Japan’s struggle with the energy supply from the “post-Fukushima” years up to now.

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1. Introduction

Electricity is a commodity that offers enormous value to modern living, from providing light at night to washing clothing, preparing meals, driving machinery, and communicating with people worldwide. Many argue that it is critical for poverty alleviation, economic progress, and higher living standards. Prior to the 2011 Tsunami, Japan derived 30% of its electricity from nuclear reactors and expected to grow that share to 40% [1]. However, on March 11, 2011, a magnitude 9.0 earthquake off Japan's east coast generated a tsunami, resulting in the meltdown of three reactors at the Fukushima Daiichi nuclear power facility. The disaster resulted in the leakage of radioactive materials and significant devastation in the surrounding area. Fearing more catastrophes, all 54 of the country's nuclear facilities were shut down for safety inspections. In 2010, nuclear power contributed to about 30% of the country's electricity generation. That percentage fell to 14% in 2011 and was less than 5% as of 2021. [2]

The sudden loss of this source of electricity put the country under pressure to find alternatives. As a result, Japan began to rely more heavily on fossil fuels, mainly natural gas and coal, to generate energy. And as a result, the country's greenhouse gas emissions peaked in 2013 when fossil fuels filled the void left by the temporary suspension of nuclear reactors after the Fukushima disaster but had fallen to 2009 levels by 2018 [3]. Figure 1 shows how fossil fuel rescinded the gap left by nuclear reactors since 2011 from Japan’s perspective.

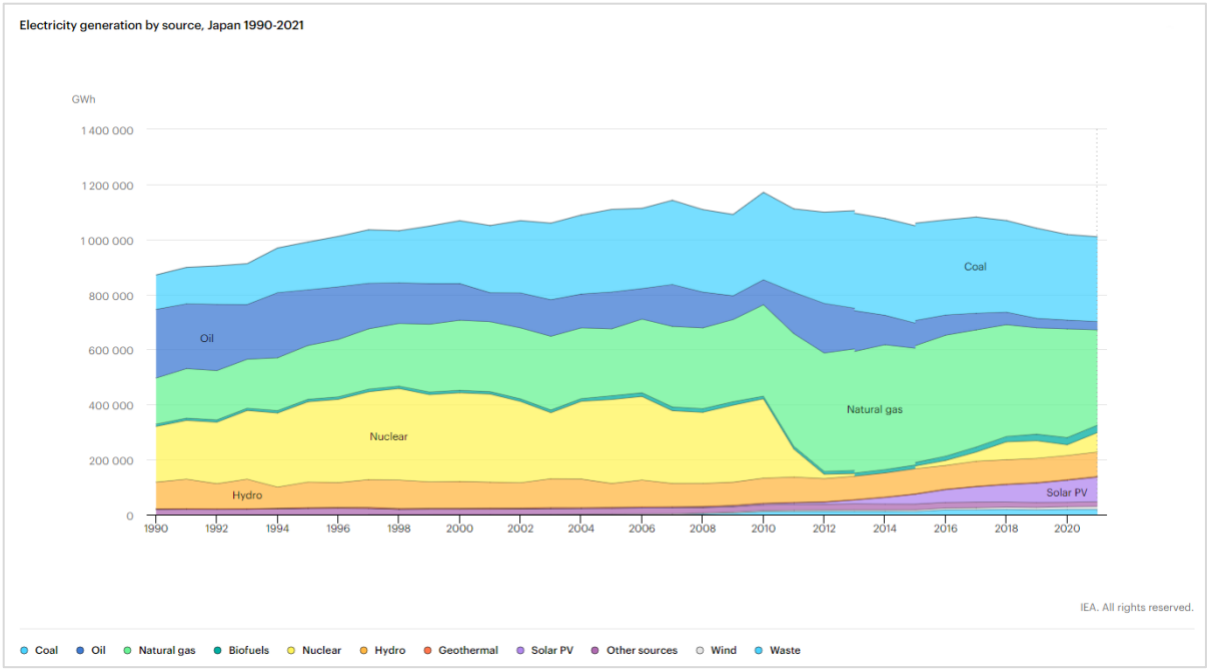

Figure 1: Electricity Generation by Source in Japan from 1990 to 2021 [3].

After the shutdown that followed the catastrophe at Fukushima Daiichi in March 2011, the first two reactors to restart did so in August and October of the same year. Since then, eight more reactors have been reactivated, while another 15 functional reactors are at various stages of restart permission. Two under-construction reactors (Ohma and Shimane 3) have also been applied. In light of the conflict between Ukraine and Russia, Japan's prime minister said that the country would restart nine units by winter 2022, and another seven units by summer 2023 [1].

