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The Effects of the Tohoku Tsunami on the Nuclear Energy Industry in Japan

Introduction

In 2011, the Japanese energy industry was forever changed. The Tohoku earthquake and subsequent tsunami devastated Japan, causing severe damage, many casualties, and the meltdown of the Fukushima nuclear power plant. The resulting chaos and devastation greatly affected the nuclear energy industry in both perception and reality. It raised serious questions about the safety of nuclear energy and Japan's energy options going forward.

Nuclear energy was a large portion of Japan's energy mix prior to the nuclear meltdown, making up 31% of the energy production. Although there were some safety concerns, nuclear energy was viewed as a clean and cost effective form of energy by a majority of the Japanese people. Prior to the Fukushima meltdown, only 21% of people wanted to reduce the country's dependence on nuclear power. In 2012, after the catastrophic nuclear meltdown, that number grew to 70%, as the Japanese people began to view nuclear energy as dangerous and unstable (Fam, Xiong, J., Xiong, G., Yong, Ng, 2014).

While many still argue that nuclear power is safe and cost effective, the Fukushima meltdown did irreparable damage to its credibility among the general public. Because of this, the energy industry in Japan will likely change form in the coming years. The Japanese government faces pressure from many groups wanting Japan to phase out nuclear energy while still being self-sufficient. Due to the lack of fossil fuels available to Japan, gas and oil prices remain higher there than in most other developed countries, which is one of the reasons Japan had such heavy reliance on nuclear energy. Japan would also face significantly higher carbon emissions if it began increasing its dependence on fossil fuels. The elimination of nuclear energy would have

wide-spread consequences on consumers including increased energy costs. Because of these issues, Japan is unable to fully phase out its reliance on nuclear power without exploring and improving renewable energy sources in the future.

With all of these issues coming together at once, Japan's energy industry stands at a crossroads. Its level of comfort with high nuclear dependence evaporated with the nuclear meltdown, and high costs of fossil fuels will force renewable energy into consideration. It is clear that the Fukushima nuclear meltdown will have an impact on the Japanese energy industry in many ways.

This paper will closely analyze energy Japan's energy data from over the period from 1980 to 2012 to look for trends both before and after the nuclear meltdown. Net electricity generation will be broken down into three categories: fossil fuel, renewable energy, and nuclear energy. The trends in these categories will then be analyzed to see what trends can be identified and the immediate impact the Fukushima disaster had on Japan's energy generation. Aspects such as yearly percentage change, yearly percentage of total electricity generated, and raw trends will be examined in detail.

Additionally, total installed energy capacity will also be broken down into the three subcategories listed above. With these, the paper will also examine trends, with emphasis on the increase of nuclear capacity over time, and how that was affected in the immediate aftermath of the Fukushima meltdown. By understanding these trends and impacts, this paper hopes to cover the sheer depth and economic shock of the Fukushima disaster. After gaining a grasp on these aspects, a window may become available into Japan's future energy mix and how the Japanese economy may react to the prospect of relying on nuclear energy in the future.

Literature Review

A study that sets the stage for the energy decisions Japan faces is an article by Fam, Xiong, Xiong, Yong, and Ng (2014). This paper examines the public opinion surrounding nuclear energy in Japan before and after the Fukushima meltdown. Using public opinion polling, the study finds that only 21% of Japanese people supported a reduction in nuclear dependence prior to the incident, while 70% supported a reduction afterward. However, a pro-nuclear government remained in place, and Japan faces high fossil fuel costs. Because of this environment, Japan must find a mix that is low cost, less focused on unpopular nuclear energy, and with low carbon emissions.

Srinivasan and Gopi Rethinaraj's (2012) paper describes the events leading up to the Fukushima nuclear meltdown. The public knew of the risks involved in nuclear energy and were unsure of it before the meltdown occurred. After the incident public perception and safety concerns about nuclear energy were at an all-time high. Due to the lack of energy resources in Japan and them having to depend on imports for approximately 85% of their energy needs, Japan will likely be forced to continue with nuclear energy even with the lack of support. The authors used electrical generation and capacity data to determine the changes resulting from the earthquake and tsunami. This paper outlines the lack of safety regulations within the nuclear energy industry and the social benefits and risks of continuing with nuclear energy within the potential energy mix.

