electricity generation or uses resources (waste) which are currently incinerated in Japan even without making use of this technology.*

*The potentials are there, they just have to be correctly regulated and supported.*

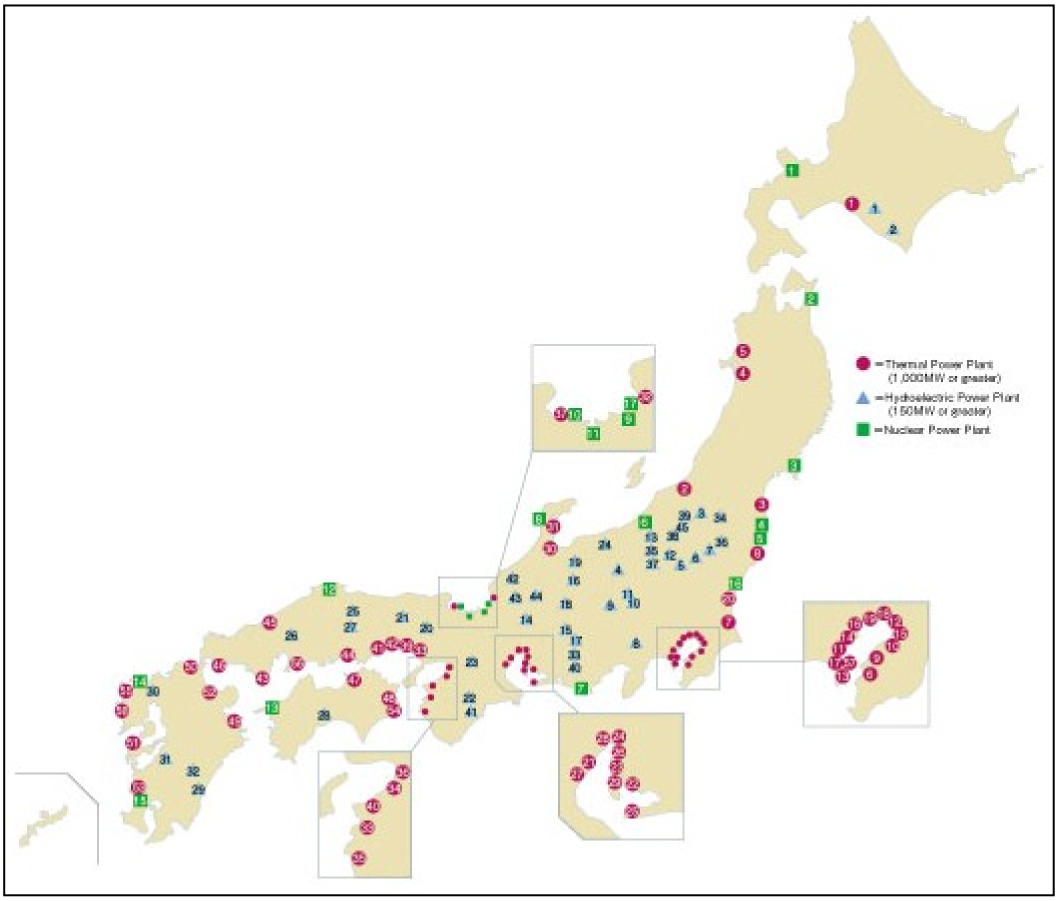
## *3.3. Future Research*

*The development direction of Japan's electricity generation sector is not clear yet. As the Japanese government has come up with some reforms of the electricity market and generation structure, it is possible that the sector gradually switches from fossil fuels to renewable energies. However, this cannot be said with certainty at the moment. Energy prices have been slowly recovering throughout the year 2016, they are not at the pre-financial crisis levels of 2008 yet, but with growing demand it is just a question of time until they reach that mark. This thesis is just a snap shot in time, long term developments – especially fuelled by political decisions need to be carefully monitored. Others may examine Japan's energy development program in three different phases, i.e., short-term, mid-term and long-term strategies.*

# Appendices

*Japan's major power plants (Data provided by the FECP)*

| | |
|---|---|
| *Thermal Power Plant:* | *Red* |
| *Hydroelectric Power Plant:* | *Blue* |
| *Nuclear Power Plant:* | *Green* |