In October 2020, Japan's Prime minister declared their intention to achieve carbon neutrality by 2050 [4]. In order for Japan to meet its goal of being carbon-neutral by 2050, it will significantly speed up the adoption of low-carbon technology by 2030, overcome institutional and regulatory impediments, and increase competition in its energy markets. It will also be establishing several decarbonization scenarios and plan for the likelihood that certain low-carbon technologies, such as nuclear, would expand slower than expected [3]. Apart from that, they will be implementing a variety of strategies to that end, which also includes planting trees and other vegetation, and promoting international cooperation. All these activities will be aimed at combating climate change by reducing greenhouse gas emissions and expanding the usage of sustainable energy sources [4].

In this report, we will discuss what challenges Japan faced since the meltdown of the Fukushima Daichi reactors, and how they averted the past-challenges and are dealing with the present-challenges of energy crisis.

2. Japan's geography and history of Nuclear Power

Japan is an East Asian country made up of a group of islands positioned around the Pacific "Ring of Fire," an area recognized for its strong seismic activity. As a result, Japan has a long history of earthquakes and is one of the world's most earthquake-prone nations. The movement of tectonic plates, which make up the Earth's crust, causes the bulk of earthquakes in Japan. Japan is located on the boundary between the Pacific Plate and the Eurasian Plate, and the movement of these plates causes the majority of the country's earthquakes. Every day, it suffers about 400 earthquakes. The vast majority of these cannot be sensed by people and must be discovered by devices. In the past, Japan has been affected by a number of high-intensity earthquakes. There have been 16000 fatalities as a result of tectonic activity since 2000 [5]. Therefore, Japan had always made sure that there were extra safety measures taken for its nuclear powerplants due to its high risk of earthquakes and tsunamis.

Japan's first nuclear power plant, the Tokai Nuclear Power Plant, was commissioned in 1966, and over the next few decades, nuclear power played an increasingly important role in Japan's energy mix. By the early 1980s, nuclear power accounted for about a quarter of Japan's electricity production, and by the 1990s, it had risen to around one-third. During this time, the Japanese government and utilities invested heavily in the development of nuclear power, building a number of new nuclear plants and expanding existing facilities. Nuclear power was seen as a reliable and stable source of electricity, and it played a key role in helping Japan to meet its energy needs while reducing its reliance on fossil fuels and imports of energy [1]. However, the Fukushima accident had a major impact on Japan's nuclear power industry, leading to a significant shift in the country's energy mix and a decline in the use of nuclear power. It also raised important questions about the safety and reliability of nuclear energy, and it has had far-reaching consequences for the global nuclear industry [6].

3. Projections after the accident

After a long period of relying on a policy plan heavily dependent and supportive of the nuclear source, the Japanese energy scenario inevitably saw a significant change in its approach after the Fukushima incident. In addition, the already fragile environmental and economic energy-related sectors were all affected by the nuclear crisis [7]. It is safe to say that developing an energy plan in this context wouldn't be easy, especially in a country with scarce natural resources and a significant dependency on imports for energy supply [3].

In the years that followed the accident, electricity generation by nuclear sources dropped completely, as all the nuclear power plants in the country were shut down after safety inspection, with only one station reopening in 2012 [3]. The main electricity sources then turned out to be coal and natural gas, essentially from imports [3]. In the environmental area, Japan was already struggling to achieve the objectives set by environmental treaties and without nuclear power generation, the carbon dioxide emissions grew by 11%, while the cost of energy imports was already putting the economy in a more vulnerable state [7].

The Pre-Fukushima period had well-defined energy policies with clear guidelines. The approach was clearly pro-nuclear, focusing on reducing environmental impacts and oil dependency and on energy security [8]. After the accident, the government quickly changed its approach and defined three different policy directions for the future of the energy scenario in the country. A document entitled "Options for Energy and Environment" was released in June of 2011 [9] and described the three options mainly focusing on the future of nuclear energy. In general, the plan's major changes compared to previous policies were the greater focus on decentralized energy systems, flexibilization of the energy supply, and green development [8].