Koyama's paper, "Japan's post-Fukushima energy policy challenges" (2013) discusses how the Japanese government reacted to the nuclear meltdown in 2011, including the power shortages. The Fukushima accident had caused the government to look beyond the short term outages and into the future of Japan's energy policy and national strategy. The Basic Energy Plan

made in 2010 called for an increase in nuclear power in order to reach a target of a 30% reduction in emissions and increase in self-sufficiency by 70% by 2030. After the meltdown, the public's concerns about nuclear energy have put this plan into question. This article gives three possible power generation mixes for the future of Japan. It also discusses the possibility of using fossil fuels and renewable energy sources in the future and how that will affect Japan in multiple ways such as self-sufficiency and increase in energy bills for consumers and industries. Different energy source consumptions are analyzed to determine how the change in energy mix would affect the prices and future energy consumption in Japan.

A paper by Hong, Bradshaw, and Brooks (2013) looks to a future mix of energy, and the challenges Japan may face in scaling out nuclear energy. Using Multi-criteria decision-making analysis, the study examines potential future energy mixes by analyzing energy production data. After considering many scenarios, the authors suggest that, while nuclear power may be unpopular, it will have to remain a major part of Japan's energy mix going forward. It would be wiser and more cost effective to phase out fossil fuels than nuclear energy. To meet greenhouse gas emission standards and keep the Japanese energy system sustainable, they estimate that Japan's energy mix will need to be made up of at least 35% nuclear energy.

In "Japan's post-Fukushima reconstruction" by Nesheiwat and Cross (2013), different scenarios are explored to examine how renewable energy could be used to lower Japan's dependence on nuclear power. Using energy production and consumption data as well as electricity generation data, possible implementations of renewable energy are explored. It is found that there are many renewable energy options, but Japanese culture would likely have to change to make these options sustainable. Many Japanese citizens would have to consider lifestyle changes focusing on using less energy. The article brings up "eco towns" and "smart

cities” as examples of areas that focus culturally on lowering energy consumption. Renewable energy will face challenges in Japan culturally and politically, and will likely require a shift culturally to become a realistic alternative to nuclear energy.

Vivoda’s paper, “Japan’s Energy Security Predicament Post-Fukushima” discusses Japan’s different energy options going forward. Being poor in resources forces them to import fossil fuels, making them costly to consumers. Nuclear energy, which was a much cheaper option, is no longer an option according to the public, but may still be a necessary part of the future energy mix. Supply and demand data and consumption and production data are analyzed to determine how future energy mixes could work in Japan. The article discussed how viable renewable energy sources such as solar and wind power are. There are many cost and structural constraints that affect the feasibility of these energy sources being used in Japan.

Data and Analysis

Several steps were taken to analyze the Japanese energy industry and the shock it saw after the Fukushima meltdown. First, preliminary research was done to gain an understanding of the Japanese energy industry and, more specifically, the role nuclear energy plays. Aspects such as historical trends, energy policy, and public opinion studies were all explored to create a clearer view of the industry both before and after the meltdown in 2011.

The U.S. Energy Information Administration’s International Energy Statistics Database provides yearly data on the generation of electricity in Japan. The fossil fuel, renewable, nuclear, and total generation are measured in billion kilowatthours from 1980 to 2012. Installed capacity in Japan for fossil fuels, renewables, and nuclear energy are also measured yearly in millions of kilowatts.

The International Energy Agency provides graphs showing how each energy source makes up the total energy production in Japan between 1972 and 2012. The composition of the energy supply is also graphed, showing how the sources of energy have changed between 1972 and 2012. The graphs from the International Energy Agency show how the Fukushima nuclear meltdown in Japan had an immediate impact on the sources of energy being used throughout the country.

The data concerning energy supply and consumption was examined searching for overall trends before and after the meltdown. The consumption of oil products from 1972-2012 was explored to see the role fossil fuels play in the Japanese energy industry and how that role changed over time.