*Map of all major power plants in Japan*
*(Source: FECP: Energy & Electricity; Location of Power Plants)*

*List of all nuclear power plants*

***In Operation***

| | Name of Plant | Unit Number | Company | Installed Capacity (MW) | Type of Reactor | Start |
|---|---|---|---|---|---|---|
| 1 | Tomari | 1 | Hokkaido | 579 | PWR | 1989.6 |
| | | 2 | | 579 | PWR | 1991.4 |
| | | 3 | | 912 | PWR | 2009.12 |
| 2 | Higashi-Dori | 1 | Tohoku | 1,1 | BWR | 2005.12 |
| 3 | Onagawa | 1 | Tohoku | 524 | BWR | 1984.6 |
| | | 2 | | 825 | BWR | 1995.7 |
| | | 3 | | 825 | BWR | 2002.1 |
| 4 | Fukushima Daini | 1 | Tokyo | 1,1 | BWR | 1982.4 |
| | | 2 | | 1,1 | BWR | 1984.2 |
| | | 3 | | 1,1 | BWR | 1985.6 |
| | | 4 | | 1,1 | BWR | 1987.8 |
| 5 | Kashiwazaki Kariwa | 1 | Tokyo | 1,1 | BWR | 1985.9 |
| | | 2 | | 1,1 | BWR | 1990.9 |
| | | 3 | | 1,1 | BWR | 1993.8 |
| | | 4 | | 1,1 | BWR | 1994.8 |
| | | 5 | | 1,1 | BWR | 1990.4 |
| | | 6 | | 1,356 | ABWR | 1996.11 |
| | | 7 | | 1,356 | ABWR | 1997.7 |
| 6 | Hamaoka | 3 | Chubu | 1,1 | BWR | 1987.8 |
| | | 4 | | 1,137 | BWR | 1993.9 |
| | | 5 | | 1,38 | ABWR | 2005.1 |
| 7 | Shika | 1 | Hokuriku | 540 | BWR | 1993.7 |
| | | 2 | | 1,206 | ABWR | 2006.3 |
| 8 | Mihama | 3 | Kansai | 826 | PWR | 1976.12 |
| 9 | Takahama | 1 | Kansai | 826 | PWR | 1974.11 |
| | | 2 | | 826 | PWR | 1975.11 |
| | | 3 | | 870 | PWR | 1985.1 |
| | | 4 | | 870 | PWR | 1985.6 |
| 10 | Ohi | 1 | Kansai | 1,175 | PWR | 1979.3 |
| | | 2 | | 1,175 | PWR | 1979.12 |
| | | 3 | | 1,18 | PWR | 1991.12 |
| | | 4 | | 1,18 | PWR | 1993.2 |
| 11 | Shimane | 2 | Chugoku | 820 | BWR | 1989.2 |
| 12 | Ikata | 1 | Shikoku | 566 | PWR | 1977.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 2 | | 566 | PWR | 1982.3 |
| | | 3 | | 890 | PWR | 1994.12 |
| 13 | Genkai | 2 | Kyushu | 559 | PWR | 1981.3 |
| | | 3 | | 1,18 | PWR | 1994.3 |
| | | 4 | | 1,18 | PWR | 1997.7 |
| 14 | Sendai | 1 | Kyushu | 890 | PWR | 1984.7 |
| | | 2 | | 890 | PWR | 1985.11 |
| 15 | Tokai Daini | | Japan Atomic Power Co. | 1,1 | BWR | 1978.11 |
| 16 | Tsuruga | 2 | | 1,16 | PWR | 1987.2 |
| | | Total 43 Units | | Total 42,048 MW | | |

***Under Construction***

| Name of Plant | Unit Number | Company | Installed Capacity (MW) | Type of Reactor | Start |
|---|---|---|---|---|---|
| Higashi-Dori | 1 | Tokyo | 1,385 | ABWR | U.D |
| Shimane | 3 | Chugoku | 1,373 | ABWR | U.D |
| Ohma | | J-Power | 1,383 | ABWR | U.D |
| | Total 3 Units | | Total 4,141 MW | | |