Option A was named "Zero nuclear power" and relied on a complete change of the Japanese energy mix to increase the use of fossil fuels/renewables and clearly reduce the share of nuclear energy rapidly. In addition, the nuclear waste already used had to be immediately disposed of. The scenario also included a significant focus on policies toward energy efficiency and was highlighted as the preferred option by the government [9]. Option B was called "15% nuclear energy" and planned a smoother decrease in nuclear energy and fossil fuels utilization; the nuclear waste could be directly disposed of or reprocessed and energy technologies for electricity generation could be more flexible. Option C was deemed "20-25% nuclear power" and presented a scenario where the country would still be dependent on nuclear energy, with new nuclear power plants to be built. The last option also stated that fossil fuels should be reduced from an economic point of view and that all the nuclear power plants should be revived after the planned safety inspections. [7,9].

Some research studies presented a feasibility analysis of the three options presented. More expressively, McLellan et al. (2012) [7], made a comparative assessment by using parameters such as technical achievability, energy safety and security, environmental and social constraints, and internal consistency. It also analyzed the possibilities of developing different energy systems based on renewable energies, like wind, solar, and biomass as part of the three plans. It was shown that even though the first option is more desirable and contributes to improving energy security, getting completely rid of nuclear energy would lead to significant problems in energy safety and

environmental and economic issues. It was concluded that a hybrid solution would be a more feasible scenario to provide sustainable solutions and improve the country's energy supply.

Still leaning towards the complete removal of nuclear generation, the Japanese government created the Nuclear Regulatory Authority to make more strict regulations for nuclear technologies [7]. Additionally, several energy policies that supported renewable energy implementation were developed. In 2012, the government introduced the Feed In Tariff Law (FIT) as a form of economic incentive for non-nuclear energy generation systems. The scheme was deemed successful after which the deployment of renewable systems saw considerable growth. New photovoltaic (PV) and hydropower systems were responsible for an increase of approximately 7% in electricity generation by renewables: before the implementation of FIT (in 2011), 12.8% of the electricity generated in the country was from renewables, while in 2014 this number increased to almost 20% [10].

The years that followed the Fukushima incident were marked by intense efforts to remove the nuclear source from the Japanese energy mix. However, economic and environmental constraints proved that the solution to the energy supply crisis in the country would be more intricate. Even though renewables started to play a more important role in the Japanese energy scenario, a slow but considerable return of the nuclear source is proceeding, and currently 6 nuclear power plants have resumed operation since their general shutdown.

4. Current situation

In the current situation, Japan is recovering from the energy crisis created after the earthquake in 2011. Since Japan is a resource poor country, it relies heavily on fuel imports for energy generation which made Japan's energy supply vulnerable to external influence. During the 1970s Japan suffered the impacts of two oil crises because of their dependency for oil imports from the middle east [11]. To ensure a safe and secure supply of energy, Japan focused on expanding its energy generation mix to increase the share of nuclear energy as can be seen in the infographic displayed in Figure 2. They managed to decrease their dependency on fossil fuels from 94% in 1973 to 81.2% in 2010 [11]. But after the Fukushima incident, the nuclear power plants had to be stopped for safety checks and the gap in energy supply had to be filled by fossil fuels. This led to an increase in the dependency on fossil fuels to 84.8% in 2019.

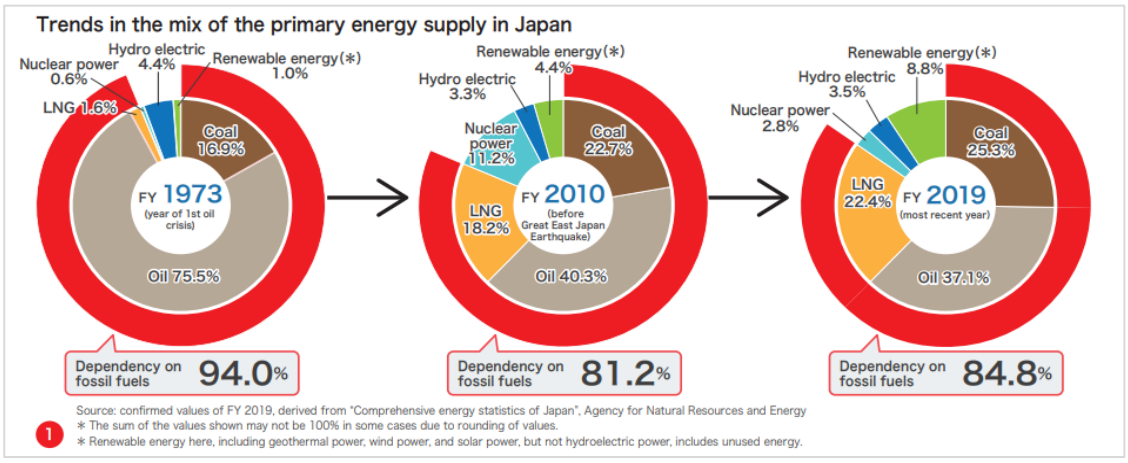

Figure 2: Trends in the mix of primary energy supply in Japan [11].