Energy consumption and production by source from 1972-2012 was also researched in order to see the trends different types of energy followed over the course of time. Nuclear energy was specifically targeted to determine how severe of an impact the Fukushima meltdown had on its share of energy production and consumption.

The data used for most of the analysis involved Japan's net electricity generation and installed capacity by energy source from 1980-2012. The net electricity generation data, in billions of kilowatt-hours, was broken into three different energy sources: fossil fuels, renewable, and nuclear. Many aspects of these sources and their relationships with one another were analyzed.

The net generation of nuclear energy was compared to that of fossil fuels over time in order to see the path both followed, and how those paths were altered after the 2011 disaster. Similarly, the percentage of total generation each energy source represented from year to year

was examined. Again, this was explored in order to gain an understanding of the trends and averages of each source, and how those were altered after the Fukushima meltdown.

The average annual percentage change for each source was also determined from the electricity generation data. This was broken up into two main time periods, 1981-2010, and then from 2011-2012 allowing the average change in electricity generation by source to be examined both before and after the nuclear meltdown. This provided a view into how much the normal behavior of the energy industry was affected by the events in 2011.

The data for installed energy capacity, which also spans from 1980-2012 and is presented in terms of million kilowatts, was analyzed similarly to that of the net electricity generation. First, the installed capacity for the two main energy sources, nuclear and fossil fuels, were compared to each other over time in order to see both historical trends and whether those trends were broken after the Fukushima meltdown. Also, the percentage of the total installed capacity each energy source accounted for was determined and plotted over time. This was done in an effort to find if the events of 2011 caused an immediate shift in the makeup of Japan's energy capacity.

Once again, annual percentage change was found for the installed capacity of fossil fuel, renewable, and nuclear energy from 1981-2010, and then separately from 2011-2012. This allowed the distinction to be made between the data before and after the Fukushima meltdown. The trend and average were able to be determined and then contrasted with the percentage changes from 2011-2012 to see the effect the meltdown had on the average trajectory. By analyzing installed capacity data from 1980-2012, the scope of influence the Fukushima meltdown had on the energy industry becomes clear.

Results

Through research and data analysis it could be determined that the Japanese earthquake, tsunami, and ensuing nuclear meltdown had a drastic and immediate impact on the Japanese energy industry, and this impact was most severely felt by the nuclear energy industry. Before the Fukushima meltdown in 2011, nuclear energy was viewed as a safe, cost effective energy alternative to more costly fossil fuels, which Japan has to exclusively import at a high cost. The Japanese citizens and government alike largely supported nuclear energy. Only a fifth of Japan's citizens opposed the expansion of the country's nuclear energy capacity before 2011.

These views are supported by the Japanese energy data from that timeframe. From 1981 until 2010, the average percentage change in net electricity generation was 4.73% for nuclear energy compared to 1.92% for fossil fuels and 1.37% for renewable energy sources. The substantial separation between nuclear and the other energy sources annual percentage change shows just how committed to nuclear power Japan was.

This commitment is also illustrated by the Japanese installed capacity data by energy source. Again from 1981 to 2010, nuclear energy saw an average annual increase in installed capacity of 3.99%. This was almost double the 2.1% average increase in fossil fuels, and substantially more than the 1.71% average increase of renewable energy capacity. Nuclear energy was growing at a rate faster than the other two major energy players.

These trends were greatly altered in 2011, when a devastating combination of an earthquake and subsequent tsunami hit Japan, causing a meltdown at the Fukushima nuclear power plant.

Predictably, this caused a shift in the public perception of nuclear energy. It was no longer viewed as a safe and reliable alternative to fossil fuel use. The calls for more reliance on

renewable, safe forms of energy became more prevalent. By 2012, 70% opposed expanding nuclear energy in Japan, a far cry from the 21% just a few years earlier.

The dramatic shift in public opinion provides insight into just how devastating the meltdown was. This can again be supported by the average annual percentage change data. Nuclear energy saw a decrease in net generation of 44.27% from 2010 to 2011, followed by an 88.97% decrease between 2011 and 2012. This sharp decrease was accompanied by an increase in net generation by fossil fuels of 16.83% in 2011, and 9.13% in 2012. Renewable energy was also altered, though not to the degree of the others, seeing an increase of 2.13% in 2011 and 3.97% in 2012.