***Preparing for Construction***

| Name of Plant | Unit Number | Company | Installed Capacity (MW) | Type of Reactor | Start |
|---|---|---|---|---|---|
| Higashi-Dori | 2 | Tohoku | 1,385 | ABWR | U.D |
| Higashi-Dori | 2 | Tokyo | 1,385 | ABWR | U.D |
| Hamaoka | 6 | Chubu | 1,4 | ABWR | U.D |
| Kaminoseki | 1 | Chugoku | 1,373 | ABWR | U.D |
| | 2 | | 1,373 | ABWR | U.D |
| Sendai | 3 | Kyusyu | 1.590 | APWR | U.D |
| Tsuruga | 3 | Japan Atomic Power Co. | 1,538 | APWR | U.D |
| | 4 | | 1,538 | APWR | U.D |
| | Total 8 Units | | Total 11,582 MW | | |

### *Closed*

| Name of Plant | Unit Number | Company | Installed Capacity (MW) | Type of Reactor | Closed |
|---|---|---|---|---|---|
| Fukushima Daiichi | 1 | Tokyo | 460 | BWR | 2012.4 |
| | 2 | | 784 | BWR | 2012.4 |
| | 3 | | 784 | BWR | 2012.4 |
| | 4 | | 784 | BWR | 2012.4 |
| | 5 | | 784 | BWR | 2014.1 |
| | 6 | | 1,1 | BWR | 2014.1 |
| Hamaoka | 1 | Chubu | 540 | BWR | 2009.1 |
| | 2 | | 840 | BWR | 2009.1 |
| Mihama | 1 | Kansai | 340 | PWR | 2015.4 |
| | 2 | | 500 | PWR | 2015.4 |
| Shimane | 1 | Chugoku | 460 | BWR | 2015.4 |
| Genkai | 1 | Kyushu | 559 | PWR | 2015.4 |
| Tokai | | Japan Atomic Power Co. | 166 | GCR | 1998.3 |
| Tsuruga | 1 | Japan Atomic Power Co. | 357 | BWR | 2015.4 |

### *Others*

| Name of Plant | Company | Installed Capacity (MW) | Type of Reactor |
|---|---|---|---|
| Fugen | Japan Atomic Energy Agency | 165 | ATR(Prototype)<br>End of Operation |
| Monju | Japan Atomic Energy Agency | 280 | FBR(Prototype) |

*Note:*
*PWR=Pressurized Water Reactor, BWR=Boiling Water Reactor, APWR=Advanced Pressurized Water Reactor, ABWR=Advanced Boiling Water Reactor, GCR=Gas Cooled Reactor, ATR=Advanced Thermal Reactor, FBR=Fast Breeder Reactor*

*List of all principal thermal power plants (1,500 MW or greater)*

| | Name of Plant | Company | Installed Capacity (MW) | Fuel |
|---|---|---|---|---|
| 1 | Tomato-atsuma | Hokkaido | 1,65 | Coal |
| 2 | Higashi Niigata | Tohoku | 5,149 | LNG, heavy, crude oil, city gas |
| 3 | Haramachi | Tohoku | 2 | Coal |
| 4 | Akita | Tohoku | 1,633 | Heavy, crude, light oil |
| 5 | Kashima | Tokyo | 5,66 | Heavy, crude oil, city gas |
| 6 | Futtsu | Tokyo | 5,04 | LNG |
| 7 | Hirono | Tokyo | 4,4 | Heavy, crude oil, coal |
| 8 | Chiba | Tokyo | 4,38 | LNG |
| 9 | Anegasaki | Tokyo | 3,6 | Heavy, crude, light oil, LNG, LPG |
| 10 | Sodegaura | Tokyo | 3,6 | LNG |
| 11 | Yokohama | Tokyo | 3,325 | Heavy, crude oil, LNG |
| 12 | Yokosuka | Tokyo | 2,274 | Heavy, crude, light oil, city gas |
| 13 | Kawasaki | Tokyo | 2 | LNG |
| 14 | Hitachinaka | Tokyo | 2 | Coal |
| 15 | Higashi Ogishima | Tokyo | 2 | LNG |
| 16 | Goi | Tokyo | 1,886 | LNG |
| 17 | Kawagoe | Chubu | 4,802 | LNG |
| 18 | Hekinan | Chubu | 4,1 | Coal |