Hence, the self-sufficiency ratio of Japan's energy supply reduced from 20.2% in 2010 to 12.1% in 2019 as can be seen in Figure 3.

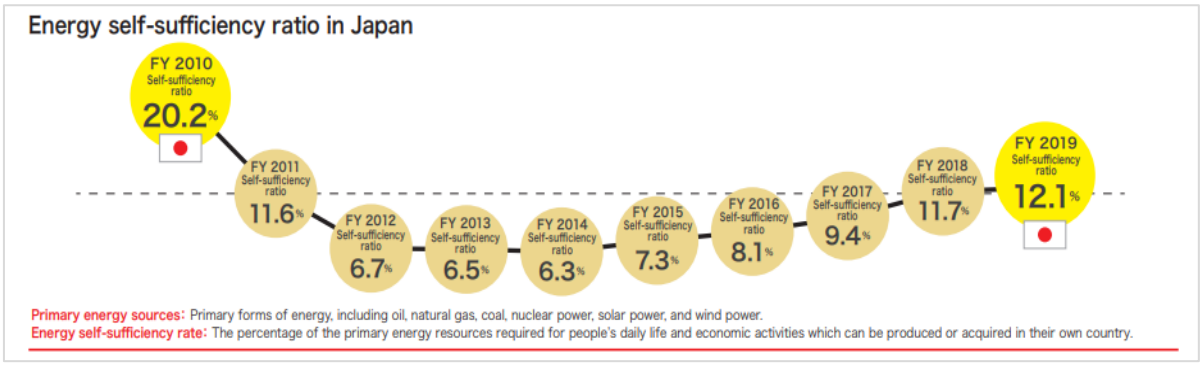

Figure 3: Energy self-sufficiency ratio in Japan [11].

To ensure a reliable supply of fuels for energy, Japan keeps a stockpile of resources (oil equivalent to around 230 days of domestic demand) and has also diversified its sources of fossil fuels imports [11].

The impact of the natural disaster can be seen in the average electric power rates also which significantly increased by 25% for homes and 38% for the industrial sector by 2014 as can be seen from Figure 4. The rates generally follow the trend of the crude oil prices because of the supply dependency, and they have gradually decreased but are still more than the "pre-Fukushima" situation.

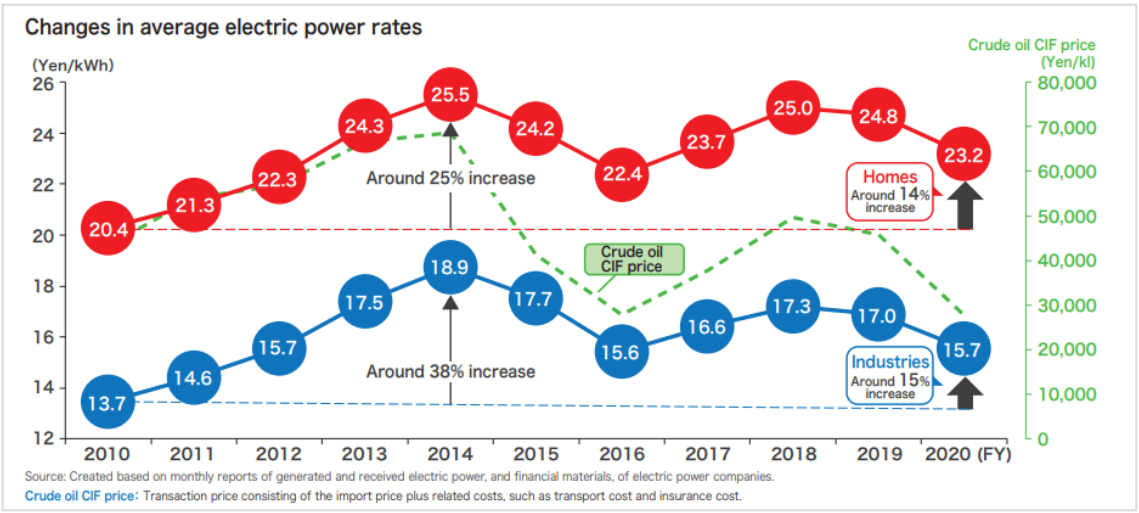

Figure 4: Changes in average electric power rates [11].