Yearly Percentage Change in Net Generation			
Year	Fossil Fuel	Renewable	Nuclear
1981-2010 AVG	1.92%	1.37%	4.73%
2011	16.83%	2.13%	-44.27%
2012	9.13%	3.97%	-88.97%

These drastic changes illustrate how immediately catastrophic the Fukushima meltdown was to the nuclear energy in particular, and how the energy industry as a whole changed. Not only did generation by nuclear energy plummet, fossil fuel generation grew by more than eight times its average in 2011, and then again, (albeit to a lesser extent than 2011) in 2012.

Renewable energy saw a deviation from its average in 2011 as well, and then a more substantial deviation in 2012, as generation increased by nearly 4%. These statistics in conjunction show not only how the nuclear generation fell off a cliff, but also the increases in other areas to compensate for that loss of production. While fossil fuel generation grew more in 2011 than 2012, renewable energy grew more in 2012 than 2011. This could suggest that, while fossil fuels had to be used in the immediate aftermath, it may be the ultimate goal to increase the scope of renewable energy to replace the losses in nuclear generation.

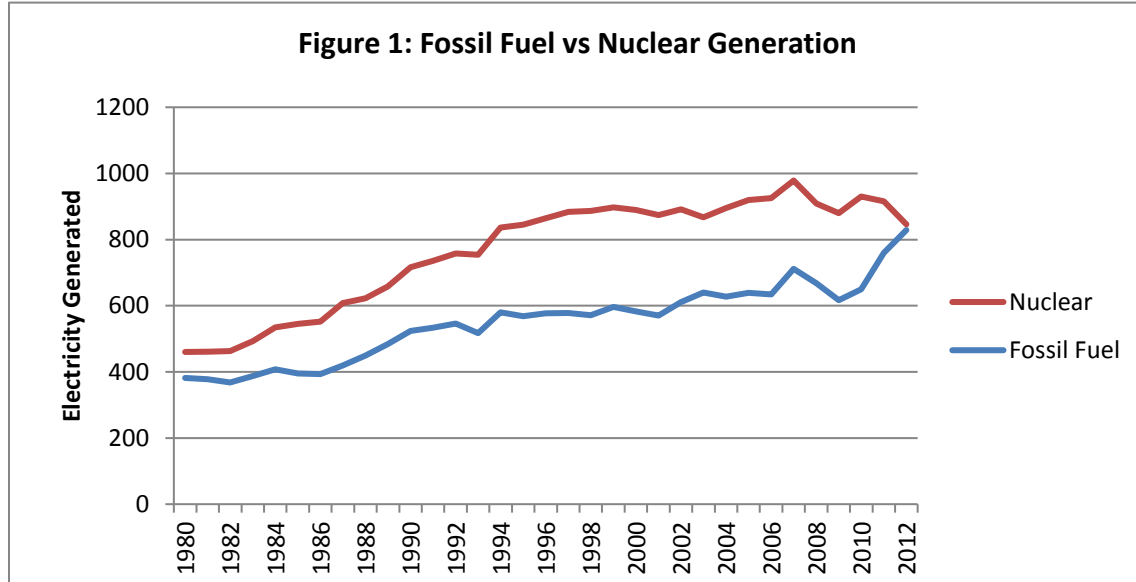
Changes in installed capacity showed some similar changes, though not as extreme as changes in generation. Installed nuclear capacity decreased by 5.57% in the year of the meltdown, and then saw no change in 2012. Fossil fuel capacity saw modest increases of 1.61% and 1.94% in 2011 and 2012 respectively. These numbers were both below the average percentage gain from 1981 to 2010.

The increased reliance on nuclear energy is also shown in the change in its installed capacity. In 2011, nuclear capacity increased by 3.97%, more than double its average for the thirty years prior, and by 6.16% in 2012. This provides more evidence for the desire to rely more on renewable energy in the wake of the Fukushima meltdown.