| | | | | |
|---|---|---|---|---|
| *19* | *Chita* | *Chubu* | *3,966* | *Heavy, crude oil, LNG* |
| *20* | *Shin Nagoya* | *Chubu* | *3,058* | *LNG* |
| *21* | *Joetsu* | *Chubu* | *2,303* | *LNG* |
| *22* | *Atsumi* | *Chubu* | *1,9* | *Heavy, crude, oil* |
| *23* | *Chita Daini* | *Chubu* | *1,708* | *LNG* |
| *24* | *Toyama Shinko* | *Hokuriku* | *1,5* | *Heavy, crude oil, coal* |
| *25* | *Himeji Daini* | *Kansai* | *4,119* | *LNG* |
| *26* | *Kainan* | *Kansai* | *2,1* | *Heavy, crude oil* |
| *27* | *Sakaiko* | *Kansai* | *2* | *LNG* |
| *28* | *Gobo* | *Kansai* | *1,8* | *Heavy, crude oil* |
| *29* | *Nanko* | *Kansai* | *1,8* | *LNG* |
| *30* | *Maizuru* | *Kansai* | *1,8* | *Coal* |
| *31* | *Himeji Daiichi* | *Kansai* | *1507.4* | *LNG* |
| *32* | *Shin Oita* | *Kyushu* | *2,295* | *LNG* |
| *33* | *Shin Kokura* | *Kyushu* | *1,8* | *LNG* |
| *34* | *Tachibanawan* | *J-Power* | *2,1* | *Coal* |
| *35* | *Shinchi* | *Soma JP* | *2* | *Coal* |
| *36* | *Nakoso* | *Joban JP* | *1,625* | *Heavy, oil, coal* |
| | | | | |
| *Note: EPDC=Electric Power Development Co., LTD.* | | | | |

*List of all principal hydroelectric power plants (360 MW or greater)*

| | Name of Plant | Company | Installed Capacity (MW) | Type |
|---|---|---|---|---|
| 1 | Daini Numazawa | Tohoku | 460 | Pumped Storage |
| 2 | Shin Takasegawa | Tokyo | 1,28 | Pumped Storage |
| 3 | Tamahara | Tokyo | 1,2 | Pumped Storage |
| 4 | Kazunogawa | Tokyo | 1,2 | Pumped Storage |
| 5 | Imaichi | Tokyo | 1,05 | Pumped Storage |
| 6 | Kannagawa | Tokyo | 940 | Pumped Storage |
| 7 | Shiobara | Tokyo | 900 | Pumped Storage |
| 8 | Azumi | Tokyo | 623 | Pumped Storage |
| 9 | Okumino | Chubu | 1,5 | Pumped Storage |
| 10 | Okuyahagi Daini | Chubu | 780 | Pumped Storage |
| 11 | Okutataragi | Kansai | 1,932 | Pumped Storage |
| 12 | Okawachi | Kansai | 1,28 | Pumped Storage |
| 13 | Okuyoshino | Kansai | 1,206 | Pumped Storage |
| 14 | Kisenyama | Kansai | 466 | Pumped Storage |
| 15 | Matanogawa | Chugoku | 1,2 | Pumped Storage |
| 16 | Nabara | Chugoku | 620 | Pumped Storage |
| 17 | Hongawa | Shikoku | 615 | Pumped Storage |
| 18 | Omarugawa | Kyusyu | 1,2 | Pumped Storage |
| 19 | Tenzan | Kyushu | 600 | Pumped Storage |
| 20 | Ohira | Kyushu | 500 | Pumped Storage |
| 21 | Shin Toyone | J-Power | 1,125 | Pumped Storage |
| 22 | Shimogo | J-Power | 1 | Pumped Storage |
| 23 | Okukiyotsu | J-Power | 1 | Pumped Storage |
| 24 | Numappara | J-Power | 675 | Pumped Storage |
| 25 | Okukiyotsu Daini | J-Power | 600 | Pumped Storage |
| 26 | Okutadami | J-Power | 560 | |
| 27 | Tagokura | J-Power | 400 | |

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