The price of electricity also depends on the renewable energy installed capacity as some cost is borne by the customers. There is a clear shift in the focus on renewable energy in Japan between before and after the Fukushima disaster. As can be seen in Figure 5, the average year on year installed capacity doubled from 9% to 18%.

Japan is prone to natural disasters and with increasing global warming, there is no sign of the situation getting any better. The only way forward is to make the energy supply safe and secure. In this regard, Japan's energy policies are based on S+3E (Safety + Energy security, Economic efficiency, Environment). In June 2020, one of the cabinet meetings concluded with decisions to strengthen the

transmission/distribution network and make the power system decentralized with disaster resilient features [11].

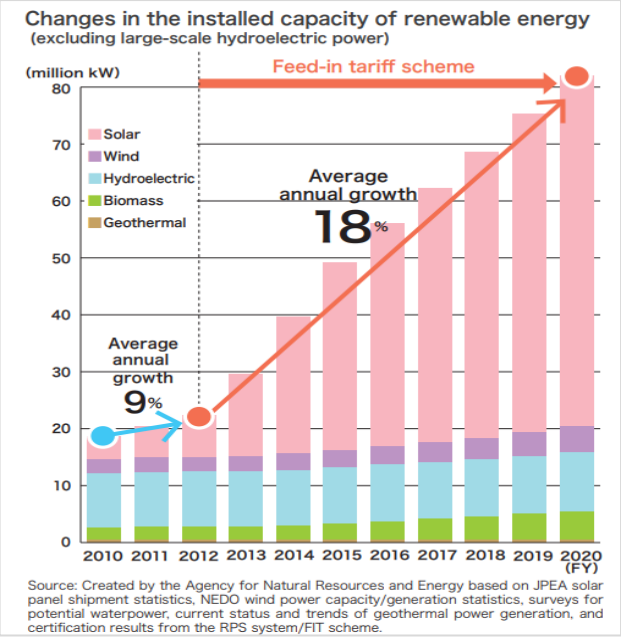

Figure 5: Changes in the installed capacity of renewable energy [11].

Along with the improvements to the existing electricity supply structure, Japan is also focusing on new technologies to incorporate in the structure. Green hydrogen is one of the alternative energies which Japan is trying to develop. Also, it is promoting more use of renewable energy and efficient use of energy to reduce the total load. To improve the energy efficiency, ZEBs (zero energy buildings) are being designed which have annual average net zero primary energy usage.

5. Future Projections

Japan major source of power was based of Nuclear power plants before Fukushima incident in 2011 when Japan closed many of the nuclear plants. After this disastrous incident, the fossils fuels based plants were increased suddenly and the adaptation of renewable energy was also increased. From the last one decade, most of Japan's energy comes from the fossil fuels imported from other countries. The current climate change urgency and voices about carbon emissions make Japan to find some alternate way for energy instead of the fossil fuels. Figure 6 shows the target set by Japan for the emissions reduction in 2030 and 2050.

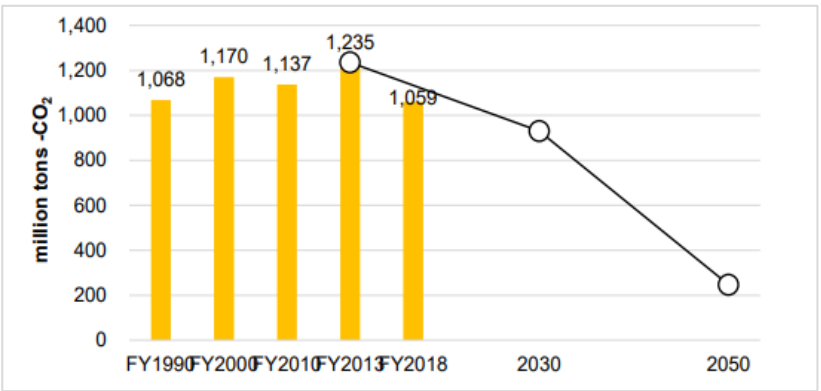

Figure 6: CO2 emissions trends and government targets [15].

It shows that the emission will be reduced by 25% until 2030 and 75% until 2050 as the target set by the government.