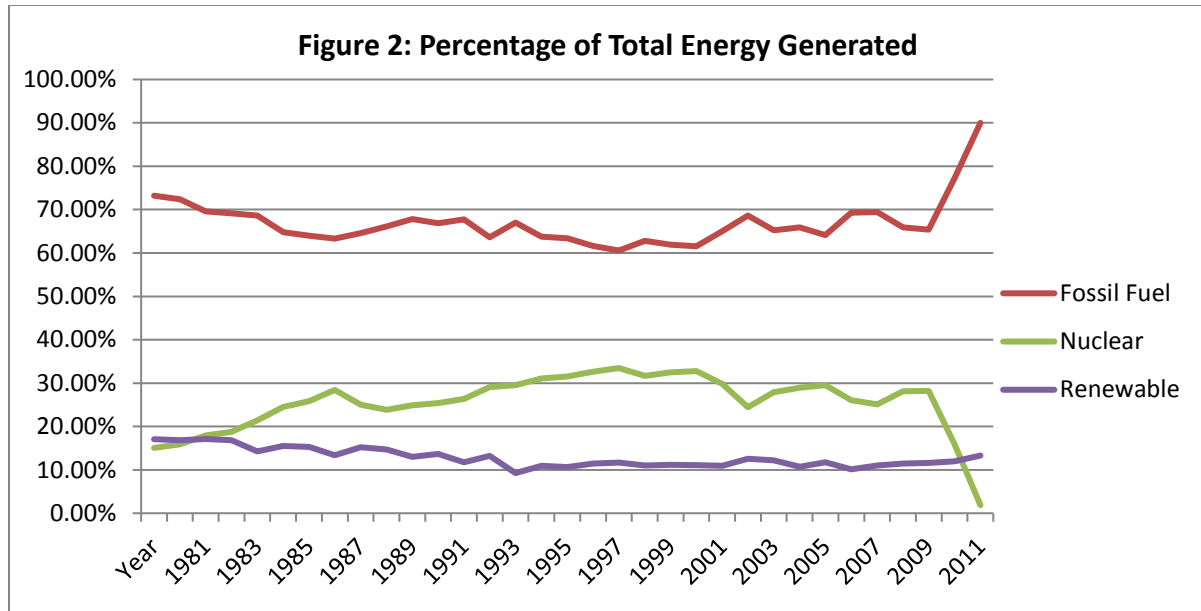
Yearly Percentage Change in Installed Capacity			
Year	Fossil Fuel	Renewable	Nuclear
1981-2010 AVG	2.10%	1.71%	3.99%
2011	1.61%	3.97%	-5.57%
2012	1.94%	6.16%	0.00%

This data can be further evaluated by looking closer at the trend over time (see figure 1). Electricity generated by nuclear energy and fossil fuels largely followed the same trend from 1980 to 2010. Both were consistently growing and following the same peaks and valleys, displaying Japan's desire to rely on nuclear energy. This changed drastically in 2011, where nuclear generation sharply declined and fossil fuel generation spiked. This supports the earlier

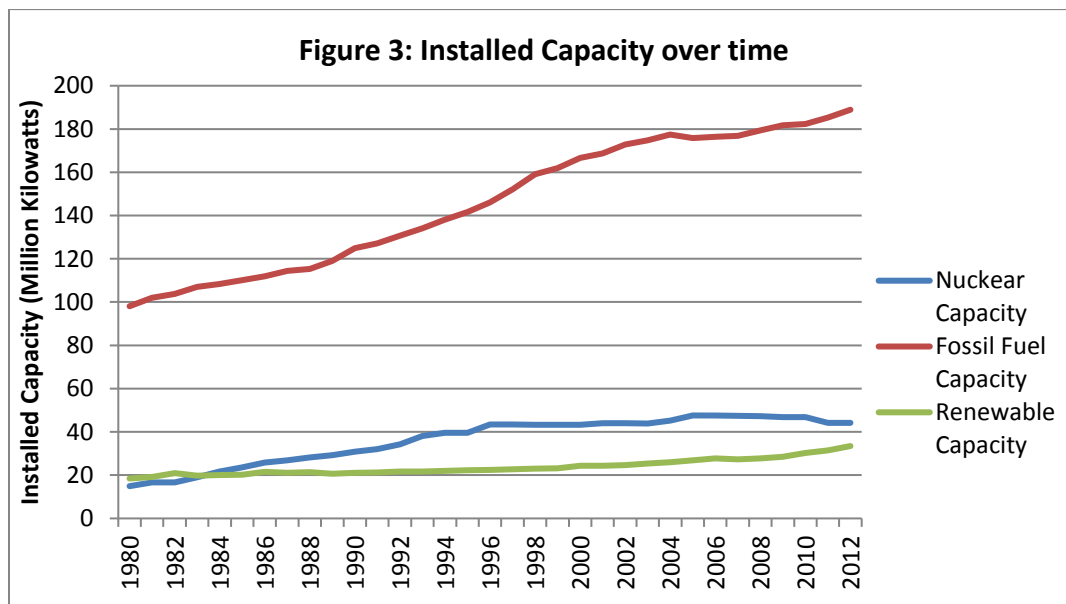
finding that fossil fuels were relied on the heaviest to make up for losses in nuclear generation.



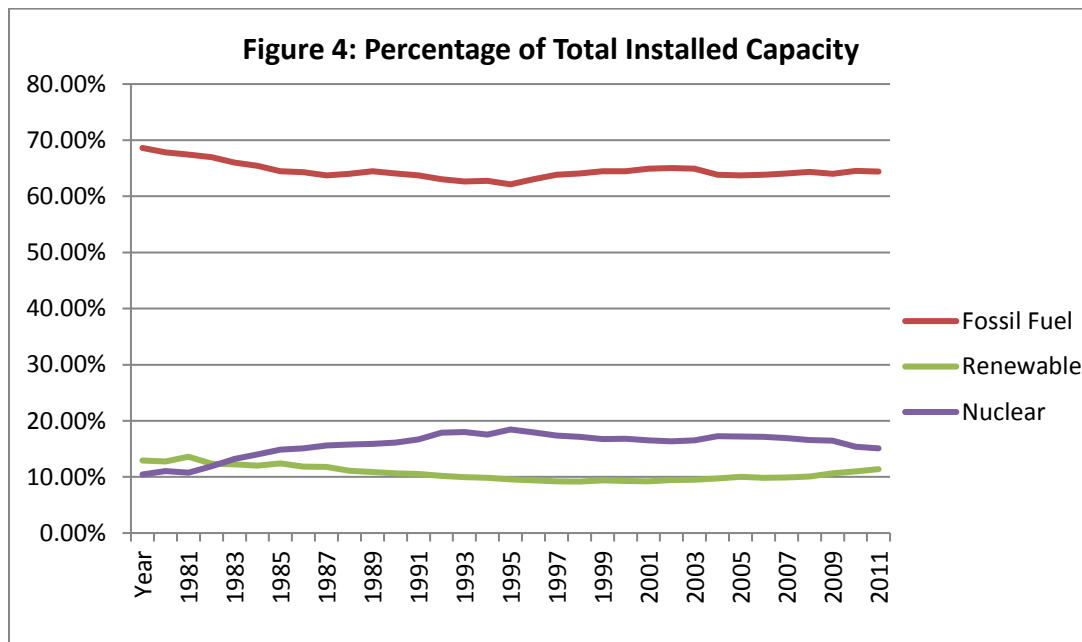
This is also supported when viewing net electricity generation by source in terms of total generation (see figure 2). This again illustrates that point that the majority of Japan's electricity generation comes from fossil fuels, but that nuclear energy also played a larger role there than in most countries. Again, it is seen that after the meltdown in 2011, the nuclear generation plummets, while the fossil fuel skyrockets to account for almost 90% of total generation. While the percentage of nuclear generation does not see an extreme increase, it does surpass that of nuclear energy.



A similar trend is seen when comparing trends in installed capacity by source over time. As stated earlier, the changes in these areas were not as drastic as the changes in electricity generation after the nuclear meltdown. Some of the largest changes were seen in the capacity of renewable energy (see figure 3). By 2012, installed renewable capacity is nearing that of nuclear, while fossil fuel capacity also saw an increase.