One of the key policy measures that Japan is considering in order to improve its energy security is the penetration of renewable energy. To achieve this goal, the government has implemented a number of incentives and policies to support the development and adoption of clean energy technologies, such as feed-in tariffs and research and development programs [13]. Japan is also working to improve the energy efficiency of its economy, particularly in the transportation and building sectors. For example, the government has implemented stricter fuel efficiency standards for vehicles and has introduced incentives for the construction of energy-efficient buildings. One of the Japan's policies for energy is to increase the domestic energy sources. Japan has limited domestic energy resources, but it is still working to develop what it does have, such as its offshore oil and gas reserves and its geothermal energy potential. The government is also considering the use of nuclear energy as a potential source of electricity.

On August 6, 2020, Japan's Renewable Energy Institute (REI) released a very ambitious proposal for the 2030 targets. The targets set by this proposal can be seen in Figure 7.

The proposal clearly shows that Japan is going to shift fossil fuels with renewable energy sources, and it is also going to increase the share of the Nuclear power to have the energy security as the total reliance on the intermittent renewable sources is not safe for the geography location of Japan as the weather conditions are very unstable there. Therefore, there are a lot of discussion these days about the possibility of restarting some of Japan's nuclear reactors, particularly those that have undergone safety upgrades. These discussions are controversial, and it is not clear if and when the nuclear power will play a significant role in Japan's energy mix of the future [17].

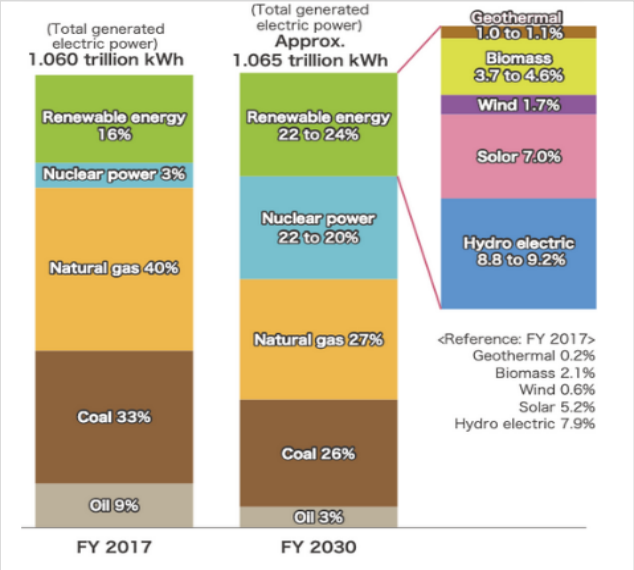

Figure 7: Japan's future energy mix plan [14].

Although Japan has made significant progress in increasing the share of renewable energy in its energy mix in recent years, it still faces a number of challenges in expanding the use of clean energy. Some of the key issues include the limited land and high costs of renewables. Japan is a small and densely

populated country, which means that there is limited space available for the construction of large-scale renewable energy projects, such as solar and wind farms. Renewable energy technologies, particularly solar and offshore wind, are still relatively expensive compared to fossil fuels, which makes it difficult for Japan to compete with other countries in terms of energy costs [16].

Japan's energy policy is facing significant challenges as the country transitions to a low-carbon energy system. The success of the future energy transition program in driving the deployment of renewable energy has been offset by concerns about its high costs, and there is ongoing debate about the role of nuclear power in Japan's energy mix. To achieve its ambitious carbon reduction targets, Japan will need to carefully balance the costs and benefits of different energy sources and policy measures. Further research is needed to understand the trade-offs involved in different energy scenarios and to identify the most viable and sustainable pathways for Japan's energy policy.

6. Conclusion

In conclusion, Japan's energy policy has undergone significant changes since the 2011 Fukushima disaster, which led to the closure of many nuclear power plants. As a result, the country has increased its reliance on fossil fuel-based power plants and has also made efforts to increase the use of renewable energy. The government has implemented a number of incentives and policies to support the development of clean energy technologies and has also implemented measures to improve energy efficiency. However, Japan still faces challenges in expanding the use of renewable energy, such as limited land availability and high costs. Japan's energy policy is also facing ongoing debate about the role of nuclear power in the country's energy mix. To achieve its ambitious carbon reduction targets, Japan will need to carefully balance the costs and benefits of different energy sources and policy measures and further research is needed to identify the most viable and sustainable pathways for the country's energy policy.

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