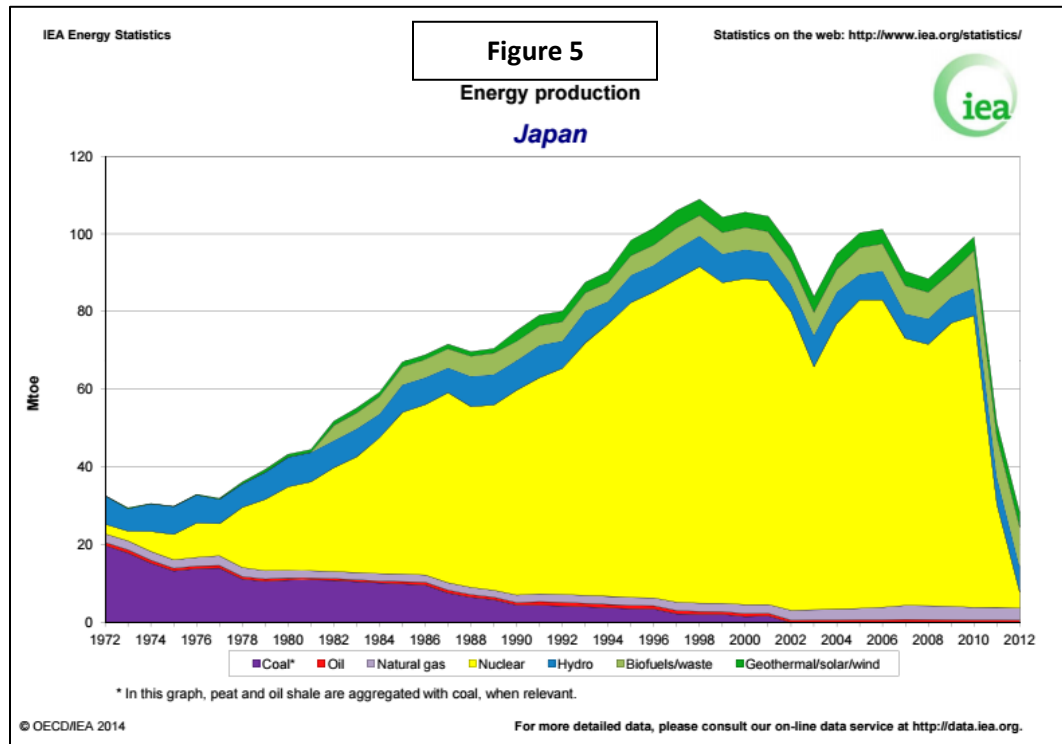
When displayed in terms of their respective percentages of total installed capacity, the same trends can be seen in the three energy sources (see figure 4). Nuclear capacity saw a steady increase from the early 1980's until the mid 1990's, before leveling off, and eventually dipping in 2011. This trend is nearly an exact opposite of the percentage of capacity accounted for by fossil fuels, further displaying Japan's willingness to embrace nuclear energy.



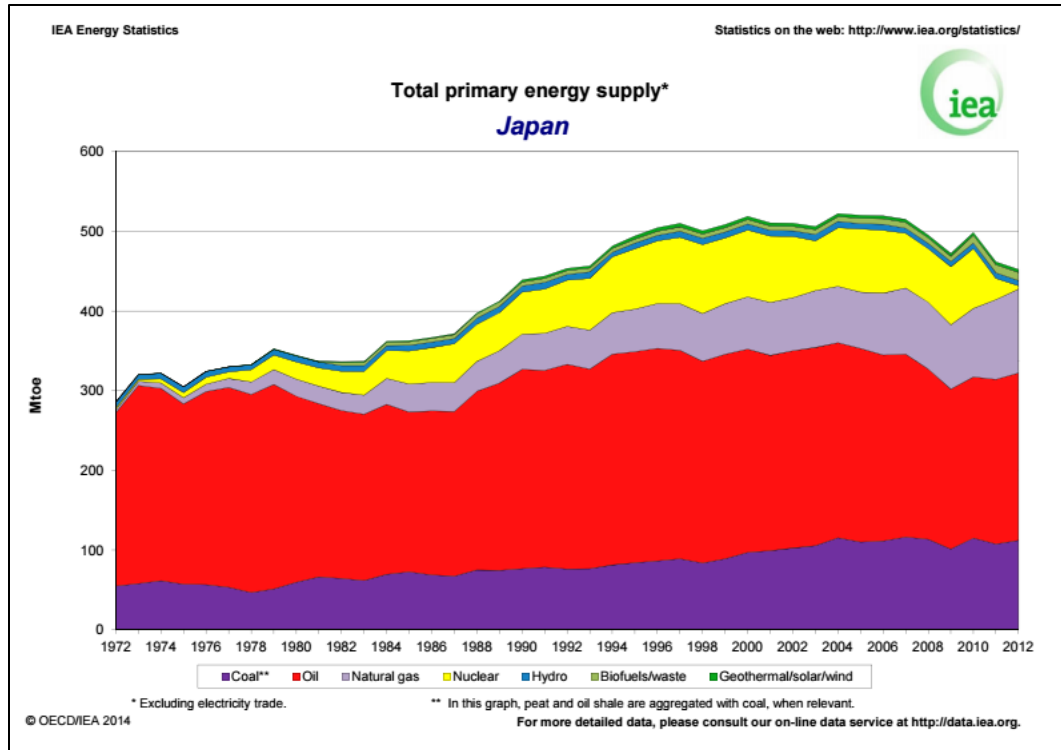
The dip in nuclear capacity in 2011 is accompanied again by a modest gain in fossil fuel capacity, and a more substantial gain in renewable capacity. This reinforces the suggestion that Japan's ultimate goal is to decrease reliance on both fossil fuels and nuclear energy in the future, therefore increasing the percentage of installed capacity accounted for by various nuclear energy sources.

Further evidence of the drastic immediate effects of the Fukushima meltdown can be seen when examining energy production data (see figure 5). International Energy Agency statistics show a massive amount of the energy production in Japan coming from nuclear energy. The

share of nuclear energy began to balloon in the late 1970's and continue to dominate energy production until the meltdown in 2011. This is supplemented with an increase in production of fossil fuels, like natural gas, and various renewable energy sources.



This trend is further illustrated through Japan's primary energy supply data from 1972 to 2012 (see figure 6). As stated earlier, nuclear energy supply grows from the 1970's and remains steady until the meltdown in 2011, where it drops sharply. Again, fossil fuels make up a majority of the energy mix, but the emphasis on nuclear reliance for much of the time period is evident, as it is also a substantial factor. While fossil fuels make up most for most of the lost nuclear supply in 2011 and 2012 by default, renewable energy sources also saw an increase. This increase illustrated a desire to replace nuclear reliance with more reliance on renewable energy sources like wind, hydro, and geothermal energy.



All Japanese energy data shows that fossil fuels and nuclear energy were consistently the largest part of Japan's energy mix from the 1970's until the events of 2011. After that, nuclear energy fell off the map in 2012. While fossil fuels replaced the majority of the lost production, renewable energy also saw an increase in the void, as the Japanese economy looks to increase the country's reliance on nuclear energy.

Conclusion

The 2011 earthquake, tsunami, and subsequent meltdown of the Fukushima nuclear power plant caused both a devastating immediate impact and altered the future of Japan's energy industry. It caused a vast majority of the public to turn against the once popular idea of nuclear energy. Japan was forced to reconsider their hope of becoming more dependent on nuclear energy, and instead focus on increasing the rule of renewable energy sources.

Energy data from the time leading up to the Fukushima meltdown and in its immediate aftermath support this narrative. Nuclear energy played a large part in Japan's pre-Fukushima energy mix; a much larger role than most countries. In 2011 and 2012, the production and use of nuclear energy dropped significantly, creating a void in the country's energy mix. This void was temporarily filled by increased fossil fuel use, but the installed capacity of nuclear energy showed signs of increasing at an increasingly quicker rate in 2012.

By analyzing Japan's policy and opinion data, along with energy data from before and in the immediate aftermath of the Fukushima meltdown, it becomes apparent that Japan hopes to decrease the role of nuclear energy in the future. For both safety and cost purposes, they also hope to increase the reliance on renewable energy. Into the future, this trend will likely continue as Japan looks to move toward an energy mix that is safe and acceptable for all.

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